Upward and Diagonal Data Packet Forwarding in Underwater Communication

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Abstract: Due to the volatile characteristics of the underwater environment, provision of better communication and maximization of the communication performance has remained a biggest challenge for the UWSN network. It is difficult for the radio signals to proliferate into the water, thus acoustic technology is required to be adopted. Node mobility, 3-D spaces and horizontal communication links are some critical challenges to the researcher in designing new routing protocols for UWSNs. In this paper, we proposed a novel routing protocol called Diagonal and Vertical Routing Protocol for Underwater Wireless Sensor Network(DVRP) to address the issues of continuous node movements, end-to-end delays and energy consumption. In DVRP, every node can calculate its flooding angle to forward data packets toward the sinks without using any explicit configuration or location information. The simulation results show that DVRP has some advantages over some existing flooding-based techniques and also can easily manage quick routing changes where node movements are frequent.

Keywords: *UWSNs, DVRP, Angle Zone, Flooding, Energy.*

1. Introduction

Recently many researchers on Underwater Wireless Sensor Networks (UWSNs) have been conducted to support practical applications such as underwater exploration, underwater tactical surveillance and seismic monitoring. The applications of UWSN are becoming popular for exploring areas in the ocean which have resources like oil/gas, nourishment products, valuable minerals etc. Underwater wireless sensor network is used to prevent oceanic accidents like disastrous pollution, submarine detection, and tsunami warning. Although UWSN inherit some common properties of the terrestrial wireless sensor network, the radio signals employed in the terrestrial wireless sensor network are not applicable in underwater environments. The radio signals can propagate on long distance with low frequencies and less channel error rates, requiring large antenna and high transmission power. Hence the acoustic medium is employed in the underwater environment.

Due to this employment, UWSNs have to face some distinct challenges. First, the available transmission speed shifted from the speed of light to the speed of sound and the speed of acoustic signals in water is five order magnitudes less than the speed of electromagnetic waves[1]. Secondly, the bandwidth is totally depending on the distance due to high channel error rates and the high-power absorption factors of acoustic signals. Thirdly, energy consumptions are different for both types of WSNs. The UWSN needs more power require than the terrestrial based sensor network due to volatile characteristics of the underwater environment. Also, there is no mechanism available to recharge the battery in underwater environment or easily replaced. From an energy perspective, packet transmission is preferred on multiple small hopes over the long links. Multi-hop data deliveries have been proven to be more energy efficient than a single long hop[2]. It is observed that packet routing over more numbers of hops ultimately degrades the end-to-end reliability especially for the harsh underwater environment.

Due to the above mentioned issues, the literature shows that the existing routing techniques for terrestrial base sensor network are not applicable in UWSN[3] . The proposed routing protocols for land based wireless networks seem to be poor in performance for underwater sensor networks. Some present protocols developed for terrestrial networks are used in UWSN with little modifications. The above-mentioned limitations claim for protocol precisely designed for UWSN. A lot of researchers have been concentrating on manipulative efficient protocols to acclimate to the core characteristics of underwater communications.

The active social networker follows both companies and other people. However, the majority of the tweets are conversational messages between people. The third group, inactive social networkers, are not interested in the two-way communication aspect available on twitter, but as an information gathering resource. Regardless of which group the twitter user falls, the objective is to filter the abundance of available information into a manageable and customizable information stream. Twitter data collection has traditionally involved downloading user profiles individually and then partitioning them using community detection algorithms [4]; however, due to the time-consuming nature of this task, more real-time node-crawling and community structure building approaches have emerged [8] to effectively filter relevant tweets. Given the twitter's popularity, airline companies have created

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individual profiles to reach their customer base for a variety of reasons. In many cases, airlines use twitter as another marketing and sales conduit. In providing customer service, airlines use twitter for flight status update during a significant weather event. We study how prevalent flight-related data is available on twitter in order to determine a commercial airline's quality of service to its customers in a significant weather event. We can then assess if twitter is a valuable communication network for air passengers and their travel needs.

2. Related Work

In [38], an energy-efficient and topology-aware routing protocol, named SEANAR, is proposed for the UWASNs. This is a greedy and location-based routing protocol in which each node has its complete location information. The main purpose of SEANAR is to obtain a high delivery ratio with low energy consumption while handling the mobility of nodes. Therefore, each forwarder node should select the best next hop node. To this end, a special topology is proposed by SEANAR in which ordinary nodes are randomly scattered in the interested volume which can move freely in the horizontal direction by water current, and only one stationary sink is deployed in the center of water surface. The volume is divided into several spherical layers with the same thickness and density which is clearly shown in Figure 2.4. According to these layers, each node has three types of neighbors including neighbors in the inner, neighbors in the aside layer, and neighbors in the outer layer. The inner neighbors are closer to sink, while outer neighbors are farther to sink, and aside neighbors have almost the same distance to sink.

SEANAR is composed of two phases: neighbors' information maintenance phase and data sending phase. In the first phase, each node periodically broadcasts a location message including its node ID, location, and residual energy. If the receiver node is in the inner or aside layer, it updates its inner neighbor table or its aside neighbor table; otherwise, it simply discards the message. Consequently, the degree of each node is computed by counting the number of nodes in the inner and aside tables. In the second phase, each sender node sends a hello message including the node ID, packet sequence number, and layer information. Upon receiving the message, each node looks at the layer information. If the sender node is in the inner layer, it simply discards it; otherwise, it replies an acknowledgment message including its node ID, distance to sink, inner degree, aside degree, and residual energy. When all acknowledgment messages are received by the sender node, it calculates their weight and selects the largest weight node as the forwarder node then sends data packet to this node.

One of the significant advantages of this protocol is the fact that since the degree of nodes is used to select the next hop node, not only it has appropriate performance in sparse networks, but also it reduces the likelihood of communication void. Furthermore, it can handle dynamic topology in UWASNs.

However, one of its important weaknesses is that it uses fully location information of nodes in routing, which can be so costly. In addition, it does not benefit from the advantages of multi-sink architecture which causes rapid drain in battery of those nodes located closer to the single sink. Since weights of neighbor nodes are calculated in each hop of data sending phase by sending and receiving messages to neighboring nodes, the end-to-end delay and energy consumption increase, especially in dense deployments. Moreover, the period when the first phase should be repeated has a direct impact on the protocol performance.

For UWSNs, the path establishment requires much overhead in the form of control messages. Moreover, the dynamic conditions and high packet loss degrade reliability, which results in more retransmissions. Existing routing protocols proposed to improve the reliability, did not consider the link quality. That's why there is no guarantee about the data delivery especially when a link is error prone. In order to increase the reliability, [4] proposed Directional Flooding-Based Routing (DFR) protocol. DFR, basically, is a packet flooding technique which helps to increase the reliability. It is assumed that, every node knows about its location, location of one hop neighbors and final destination. Limited number of sensor nodes takes part in this process for a specific packet in order to prevent the flooding over the whole network, and forwarding nodes are decided according to the link quality. In addition, DFR addresses the void problem by allowing at least one node to participate in the data forwarding process.

The flooding zone is decided by the angle between FS and FD; where F is the packet receiving node, while S and D present the source and destination node, respectively. After receiving a data packet, F determines dynamically the packet forwarding by comparing SFD with a criterion angle for flooding, called BASE_ANGLE which is included in the received packet. In order to handle the high and dynamic packet error rate, BASE_ANGLE is adjusted in a hop-by-hop fashion according to the link quality, which helps to find a flooding zone dynamically. That is, the better the link quality is, the smaller the flooding zone is.

The performance of DFR depends on the number of nodes chosen as the next hop after flooding the data packet. Although, the problem of void region is addressed by making sure that at least one node must participate in this process. While, in areas where the link quality is not good then multiple nodes can forward the same data packet; so, more and more nodes will join the flooding of the same data packet which ultimately increase the consumption of critical network resources. Secondly, they have controlled the void problem by selecting at least one node to forward the data packet towards the sink. However, when the sending node cannot find a next hop closer to the sink, the void problem would still be encountered as no mechanism is available for sending the data packet in the reverse direction.

In [45], a greedy and depth-based multi-hop routing (DBMR) is proposed to improve the energy consumption. Unlike DBR in which each node floods the data packets for its neighboring nodes, in the DBMR, only one node is selected as the next hop node to reduce the communication overhead. In the architecture of DBMR, several stationary sinks are deployed on water surface, while ordinary nodes are equipped with an inexpensive pressure sensor and scattered randomly in underwater environment. They move based on the random walk pattern. DBMR is composed of two phases: route discovery and send packets. In the first phase, the next hop node of each node is discovered. To this end, each node measures its depth by pressure sensor and broadcasts its own ID and depth information as a control message. It waits to receive the reply message for a specific period of time. Each neighbor node which receives the control message compares the depth in the message with its own depth. If its depth is less than the depth in the control message, it calculates its weight according to its depth and residual energy, then it embeds its ID and weight in the message and replies it; otherwise, it readily discards the control message. When the waiting time is over, each node selects the largest weight node as the next hop node and saves it in the routing table. The second phase is responsible for data packet forwarding. To this end, each node retrieves the next hop node from the routing table and transmits the data packet to this node in order to avoid the high communication overhead.

The main benefits of DBMR are that it handles the high mobility of nodes through water current and it employs a multi-sink structure to decrease the likelihood of traffic in the nodes located closer to the sinks. It applies a single-next hop strategy to reduce the communication overhead and increase the network lifetime. However, it has some remarkable drawbacks; for instance, it cannot handle the communication void problem, which causes high packet loss. Due to the high mobility of nodes by water current, the discovery phase should be done at short intervals, which results in an increase in the network overhead. Since acoustic links are unreliable and DBMR does not consider link quality for selecting the next hop node [5, 6], the amount of packet retransmission increases significantly, which causes a remarkable increase in energy consumption.

3. Problem Statement and Contribution

The horizontal communication between the sensor nodes on the same depth levels is caused to increase the routing data path from lower layer nodes to the surface sinks deployed on the surface of the water. The large data routing path might be the issue that increase end to end routing delay in an underwater environment as well overhead for consumption In DVRP, it tries to reduce or overcome the horizontal communication between the sensor nodes on the same depth levels in underwater environments. The angle based flooding architecture is used in DVRP to overcome the horizontal communication in UWSN. The anchored nodes flood the sense data towards upper layer nodes using the formula θ = 90±10K, to calculate the flooding zone where the angle of the zone is always greater than zero and less than π. This condition is applied to execute the flood of data packets in diagonals or vertical form gradually, because we know that the distance covered in the vertical direction or in diagonals toward the destination in underwater is always smaller than the distance covered even one hop is involved in horizontal communication to the sink on water surface.

In Fig. 1, it is illustrated that O, D and Pare ordinary floating nodes and S is the sink on water surface. The nodes O and D on the same depth level from the surface sink and the angle between them is zero and π.Node O has a data packets and ready to send toward sink. Therefore, these are some possible routes for node O, to send data packets toward the sink node. The first route is, O to D, D to P and P to S. The Second route, O to P and P to S. Third route, O to S, through this route the node O can directly send data packets to the sink node.

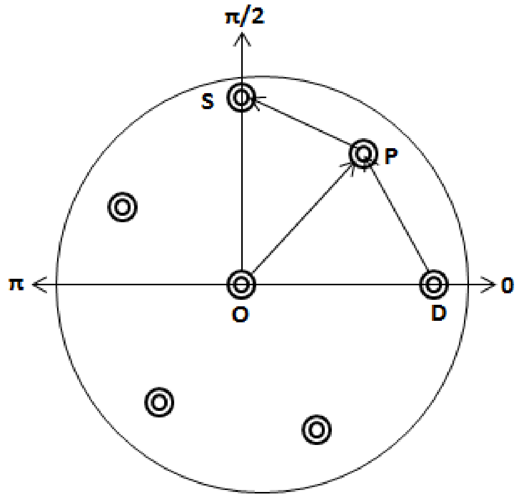


Figure.1. Angle base communication model for UWSNs

Here we only consider the first two routes, to compare the covered distance by data packets toward the sink node. If node O sends data packet to node D and node D forward data packets to upper layer node P. Finally, node P forward data packets to the sink node S. Due to this selection of the data path, the data packets will cover long data route toward the sink node due to the involvement of horizontal communication link with node D. However, node O can directly send data packets to node P, which is diagonal to node O and near to the sink node.

By using the theorem triangular inequality, we proved that the distance covered by the data packets through vertical or diagonal path to the destination is always smaller than the distance in which horizontal path is exist. This is due to the presence of a horizontal peer link between the communication nodes.Here O, P and D are considering as a coordinate of the triangle.

From the triangle ΔODP

$$|OP| < |OD| + |DP| \tag{1}$$

Equation (1) shows that the sum of two distances is greater than the third distance. Hence, it's proved that if data packets send by using the route $|OD|+|DP|$ will cover the large distance as $|OP|$ route.

By adding $|PS|$ on both side of equation (1)

$$|PS| + |OP| < |OD| + |DP| + |PS| \tag{2}$$

From equation (2), it is clear that the vertical or diagonal communication toward the sink node is better than involvement of horizontal communication betweennodes in the underwater wireless sensor network. So, it is also proving that the flooding of data packets by the nodes within the calculated zone that has maximum angle is always greater than zero and less than π, can provide vertical or diagonal communication in UWSN. Therefore, nodes on the same depth level from the sink node and the angle between them is zero and π, could not communicate to each other, due to the calculation of flooding zones, until we allow the horizontal communication.

3.1 Way of data packet forwarding in DVRP

In this phase, node forwards the data packets toward the surface sink. The forwarding process is as follows. The node has a data packets and it's ready to be sent. First, the node will calculate its flooding zone by using the basic formula $\theta = 90\pm10K$. The purpose of this flooding zone is to prevent the flooding on the whole network. The node will flood the Hello Packets (HP) within the flooding zone area and wait for Hello Reply (HR). If HR is received, the node will forward the sense data packets to the corresponding nodes. The nodes in the flood zone can only reply of HP. If node could not receive HR within the calculation time, the node will use the next value of ±K in the initial formula to increase its flooding zone until the basic condition meets ($0 < \Theta < \pi$). The range of value for variable K is (1, 2… 8) [7]. The largest value of K is 8 to prevent the horizontal communications between the sensor nodes. Here it is important to note that nodes can use random value of variable K, to increase the size of flooding zone. The randomness of K value is more helpful to control the end-to-end delays and as well as power consumption of the nodes. The selection of random values of K depends on the movement of nodes.

- If a node receives a very small number of Hello Reply. Therefore, nodes will consider the movement is slow. So, nodes will use a large value of variable K to increase the flooding zone.
- If a node receives more number of Hello Reply. Therefore, nodes will consider the movement is fast. So, nodes will use a smaller value of variable K to increase the flooding zone.

Let us take Figure 2 as an example. The nodes are deployed from the surface to the bottom. Sinks are on water surface and consider static after being deployed. The floating nodes are deployed on different levels of depth using the bouncy control mechanism and only consider horizontal movements on floating nodes. The vertical variation is very little and normally ignored. The distance between layers is 500m [8]. The node A has data packets and is ready to be sent. The node A defines its flooding zone area by adding the K value on both sides of its base angle 90. After defining the zone, the node A sends HP in the define zone. The node C is in the zone. The node C will calculate its priority on the bases of its own energy status and layer number. Node C will reply to HP with its calculated priority.

The Node A will check the priority of node C and send bursts of data packets to node C with the highest priority to become the next forwarder of these data packets. Now, node C is a qualifying node to become the next data packets forwarder. Here, we are assuming that the nodes in the flood zone will only reply to HP. In the case of multiple nodes in the flood zone, all nodes will reply of HP with their calculated priorities and the sender node will choose the best next forwarder based on received information in hello reply.

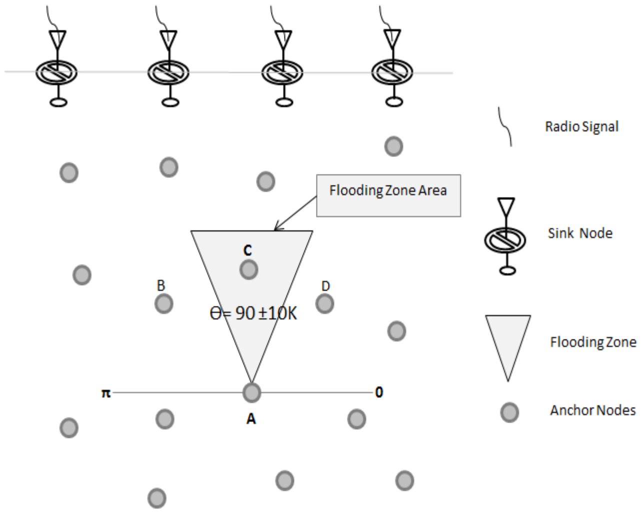


Figure.2. Data packet forwarding

3.2Control of multiple packet forwarding by same node

As mentioned in the previous section, DVRP uses a flooding base approach. So, it is very possible that many nodes are qualified candidates to forward a data packet at the next upper layer. The high collision and high energy consumption will be the result if all these qualified nodes try to flood the data packets. Consequently, to decrease the collisions as well as energy consumption, there is need to be controlled the forwarding nodes in the network. Moreover, due to the inherited multiple-path feature of DVRP multiple nodes may receive the same packet. Therefore; nodes can forward data packets multiple times. To get better energy efficiency, ideally only one node needs to flood the data packet. To do so, we introduced the concept of multiple queues. To save energy as well as to reduce collisions, there are two major reasons needed for multiple queues. One is that multiple nodes may forward same data packets. The other is that a node may send a same packet many times [9]. The priority queue is used to reduce the forwarding nodes and control the number of forwarding paths. For the second problem, packet history buffer is used in DVRP to ensure that a node forwards the same data packet only once in a certain time interval. A maximum of 50 data packets can be kept in the history buffer. When the buffer queue is full, new packet will replace the least used packet. The priority queue only contains the values to calculate the priority for next forwarder based on its layered number and energy status.

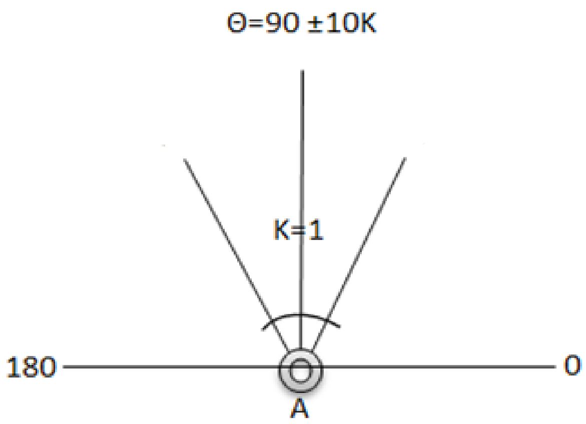
3.3 Concept of angle calculation for flooding zone

As mention earlier, DVRP uses the angle based flooding technique to forward the data packets toward the upper layer nodes or surface sinks. The calculation of angles to define the zone is straight forward. Here we are assuming that every sensor node knows its base angle that is $\pi/2$ in the upward direction and it is a built-in hardware module. Every node has the capability to compute the angle to increase the flooding zone size according to the environmental situations. Here it is important to know that, on every attempt the previous calculated area will be added into new define zone to take the advantage of mobility.

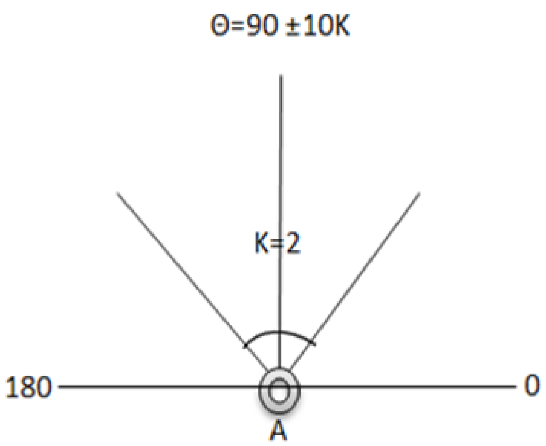
The conceptual examples of computing the angle in 2D is as follows. Fig. 3 (a), presents the flooding zone size when node uses the value K = 1, (b) when node uses K=2 and (c) when node uses K=8 to compute the angle. The basic formula is Θ =90 ±10K, here K is a variable and has a finite set of values as previously mentioned. Here it is important to note that this is not an actual mathematical presentation of calculation but it is only the conceptual presentation of flooding zone expansion. These angle calculation examples are presented in 2D. It is only to understand the concept of angle zone calculation and expansion in 3D.

As mentioned earlier, that K has a finite set of values from 1 to 8. In Fig. 3, only three scenarios are discussed, the first two scenarios in which the values of variable K are taken in sequence and then the last value of K=8.

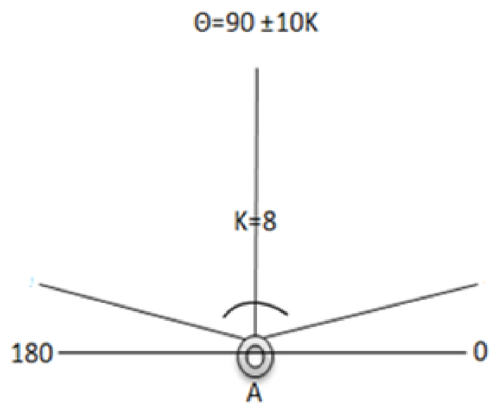
Here the maximum range of values for variable K is 1 to 8, to reduce the horizontal communication links between the nodes on same depth level from the surface sink. It is observed during the simulation that the results are more satisfactory if the maximum range of values for variable K is 1 to 8.



(a) First possible flooding zone when node uses K=1



(b) Second possible flooding zone when K=2



(c) Last possible flooding zone when K=8

Figure.**Error! No text of specified style in document.**. Flooding zone calculation

However, this range can vary according to the environmental condition. If the environment is more stable, the range of k values can reduce. The vertical and diagonal communication path between the nodes depend on this range ok K.

3.4 Algorithm for data packet forwarding

Table 1: Pseudocode for data packet forwarding

Data packet Forwarding
Data Packet (DP), Hello Packet (HP), Hello Reply (HR)
1. *Check the status of DP in Q2 //Q2 is a buffer history* 2. *If (DP in Q2)* 3. *Discard the packet // Packet already sent* 4. *END if* 5. *If (DP not in Q2)* 6. *Calculate the Flooding Zone using θ = 90±10K // K is variable that has a set of values [1,2.....8]* 7. *Send HP // Inside the defined flooding Zone* 8. *Wait for HR* 9. *If (HR received) = yes* 10. *Sort out the priorities* 11. *Send DP to highest priority node* 12. *ACK received* 13. *Go to rest mode //Acknowledge Node is Qualified for further flooding* 14. *Else* 15. *If (K ≤8)* 16. *K++* 17. *Go onto step 6 // increase the size of the zone with increasing the value of "K"* 18. *Else* 19. *Move up and find nodes or directly send to Sink* 20. *End If* 21. *End If* 22. *End*

3.4 Waiting time to go for next angle calculation

The waiting time *T* is inversely proportional to speed of node*S*. If speed of nodes will vary, the waiting time will also vary. The relation of waiting time to speed of node is expressed in Eq (3).

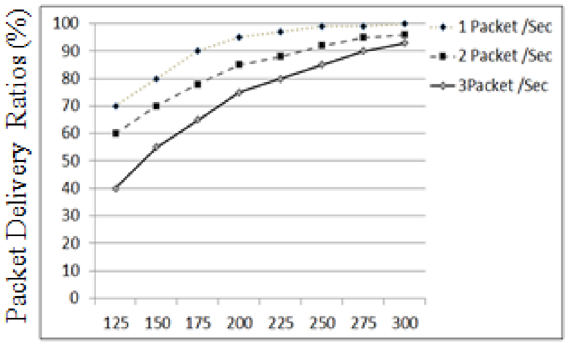
$$T \propto \frac{1}{S} \tag{3}$$

The same process will be adopted to calculate this waiting time for other side of the flooding zone. Here it is important to note that this waiting time is only for the mobile nodes. If nodes are stationary or statics then this waiting time is non-significant. Every node can quickly find the next forwarder based on the stored information in routing table.

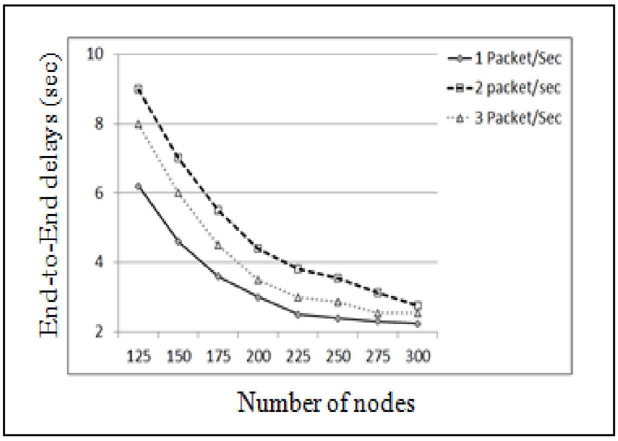
4. Results and Discussion

Network Simulator was used to evaluate the performance of DVRP. In our simulation, 300 sensor nodes (both sink and floating nodes) were deployed in 3D area of (800m ×800m×800m). Multiple sinks are used at water surface and all sinks are static having a support of both (Radio, Acoustic) types of communication [10]. The distance between the layers of floating nodes can be up to 500m. In this experiment, sink nodes is considered to be static after deployed but remaining nodes are floating in nature and we ignore the vertical movement of floating nodes.

The horizontal movement was considered between the floating nodes due to different water current up to 1-4m/s at fixed notions. End -to-end delay, data delivery ratio and energy consumption was considered three matrices to evaluate the performance of our routing protocol. The performance of DVRP was checked by different number of packets generated in the network. Figure 4 (a) illustrates the delivery ratio with different number of data packets. The delivery ratios are almost the same in the dense network.



(a) Data Delivery Ratios



(b) End-to-End Dela

Figure.4. Performance by using different number of packets

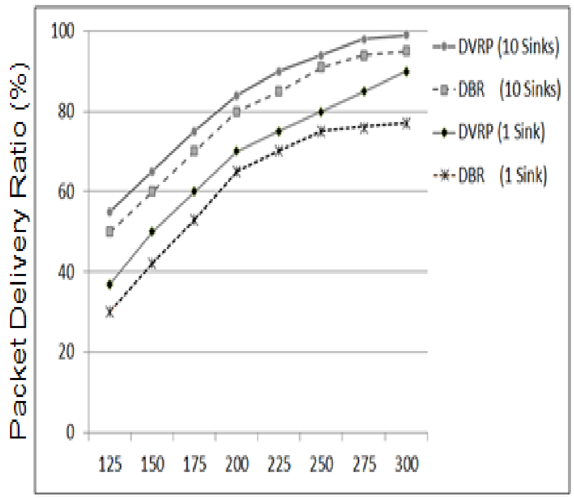
The result shows, with the sparseness of nodes the variation is slow. With more number of data packets and few numbers of nodes in the network, sometime may cause to increase data packets in the buffer which results in discarding them. Figure 4 (b) presents the difference in end-to-end delays when the numbers of packets in the network are increased. The result shows that, the network can be handled easily when 60% more data packets are generated in the network. These delays are reasonable, when the generated data packets are double.

Every node in DBR, get a decision on the base of its current depth to forward data packets. A node has a data packet and its ready to be sent, first node compare its current depth with the embedded depth in receiving data packets. If its current depth is less than the sender's depth, node forward the data packets otherwise discarded the packets. DBR has some serious issues as compared to DVRP like it is possible that multiple nodes can have smaller depth levels and at the same time these nodes forward data packets, which not only can cause collisions in the network but also increase the energy overhead.

4.1 Comparison between DVRP and DBR

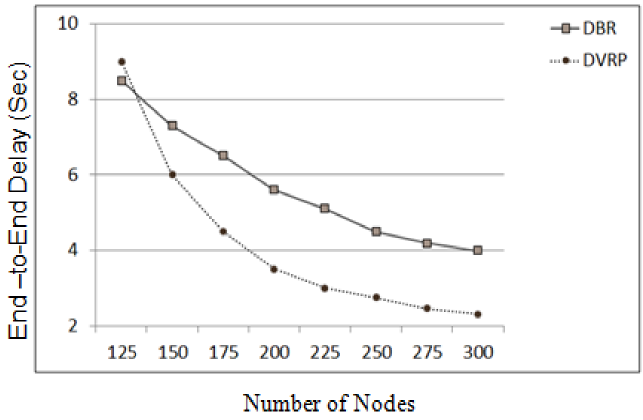
Further we compared DVRP with DBR to evaluate the performance. First, we compare the data delivery ratios with single sink and multiple sinks as shown in Fig.5 (a). With multiple sinks, we found that both algorithms (DVRP, DBR) provide almost the same results with the density of nodes. As the number of nodes starts to decrease the delivery ratios of DBR also start to decrease while it has less effect on the delivery ratios of DVRP. It happens with DBR due to its greedy mode, even number of nodes are available in network with high depth levels but cannot participate in forwarding of data packets.

The data delivery ratios of DVRP and DBR with single sink, which is placed at the center of the surface, the result shows that the delivery ratios of DBR are more exaggerated than DVRP. It is again due to the greedy mode of DBR, nodes only forward data packets to water surface but not forwarding it towards the sinks



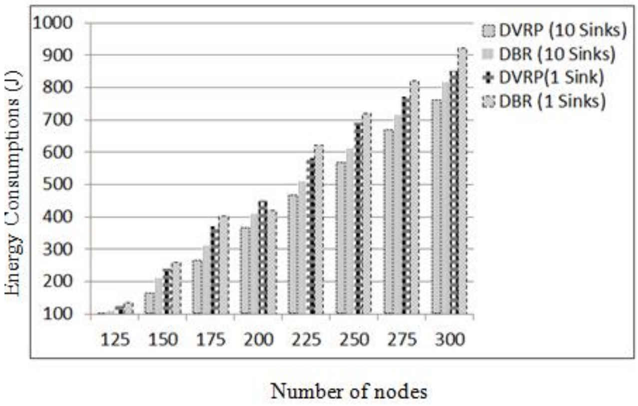
Number of Nodes

(a) Packet Delivery Ratios



.(b) End to End Delay

Figure 5 (b) shows, the comparisons for end-to-end delays between DVRP and DBR. Here DVRP delivers data packets with less end-to-end delays when reasonable sensor nodes are available in the network. It is only due to the holding time used in DBR. On the other hand, DVRP only used angle based zone to flood the data packets and every node can forward data packets immediately.



(a) Energy Consumption

Figure.5. Comparison between DVRP and DBR

Further we compared energy consumptions in Fig.5 (c) with different number of sinks. First, we check with less number of nodes and the results were almost similar but when the number of nodes starts to increase the difference in energy consumptions start to increase. DBR uses the broadcasting for every data packet in greedy fashions and it increase the energy consumption with a dense network for the same data packets. In DVRP, the concept of angle base zone is used to perform flooding of data packets. The nodes will calculate flooding zone and flood the data packets within the define zone.

5. Conclusion

In this paper, we have proposed Diagonal and Vertical Routing Protocol (DVRP) to handle some critical routing issues in UWSNs. DVRP is scalable and efficient for end-to-end delays and energy consumption. We have found that, DVRP relies on the flooding base technique to increase the reliability of the network. However, the number of nodes which flood the data packets is controlled by calculating the angle for flood zone to prevent the flooding over the whole network. The flooding zone is adjusted using layer by layer manner through angle base technique among the upper layer nodes. The novelty of our proposed protocol is that it does not depend on location information and as well as there is no need to maintain the complex routing tables. It is very easy to add new nodes in the network at any time and any location. The real beauty of DVRP is that, delivery ratios are not much affected with the density or the sparseness of nodes. The simulation results show that it is better for long term and real time applications. In the future, we are planning to increase the number of evaluation metrics to investigate the relative performance of the protocol.

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