Angle Adjustment for Vertical and Diagonal Communication in underwater Sensor Networks

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***Abstract*—Underwater wireless sensor network has been an area of interest for a few previous decades. UWSNs consists of tiny sensors responsible for monitoring different underwater events and transmit the collected data to the sink node. In the harsh and continuously changing environment of water, gaining better communication and performance is a difficult task as compared to networks available on land because of different underwater characteristics such as end-to-end delays, node movement, and energy constraints. In this paper, a novel routing technique named angle adjustment for vertical and diagonal communication was proposed, which doesn't use any location information of nodes. It is also efficient in terms of energy and end-to-end delays. In this approach, the source node evaluates the flooding zone based on the angle by using the basic formula for forwarding the packet to the sink. After evaluating the flooding zone, the angles of each node are compared and the packet is sent to the node closest to the vertical line. The proposed approach is evaluated with the help of NS-2 with AquaSim. The results show better results performance in data delivery, end-to-end delays, and energy consumption than DBR.**

Keywords*—*Wireless Sensor Networks; Underwater wireless sensor network; DVRP; Terrestrial Wireless Sensor Networks; Depth Based Routing (DBR)

I. Introduction

Wireless Sensor Network (WSN) is a worldwide interest. It is a network that consists of tiny nodes that are equipped with power supply, analog to digital converter, small memory, processor and a radio interface. Sensors have the capability to communicate with other sensors. WSN is divided into different groups such as Terrestrial Wireless Sensor Network (TWSN) and Underwater Sensor Network (UWSN) etc. In TWSN, nodes are deployed on land and must be able to communicate effectively. Nodes can have a secondary power source. Whereas the architecture of UWSN has sensors randomly deployed in the form of one dimension, two dimensions, three dimensions, and four dimensions in the oceanic environment flood data forwarding towards the base station and have limited battery and are also expensive.

Ocean covers more than 70% of the earth. UWSN is gaining lots of attention because oceans are playing vital role in transportation, ocean exploration, defense, obtaining valuable minerals, oil and gas, surveillance data collection and adventurous means [1][2][3]. It also helps in avoidance of different disasters i.e. flood, tsunami, submarine detection and pollution control [4][5]. Underwater Exploration: Sensors helps in extracting resources such as rare metals and minerals, monitoring of equipment, oil platforms, buried communication cables, and gas pipes. Sensors are also used in the localization of objects and in the successful discovery of many lost treasures. Seismic Monitoring: Water resources hides most of the oil and gas resources. To extract the oil and gas resources, frequent 3D, and 4D seismic monitoring is required [3].

Mine Reconnaissance: Early detection of minefields to avoid disasters was always difficult. UWSNs can effectively help as a tool for early detection and deactivation.

Disaster Prevention: In UWSNs, research is conducting in the area of disaster prevention and recovery [2]. With the help of UWSNs, early warnings of the tsunami can be provided to coastal. It can also aid in oil spills, disaster recoveries, and investigation of marine incidents.

Assisted Navigation: Sensors can be helpful in locating different harmful objects such as rocks, shoals, and wrecks in shallow as well as deep water.

Underwater Sensor Network and terrestrial wireless networks have some resemblances but are not applicable in underwater environments as radio signals cannot propagate in water, but sound signals are responsible for propagation [6]. So the terrestrial protocols cannot be used in an underwater environment [7]. Routing in the underwater environment is challenging to make its applications reliable [11] and also because of its multiple limitations which are more power consumption, high error rates, limited bandwidth, high end-to-end delay, no recharging mechanism, and continuous node movements [12][8][13]. For the efficient use of energy, multi-hop communication is preferred [12]. UWSN protocols are classified into two classes: 1) Localization Based Routing Protocols, 2) Localization Free Routing Protocols. Localization based protocols require accurate information of localization for packet forwarding which is the main liability. Localization free protocols can depend upon different parameters such as link strength, residual energy, and depth. A localization free routing protocol named Depth Based Routing Protocol (DBR) was proposed which does not require any geographical information but only needs the information about the depth of each node. The source node broadcasts the data to all its neighbors having a depth less than the source node. The process continues until the data is received at the sink [8] [9]

[10]. But broadcasting the data can degrade network performance [11]. To avoid horizontal communication a Diagonal and Vertical Routing Protocol (DVRP) was proposed which uses angle-based flooding. In this protocol, the nodes flood the data either vertically or diagonally because the vertical or diagonal distance is always less than the horizontal distance towards the sink. Nodes flood the data to nodes at the upper layer with the help of a formula $\theta=90\pm10K$. The flooding zone is always greater than 0 and less than π [7] [12].

A. Challenges of underwater Wireless Networks

- Limited Energy: Harvesting and consumption of energy is one of the key challenges in UWSN. Underwater sensors are of large size; hence they need more energy for communication [5]. Sensors are deployed in the deep sea where sunlight is unavailable which means recharging of batteries is very difficult. UWSN must focus on power efficient designs and some power-efficient and robust protocols should be developed [13].

- Low Data Rates: Although acoustic communication is ideal in an underwater environment for its long transmission range and reliability. But acoustic communication offers the data of 5kbps to 20kbps which is extremely low as compared to radio communication which offers data rate in Gbps.

- Propagation Delays: The acoustic communication provides a speed of 1500m/sec which is five times less than that of radio communication [5]. The slow speed produces a delay of 0.67s/km [14]. These delays decrease the throughput of the network.

- Dynamic Topology: Dynamic topology is one of the challenges of the underwater environment. As the nodes move 1-3m/sec with the water currents [16]. Due to the movement of nodes, it is difficult to maintain a static topology which greatly effects the performance of routing protocols [5][17]. To handle such a situation, the routing protocol must have the information of nodes' location or depth [5].

- Reliability: The oceanic environment is very unpredictable for communication because of Doppler spread, pressure, marine life, man-made noise, salinity, and ocean currents. In the water, nodes move about 2-3m/sec due to water currents which effects in localization of nodes, communication link, and the network topology. All of these results in unreliable data transmission [15].

- Noise: Noise is the communication quality due to which strength of signal degrades. Noise can be produced by fishing, ships, human, and marine activities [18]. Noise is classified into two classes which are man-made noise and ambient noise.
    - Man-Made Noise: The noise which is produced by different activities such as fishing, use of machines, sonar, shipping, and military [18]. These activities produce interference and disturbance in communication [19].
    - Ambient Noise: It is a complex process that occurs by a combination of different undefined sources which cannot be identified uniquely [20]. It is also known as background noise. Ambient noise is majorly produced by factors like wind, shipping, and turbulence [21]. The destruction of waves due to air bubbles is referred to as wind noise. Ships can be considered as a major cause of ambient noise. The presence of ships at a large distance from communication can produce high noise ratios. The tides produce a disturbance in the surface of the water. This disturbance results in continuous low-frequency noise [19].
    - Multipath: Horizontal communication channel is highly affected by multipath as compared to vertical channel. Reflections weaken acoustic signals, produce long delays, inter-symbol interference and make the data erroneous [22][23][24] [25].
    - Doppler Spread: The shift of mean frequency due to relative motion of transmitter and receiver is known as the Doppler shift. Frequency fluctuation in the area of the Doppler shift is termed as doppler spread [19][26].

B. Research Objectives

The key challenge in UWSN is to receive data packets on the surface of the water. The proposed algorithms for vertical and diagonal communication are based on an angular technique that causes the dark shaded areas in communication. The nodes inside the dark area cannot participate in the communication process due to improper adjustment of angle to restrict horizontal communication. These angle adjustments can cause for high end to end delay, long data routing path, data packet losses, and network lifetime.

A specific objective of the research is to design and develop a new Angle Optimization for Vertical and Diagonal Communication in Underwater Sensor Networks to:

1) Minimize the dark shade area.
2) Optimal adjustment of angle
3) Reduce the horizontal communication among nodes.
4) Overcome high end to end delays.
5) Increase throughput and network life-time.

These Objectives are transformed into the form of research questions.

RQ1: How dark shaded area increases end-to-end delay?

RQ2: How can we design the protocol to adjust the angle for the optimal solution of the dark shaded area?

RQ3: How to decrease the delay caused by the dark shaded area?

RQ4: How the proposed algorithm can increase the throughput for efficient communication?

II. Related Work

About 70% of the surface of the earth is covered with water which is in the form of rivers, canals, and oceans. Oceans have a huge amount to precious resources such as oil and gas. The exploration of these resources depends on the technology. Recent advancements in technology help in the exploration of resources also for the avoidance of disasters, detection of pollution and data collection. Technology that is applicable to all these applications is UWSN [1]. The architecture of UWSN consists of three parts which are sensors, sinks and surface stations. The data is sensed by sensor nodes and forwarded towards the surface station by using sinks [27][25]. The architecture of UWSN has sensors randomly deployed in the form of one dimension, two dimensions, three dimensions, and four dimensions.

A. *One Dimension UWSNs*

1D architecture uses the autonomous deployment of sensors. Every node is a singleton network which performs the task of sensing, processing, and transmission of information towards remote station. Each node is a floating buoy having sensing capabilities deployed for a specified interval of time to gather information. After this specified time, it floats back towards the surface to send data to the remote station. Nodes can also be an AUV that dives into the water to sense underwater activities and carry the information to the remote station. 1D can use acoustic, optical or radio waves as the communication medium. The communication can be transmitted to remote station only by using single-hop [15].

B. *Two Dimension UWSNs*

In 2D underwater sensor networks, several nodes are deployed in the seabed with anchors nodes. Sensors are connected to the sink node via acoustic signals as shown in Fig. 1. Sink nodes are responsible for the transmission of data from sea bed to surface. Each underwater sink has a horizontal and vertical transceiver. To perform data collection and transmission of configuration commands between sensor nodes and sink nodes, it uses horizontal communication. Whereas vertical transceiver is used to send data to surface station. The surface station has an acoustic transceiver to communicate with the sink node and radio transceiver for communication with the surface sink [28]. For connecting with underwater sinks, sensors nodes can either use direct link or a multi-hop route. Using a direct link is the simplest method for sending data, but it is not energy efficient. The use of direct links results in a decrease in network throughput and an increase in interference. On the other hand, in multi-hop communication, data collected from the sea bed is forwarded using intermediate sensors until it reaches the sink. This enhances network capacity, saves energy and also increases the complexity of network [24]. Terrestrial wireless sensor networks cannot be used in oceans because radio waves cannot travel in water, and the ocean's diverse environment creates many challenges such as high delays, limited bandwidth, limited battery and node mobility [19].

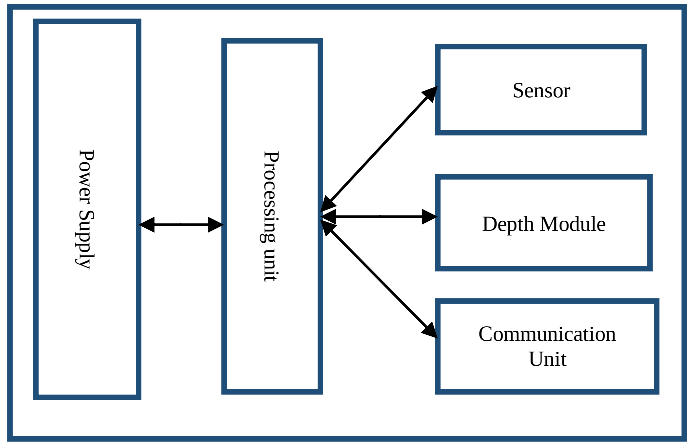

Fig. 1. Internal Architecture of underwater Node.

C. *Three Dimension UWSNs*

The 3D UWSNs are helpful in observing different processes or activities in the ocean bed. In the architecture of 3D UWSNs, sensor nodes are deployed in an ocean bed. Each node has a floating buoy with a pump. The sensors are pushed on the surface with the help of a buoy. A wire connecting sensor and anchor helps in the adjustment of the sensor's depth. The wire is adjusted by an electronic engine that is placed on sensors. The issue of ocean current was addressed in the architecture, but many other issues arise in with this architecture which are

1) *Sensing coverage:* All the sensor should adjust their depths to gain complete 3D coverage of ocean with respect to sensing ranges.

2) *Communication coverage:* Sensing nodes should have the ability to carry information towards the surface by using multi-hop links. Nodes should regulate their depths so that the topology remains connected and there must exist at least one path from each sensor to surface station [28] [24].

D. *Four Dimension UWSNs*

This architecture is a fusion of mobile and fixed networks, where fixed networks refer to 3D UWSNs and mobile network consists of remotely operated underwater vehicles (ROVs). ROVs can be submarines, ships or submersible robots. ROVs gathers the data from deployed nodes and carry it to the remote station. The nodes having a lot of data and are close to ROV can use radio waves to send data directly to ROV [15].

E. *Available transmission medium for UWSN*

Communication by using acoustic signals is widely used in underwater communications. In the conducting nature of seawater, acoustic signals propagate well in low frequencies even at long distances [29][30][31]. Although acoustic communication is affected by noise, temperature, multipath propagation. Because of the slow speed of 1500m/s acoustic medium has low bandwidth of less than 100KHz [32]. But acoustic communication is still favorable due to low attenuation rate and long transmission range of 50m to 5km as shown in Table I.

TABLE. I. COMPARISON OF AVAILABLE TRANSMISSION MEDIUM

	ACOM	EMCOMM	OCOMM
Range of Transmission	~50m-5km	~1m-100m	~1m-100m [2]
Data Rate	100Kbps[25]	10Mbps	1GBps [25]
Complexity of Antenna	Medium	High	Medium
Antenna Size	~ 0.1 m	~ 0.5 m	~ 0.1 m [20]
Power Loss	> 0.1 dB/m/Hz	~28 dB/100mHZ	∞ turbidity [20]

The most useful property of electromagnetic waves is that it uses higher bandwidth. Due to the conducting nature of seawater, radio waves cannot work properly [25]. If electromagnetic waves work in water, it will provide high data rates of 10mbps by using a highly complex antenna. But electromagnetic waves are highly affected by signal attenuation and electromagnetic interference [33][29].

The nature of light is the key reason for limited optical signals. The optical wave communication provides the fastest data rates as compared to radio and acoustic signals [34]. It offers data rates of 1Gbps. The optical signals are absorbed in water due to which its intensity reduces, attenuated, noisy and scattered in water [35][36]. As the presence of sunlight is one of the major causes of ambient noise. So, the strength of the signal will be less than the noise produced by ambient light. To reduce ambient noise optical modems, use high-pass filter technique but the use of filters increases the cost [29] [37].

Many underwater routing protocols have been introduced based on different parameters i.e. reliability, mobility, delivery ratio, and energy efficiency, etc. [38]. Some of the routing protocols forward the data on the basis of angles, two of which are: 1) Layer by Layer Angle Based Flooding and 2) Diagonal and Vertical Routing Protocol.

F. Layer Angle Based Flooding (L2-ABF)

Layer by Layer Angle Based Flooding was proposed by the author in [39]. The goal of this protocol was to avoid horizontal communication between the nodes at the same levels. The sensors do not require any localization information. For packet forwarding sensor nodes sends the packets to nodes at upper layer for investigation of eligible nodes within specified area and send it to nodes having low Hop ID at the upper layers with help of basic formula of $\theta = 90 \pm 10K$ where K has the values of 1 to 8 and the θ always lies between 0 and π. With the increment of value of K flooding zone also increases. The restriction of angles helps in the avoidance of horizontal communication [14] [21] [40].

Furthermore, in our previous work like [41-45] in which, we performed simulation under different traffic agents such that TCP and UDP. In addition, link failure detection between two nodes, subnet based approach and some relevant article to support our words, for this, see [46-50].

G. Diagonal and Vertical Routing Protocol (DVRP)

Diagonal and vertical routing protocol is an angle-based flooding protocol. In the protocol, the source node does not require any localization information for packet forwarding. The aim of developing is to reduce horizontal communication among nodes as the horizontal distance is always greater than the diagonal or vertical distance towards the sink. The reduction in horizontal communication increases network lifetime and reduces delays. When a node has a data packet to send, it sends a hello packet to upper layer nodes to get the information about nodes that are eligible for data forwarding. Packets are only sent to the eligible nodes having a depth less than the source node, and multiple nodes can be eligible for transmission at once. The specified area to which packets are forwarded is called flooding zone which is calculated by of $\theta = 90 \pm 10K$ where K has the values of 1 to 8, and the θ always lies between 0 and π. If the source node does not get a hello reply in the response of the hello packet, the angle is incremented in order to increase the flooding zone of the source node [7][18].

III. RESEARCH METHODOLOGY

The deployment of sensor nodes within the water for the purpose of communication has gained worldwide interest in the past few decades. UWSNs have many similarities with TWSNs. But, UWSNs and TWSNs are also different in many aspects. The environment and applications of UWSNs are different. Due to these differences, terrestrial routing protocols cannot be used in the oceanic environment. These challenges require optimal solutions for situations i.e. water currents, long delays, and horizontal communication. A routing scheme is required which can minimize the mentioned challenges as much as possible.

Routing is the basic need of any network. The routing protocols are responsible for the discovery and maintenance of routing paths. A lot of research has been conducted on the physical layer, whereas the network layer issues are relatively new.

A. Justification for Vertical and Diagonal Communication

In the water, the goal of communication is to transmit the data to the sink via nodes of the upper layer. The data can be sent to other nodes in the horizontal, diagonal or vertical direction. The proposed routing techniques restrict the horizontal communication and prefer either diagonal or vertical communication because the distance that is covered in either diagonal or vertical direction is always less than that of the horizontal direction.

In Fig. 2, O, A, and B are ordinary sensor nodes floating at different depths of water, whereas S is the sink node that is placed on the surface of the water. The nodes O and A are deployed at the same depth level from sink S. If a node O has a data packet to send, it can send the data via any of three routes which can be

1) O to S
2) O to B and B to S
3) O to A, A to B, A to S

For the distance comparison, only routes 2 and 3 are considered. By using route 2, O can send packet to the diagonal node B which is closer to sink and then the node B will forward the packet to sink node S. whereas, in the route 3, packet will be sent to node A which is at the same depth level of O, A will send the data to node B of upper layer and finally, B will send data to S. By the theorem of triangular inequality, we prove that vertical and diagonal distance is always less than horizontal.

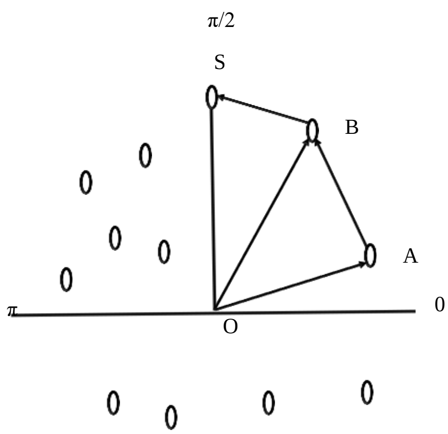

Fig. 2. Comparison of Horizontal Distance with Diagonal or Vertical Distance.

Consider the triangle ΔOAB.

$$|OB| < |OA| + |AB| \quad (1)$$

The above equation shows that the third distance is always less than the sum of two distances. So, if the packet is transmitted by the route consisting of |OA|+ |AB| it will cover more distance as compared to |OB|. Even if the addition of |BS| is done on each side of the above equation.

$$|BS|+|OB| < |OA|+ |AB|+|BS| \quad (2)$$

Still, it is clear that the diagonal or vertical communication is better than horizontal communication.

B. *Angle Adjustment for Vertical and Diagonal Communication*

An angle adjustment technique is proposed in this research. This is a layered delay minimizing approach. It uses only diagonal and vertical communication between nodes. It uses multi-sink architecture, which gathers data from sensor nodes. Sensor nodes are deployed in multiple layers at different depths. Nodes flood the collected data within the computed angle. But when the data is flooded in the flooding zone, there may be some nodes that cannot participate in the communication creating a dark shaded area, as shown in Fig. 3. The data is sent to the upper layers until it reaches any sink. The reception of data at any sink node will be considered as a successful delivery. Sinks can transmit the data to the base station via radio signals.

The major advantages of the proposed approach are:

1) No need for localization information
2) Easily survive with node mobility occurred due to water currents
3) No maintenance of complex routing tables

The goals behind the development of this approach are as follows.

1) Minimize the dark shaded area.
2) Reduce horizontal communication among nodes.
3) Reduce propagation delays.
4) Increase the packet delivery ratio.

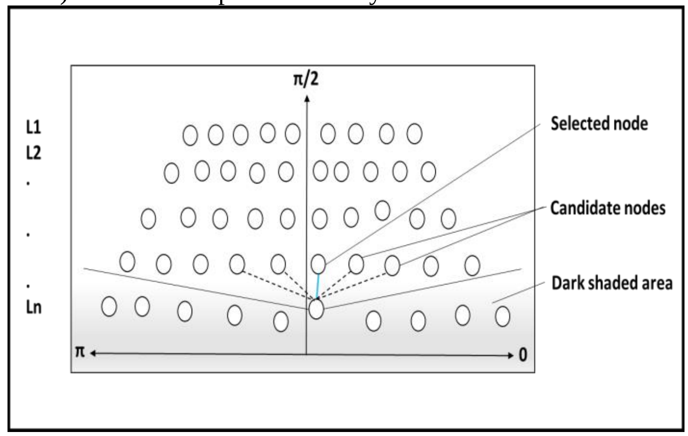

Fig. 3. Working of the Proposed Solution.

C. *Control Packets*

The sensor node generates a hello packet that is flooded in the flooding zone to identify its neighbors. The hello packet includes the following fields as depicted in Table II S_ID: the source ID identifies the id of the sender node.

The format of hello reply is shown in Table III. S_ID identifies the source node, R_ID identifies the ID of reply node.

1) *Data Packet Format:* The format of the data packet is shown in Table IV. The header of the data packet comprises three fields which include S_ID, R_ID, and SN_ID.

S_ID is used for the identification of the source node. F_ID consists of the id of the receiver node which was selected as a forwarder node by the sender. SN_ID is used to distinguish packets.

D. *Layer ID Assigning Algorithm*

For the purpose of assigning Layer IDs (L_ID) surface sink broadcasts a hello packet. At the beginning, all the ordinary nodes are assigned with L_ID 00 and the Total Layers is 9. The Total Layer is dependent on the depth of area of network. When a node receives a hello packet, it first checks its type. If the type of packet is S_hp and Total_Layer is less than i and if L_ID is equal to 00, then the value of i is assigned to L_ID. Else if L_ID is less or equal to i then the packet is discarded. If the type of packet is S_hp and Total_Layer is less than i but L_ID is not equivalent to Total_Layer then the current value of Total_Layer is assigned to L_ID.

Former this procedure, for updating L_ID the current node will send HP to the nodes of layers below it. But before sending it to lower layers the Total_Layers is decremented by 1. After decrement, if Total_Layer is equivalent to 0 then further broadcasts are not required and S_hp are discarded. The pseudocode of this Algorithm is shown in Table V and the flow is represented in Fig. 4.

TABLE. II. HELLO PACKET FORMAT

S_ID	L_ID	Angle

TABLE. III. HELLO REPLY FORMAT

S_ID	**R_ID**	**Angle**

TABLE. IV. DATA PACKET FORMAT

S_ID	F_ID	SN_ID	Data

TABLE. V. PSEUDOCODE FOR LAYER ID ASSIGNING

```
L_ID = 00       //when layer id is not assigned to node
Total_Layers=9
i=1             // initialization of number of layers
if (P_type == S_hp) && (i < Total_Layers)
    if (L_ID = = 00)
        L_ID = i          // Each node will get layer id
else
        if (L_ID ≤ i)
            Discard DP        // layer id is already assigned
        Else
        L_ID = i
          i++
        Send S_hp further
        End if
    End if
End if
Total_Layers=9
No further broadcast for S_hp
Exit
```

1) *Updating Layer IDs:* The presented approach is suitable for both types of applications time-critical and non-time critical. The sensor nodes always remain active for time-critical applications due to which the energy usage increases. Whereas for non-time critical applications, nodes can sense and send data in a time interval after which nodes operate in sleeping mode or their transceivers are turned off.

Nodes in the water can easily move horizontally and may also slightly in a vertical direction. The movement can also change the neighbor of nodes. The Layer ID defines how many layers a packet has to cross to reach to sink node. The layer ID of the current node is always smaller than that of the lower layers and is larger than the upper layer.

In the proposed approach, after a particular time, new L_IDs are assigned to each node. When the lifetime increases a threshold value of 30 min, the entire network is assigned with new L_IDs by using HPs. If a node has a data packet ready to be sent prior to the change of L_ID, it will hold the packet till new L_ID is assigned. The procedure of new L_ID assigning can effectively tackle vertical node movement as the nodes will have new L_IDs as per their new layers.

E. Flooding Zone Calculation

The proposed approach is an angle-based flooding approach. In this approach first of all the flooding zone is computed. The flooding zone is the area of the network consisting of nodes of upper layers in which the data packets are sent. Here we made an assumption that each node knows about its *hardware* built-in base angle $\pi/2$ in the upward direction. Each node has the ability to calculate the angle and also to increase the size of its flooding zone as per requirement. The computation of flooding zone is done by using the basic formula $\theta = \pi/2 \pm \alpha$ where α is a variable having a finite set of values between 0 and $\pi/2$. The conceptual illustration of flooding zone increment is given below in Fig. 5, 6 and 7.

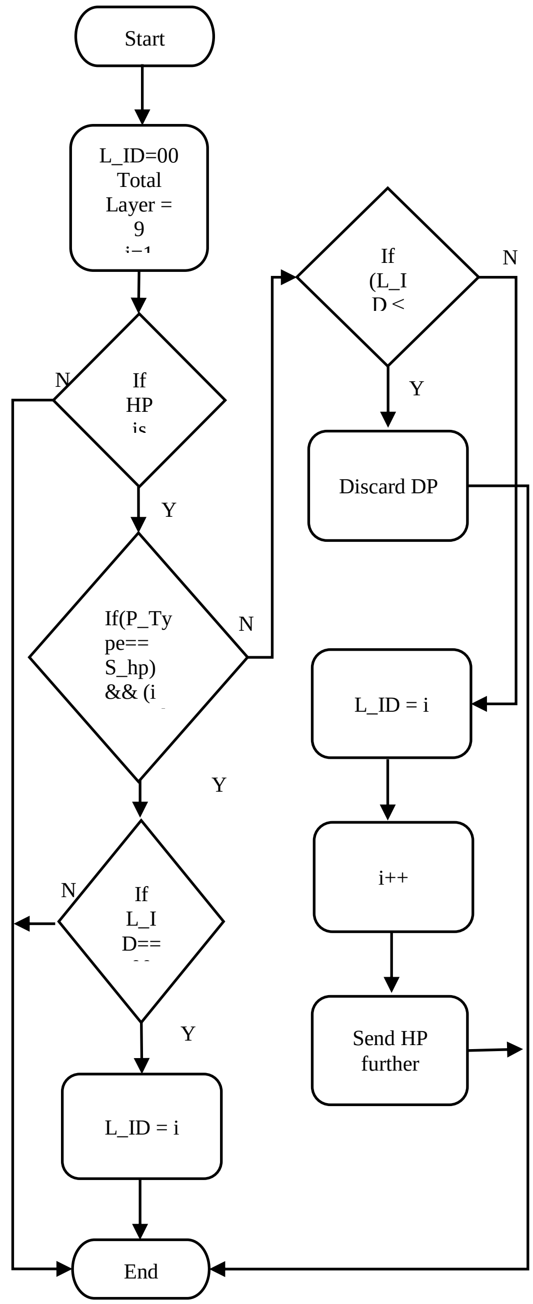

Fig. 4. Flowchart for Assigning Layer-ID.

$$\theta = \pi/2 \pm \alpha, \theta = \pi/2 \pm 1, when\ \alpha = 1 \quad (3)$$

$$\theta = 91, \Theta = -89 \quad (4)$$

$$\theta = \pi/2 \pm \alpha, \theta = \pi/2 \pm 12, when\ \alpha = 12 \quad (5)$$

$$\theta = 102, \Theta = -78 \quad (6)$$

$$\theta = \pi/2 \pm \alpha, \theta = \pi/2 \pm 89, when\ \alpha = 89 \quad (7)$$

$$\theta = 179, \Theta = -1 \quad (8)$$

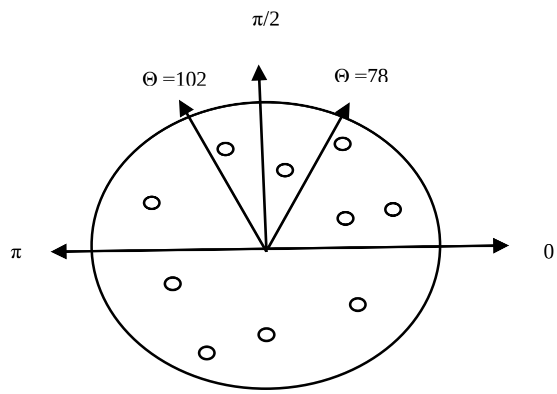

Fig. 5. Flooding Zone Calculation at α = 1.

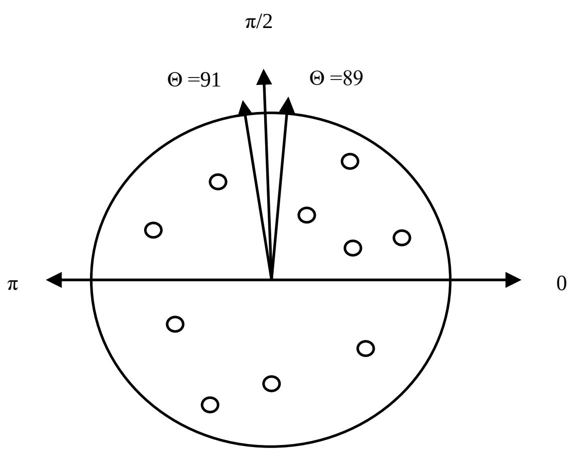

Fig. 6. Flooding Zone Calculation at α = 12.

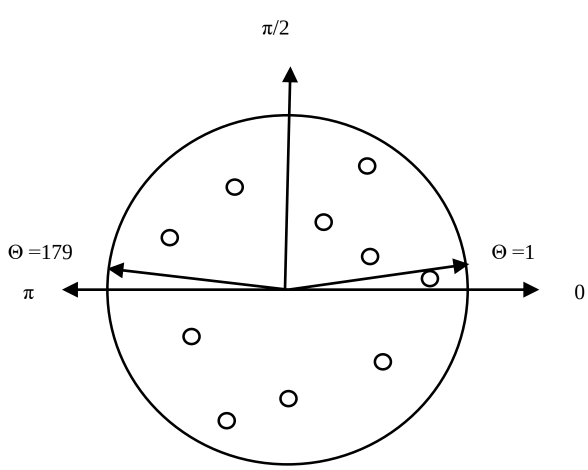

Fig. 7. Flooding Zone Calculation at α = 89.

F. Packet Transmission

The angle adjustment technique is a localization free approach that does not require the knowledge of source node and sink prior to packet forwarding. The approach is developed for minimizing dark shaded areas and delays. Each node has the ability to calculate the flooding zone with the help of basic formula θ= π/2±α where α has the finite set of values between 0 and π/2. After computing flooding zone sensed data is flooded towards sink nodes. Sink node receives sensed data via upper layer nodes. Table VI shows the procedure of data packet forwarding.

The sender node N05show in Fig. 8 has a data packet ready to be sent with its L_ID. By using a simple Hello Packet (HP), the source node discovers candidate nodes within the flooding zone. Nodes that receive HP will reply to the source node with the help of Hello Reply (HR) which contains ID, L_ID, and its current Angle. The formats of HP and HR are illustrated in Table II and Table III. A node N14 resides in the flooding zone which will reply to source node N05 via HR. N05 will send the data packet to node N14 as its angle is closest to the vertical line as compared to other candidate nodes. The same procedure will be used by each node that wants to send data until it reaches the sink.

If multiple nodes reside within the flooding zone then each node will compute its angle and send it to the source node in the form of HR. the source node will compare the angle of each node, the data packet is sent to the node having the angle closest to the vertical line.

If the source node doesn't get any HR, the source node will increase the size of the flooding zone by incrementing the value of α until it meets the base condition 0 ≤ α < π/2. The nodes can use any random value of α because it is more useful for controlling power consumption and end to end delays. The values of α are dependent on the network. For sparse networks, the network uses higher values of α whereas, for dense networks, smaller values of α are used to adjust the size of the flooding zone.

In the worst case, if the source node has checked all values of α but does not get any HR from any node, then the source can forward the data packet to a node of the same depth level or at the horizontal line.

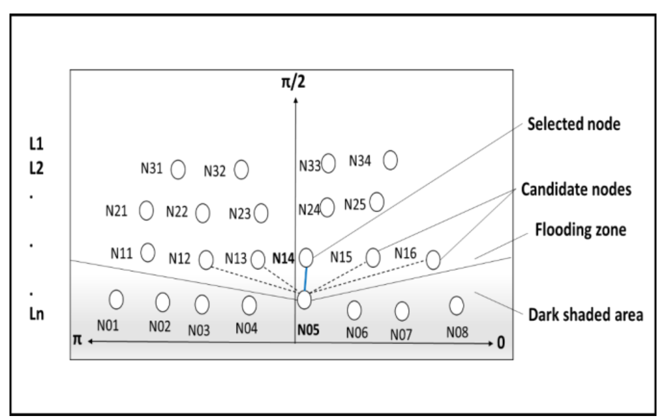

Fig. 8. Packet Transmission Process.

TABLE. VI. PSEUDOCODE FOR DATA PACKET FORWARDING

```
1.  Initialize θ= π/2±α where 0≤α< π/2      // Here α is a variable
2.    If Ns have DP            //Ns is the sensor nodes and DP are the data packets
3.        If 0≤α< π/2
4.          Send HP to the Nn //HP are hello packets which are sent to neighbor nodes Nn
5.            If HR received
6.              Compare and store θ of Nc // Nc are candidate nodes for packet forwarding
7.                If θ is close to Vl // check that if angle θ is close to Vertical line Vl
8.                  Consider it θa   // consider that angle as adjusted angle θa
9.                  Send DP to Ns close to Vl
10.               else go to step 6
11.           else if α = π/2
12.             Send DP to Hl // data packets will be sent to horizontal li
13.           else increase Tr // if α is less than π/2 then transmission range is increased
14.             Go to step 4
15.       else go to step 17
16.   Else go to step 17
17. End
```

In the rare case, if the source node can't find any node even on the same depth level, then the source node can eliminate the restrictions of the recommended communication range, which is 1km, and the node can directly send the data to the sink using maximum energy.

1) *Pseudocode for Packet Forwarding:* In the network when any node has a data packet ready to be sent which is either created by that node or is received from any other node, it firstly computes the flooding zone with the help of basic formula as discussed in section E. After computing the flooding zone, Hello Packets (HP) are flooded within it. The nodes which get hello packets will send Hello Reply (HR) in response to the hello packet along with their current angle. After receiving hello replies from all candidate nodes, the current angle of each node is compared. After comparison data is sent to the node having the angle closest to the Vertical Line (Vl). In case if the source node doesn't get any reply, the source node increases the flooding zone by incrementing the value of α. If no node is available till the maximum value of α, then the node can send data to Horizontal Line (Hl) or at the same depth level. The Pseducode and flowchart for Data Packet Forwarding is represented in Table VI and Fig. 9.

G. Implementation Tools

1) *Network Simulator (NS-3.26):* The development of simulation models that are sufficiently realistic for real-time network emulator, interconnected with the real world and allows many existing real-world protocol implementations to be reused.

2) *DESERT Framework:* It supports network simulator to design and implement of new underwater network protocols.

IV. RESULTS AND ANALYSIS

The chapter describes the simulation results to assess the performance of angle adjustment for diagonal and vertical communication which was presented in the previous chapter. Firstly, the simulation environment and criteria for assessment is described. The routing technique is assessed as per different parameters which involve node mobility and load on the network in Section C.

For the assessment of performance, AquaSim was used which is a network simulator based on NS-2 for the underwater environment. Aquasim supports node mobility, attenuation and 3-D deployment of nodes.

A. Simulation Environment

For the evaluation of the performance of the proposed approach NS-2 was used. Including the ordinary and sink nodes, a total of 300 nodes were deployed in a three-dimensional area of 800m×1000m2. Multiple sinks consisting of both acoustic and radio modems were deployed on the surface of the water.

The maximum distance among layers is 100m. The ordinary nodes which are deployed in the water were considered as floating between ground and surface of water whereas the sinks are static and placed on the surface of the water. Ordinary nodes can move horizontally with water in fixed motion up to 1-4m/s. The data can be delivered up to 9 layers from bottom to the surface.100m is the range of transmission of sensors. The average depth and width of layers is 100m. surface sinks are also deployed 100m away.

Consumption of power is different for different events. 1 unit of energy is required for transmission and 0.02 for receiving. For the prevention of packet collision, one node can transmit the packet at a time in the domain of collision. The MAC protocols are based on IEEE 802.11 with the Constant Bit Rate (CBR) of 512 bits per packet. 500 packets were produced at a rate of 1 packet/s. the anchored nodes produce 250 packets and the remaining were produced randomly by the floating node. Table VII presents the details of the simulation parameters. As a supplement tool, for plotting and analysis of graphs MATLAB was used.

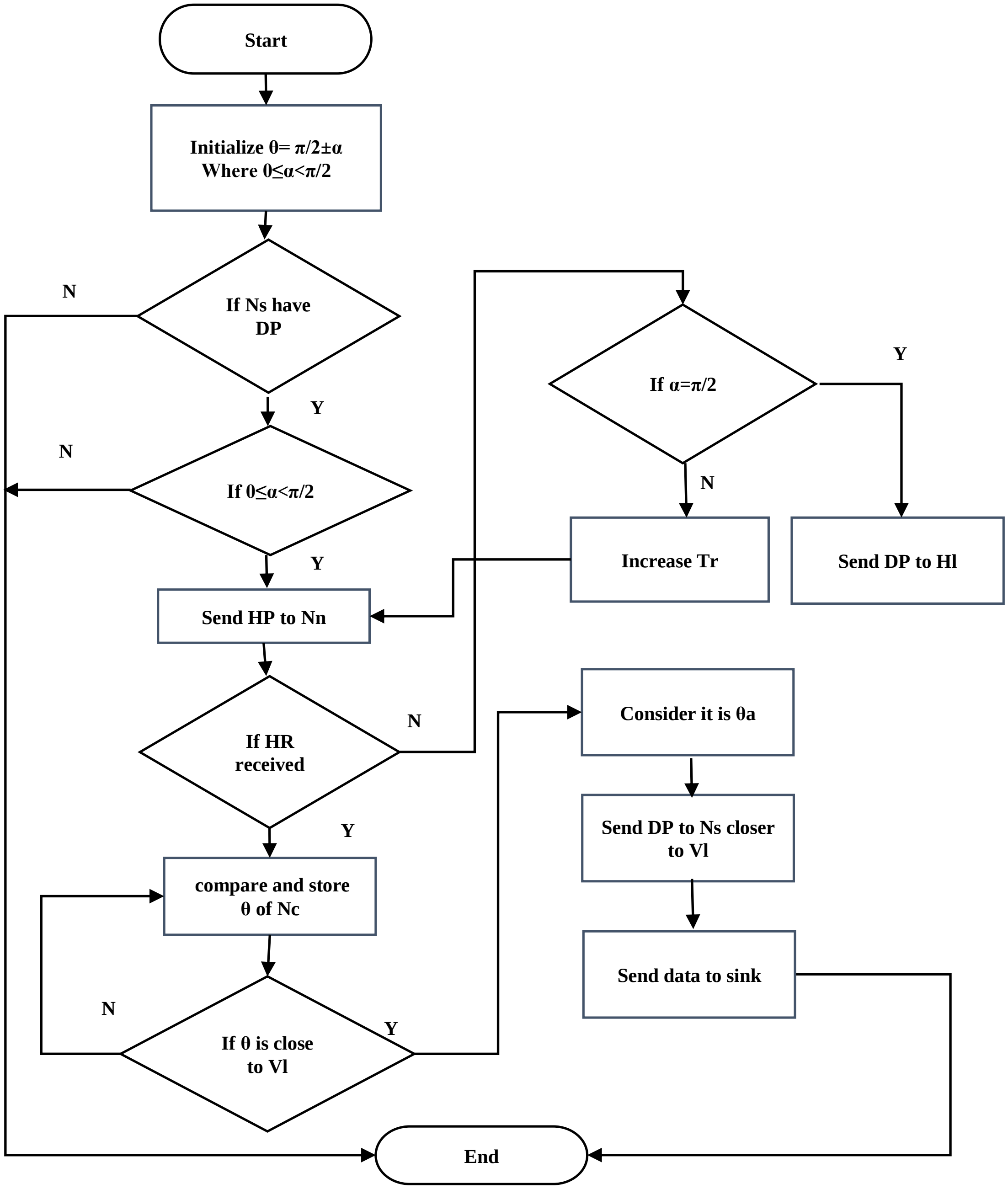

Fig. 9. Flow Chart for Data Packet Forwarding.

B. Performance Metrics

For the evaluation of performance proposed scheme consumption of energy, data delivery, and end-to-end delays were considered as evaluation parameters (as described in Table VII).

C. Performance Analysis

This section defines the evaluated performance of the presented approach based on the parameters which are node mobility, network load, and energy consumption.

1) *Mobility of nodes:* For data delivery ratio two-node movement speeds (2m/s, 4m/s) and static nodes were considered as illustrated in Fig. 10. With 300 nodes delivery ratio was 100% and it remains static. The delivery ratios don't face any major effects with the decrease of node density. If 30% of the nodes are not available still the network can achieve a 90% delivery ratio. Even if the network gets sparse and only 50% of nodes remain available, 85% delivery can be achieved. Only a minor difference was seen when the number of nodes decreases. But the difference was not high as 50% of nodes were available. Fig. 11 presents end-to-end delay and energy consumption with different node movements. A minor difference in the delay was noted at different speeds. This describes that no critical effect was on delays and energy consumption due to node movement.

TABLE. VII. SIMULATION PARAMETERS

Parameters	**Values**
Software Version	NS 2.33
Network Field	1500x800x800
Topology	3D
Simulation time/hr	6
Antenna	Directional (Parabolic)
Number of sensors	300
Number of sinks	8
Distance between layers	100 m
Transmission Range/m	100-150
MAC Protocol	IEEE 802.11
Packet Size	512 B
Bandwidth/Mbps	10
Packet rate/Kbps	6-16
Initial Node Energy/J	1000
Packet Transmission Energy/unit	1
Receiving Energy	0.02

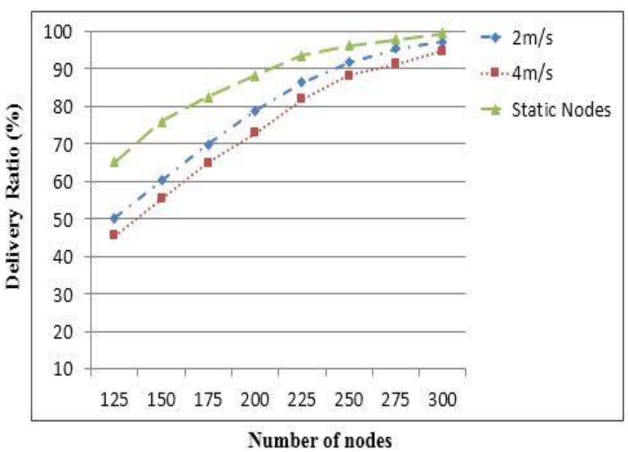

Fig. 10. Delivery Ratio for different Node Speeds.

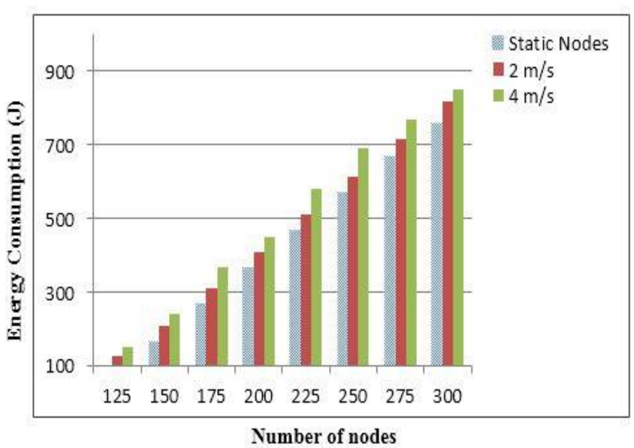

Fig. 11. Energy Consumption for different Node Speeds.

Mobility of node can affect average delays in sparse conditions, whereas all matrices show almost similar results in dense conditions.

Movement of the node doesn't affect the delivery ratio and energy consumption because complex routing tables were not maintained as per the node's location. Layer_ID of each node is maintained by node so its location can be easily handled.

Movement of the nodes don't affect the delivery ratio and energy consumption because complex routing tables were not maintained as per the node's location. Layer_ID of each node is maintained by node so its location can be easily handled.

2) *Network Performance with Different Number of Packets:* By generating one or more than one data packets, delays and delivery ratios of the proposed technique were analyzed so that the performance can be evaluated with different loads. Usually, 1 packet/sec is produced in the network but for non-normal cases, performance is assessed for 2 packets/sec and 3 packets/sec were also checked. The delivery ratio with different loads is shown in Fig. 12. The packet delivery ratios in the dense network were approximately the same. But, in sparse conditions, the difference appears where the load was high, but there were a smaller number of nodes in the network. Fig. 13 shows that the network can conveniently handles the situation when double packets are produced in the network, the end-to-end delays were still affordable.

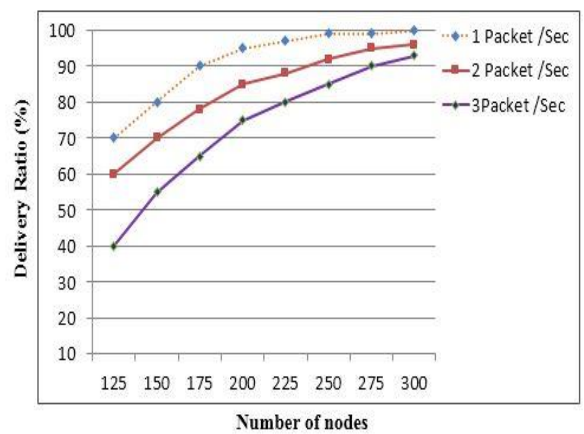

Fig. 12. Delivery Ratio for different Packet Loads.

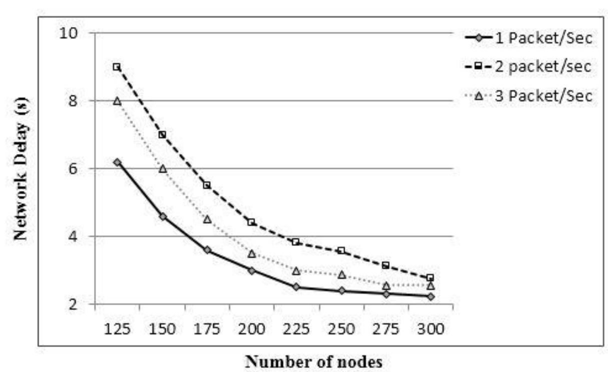

Fig. 13. End-to-End Delays for different Packet Loads.

3) *Performance Analysis with Different Flooding Zones:* Fig. 14 and Fig. 15 present the ratio of data delivery and end-to-end delays respectively with various values of α were selected randomly for analysis. Minor change can be observed with different values of variable α. The effect of using smaller and larger values of α for forwarding data packets can be seen in the dense network but the difference arises when the network becomes sparse and larger values of α are used to find a forwarder. However, the difference is obvious with less nodes. Still, the effect is affordable even with only 50% of available nodes.

D. Comparison with DBR

A lot of location-based routing protocols have been proposed. But in the water, it is quite difficult to get location information due to the unavailability of GPS [43][44]. Instead of using location information, DBR uses the depth of sensors for forwarding packets. Whenever a node has a data packet to send, it compares its current depth with the depth embedded in the packet. The packet is forwarded if the depth of the candidate node is less than the source node. Every node has the ability to calculate its current depth. The issue that DBR faces are: 1) more than one node can same data packet due to same depth which can cause power overhead. 2) DBR don’t handle void area where no node is available which could be qualified as forwarder. Source node makes multiple tries but it doesn’t select the route with higher depth due to greedy approach [45].

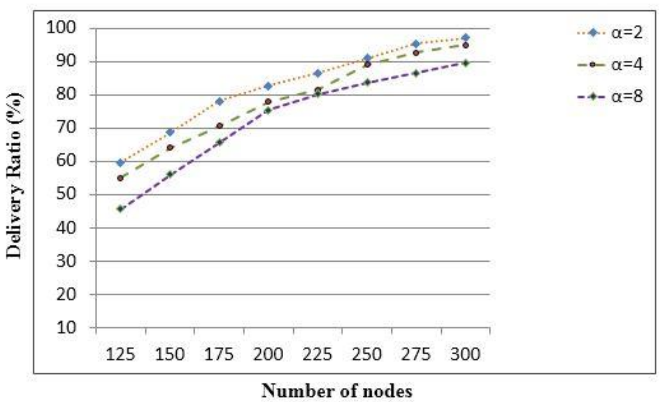

Fig. 14. Delivery Ratios for different Flooding Zones.

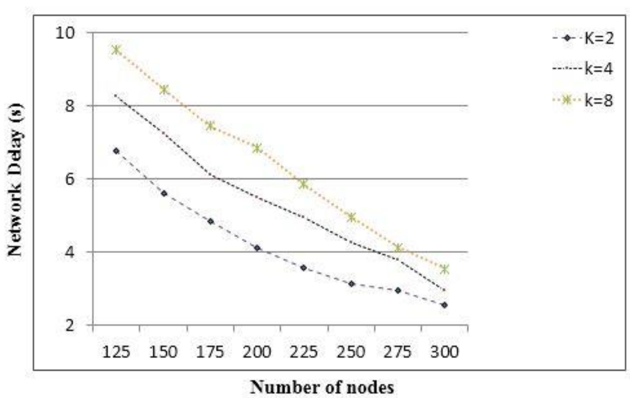

Fig. 15. End-to-End Delays for different Flooding Zones.

1) *Delivery ratio:* For evaluation of performance, delivery ratios of DBR and the proposed angle adjustment approach were compared in Fig. 16. The delivery ratio of both protocols decreases in sparse conditions but the effect on angle adjustment is less as it can send the data packet to the water surface without considering the location of sink nodes because multiple sinks are deployed unlike DBR [39].

2) *End-to-End delay:* The comparison of end-to-end delays among DBR and Angle adjustment are shown in Fig. 17. The holding time of DBR is responsible for delays whereas in angle adjustment approach node can directly flood the packets within the flooding zone.

3) *Energy consumption:* The power consumption of DBR and angle adjustment is presented in Fig. 18. The consumption of power is almost the same for a smaller number of nodes. But it increases in dense networks. The dense environment in DBR increases power consumption because it uses packet broadcasting and it also computes depth for selection of forwarder nodes, whereas angle adjustment only computes flooding zone for selecting next forwarder.

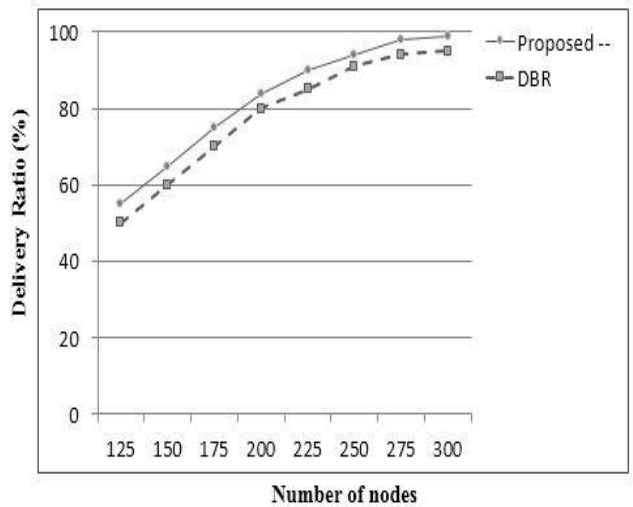

Fig. 16. Delivery Ratio Comparison with DBR.

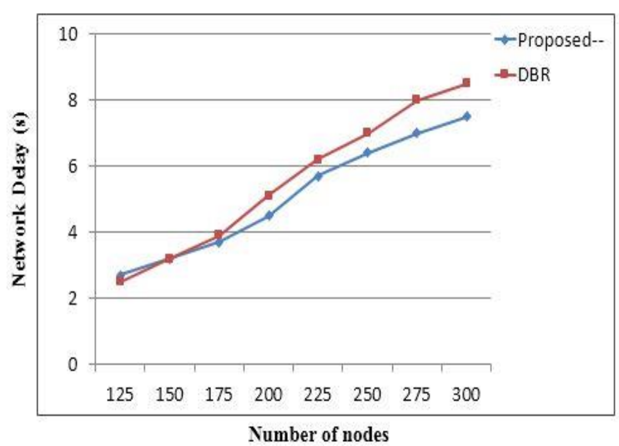

Fig. 17. Comparison of End-to-End Delays with DBR.

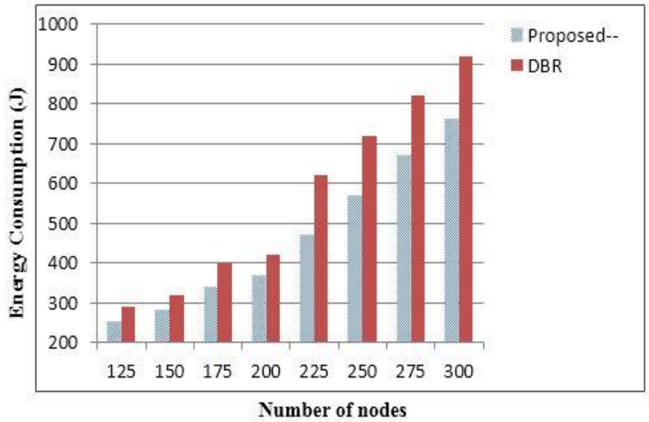

Fig. 18. Energy Consumption Comparison with DBR.

V. Conclusion

This research work aims to explore the problem of the dark shaded area within the environment of water. The solution for reducing the area is presented in the proposed approach. In this paper, an angle adjustment technique for diagonal and vertical communication is presented. It doesn't need the location information of nodes so don't maintain complex routing tables.

The approach is designed for selecting a fast routing path. It also reduces dark shaded areas, end-to-end delays, and horizontal communication. The approach considers all the values of angles between 0 and $\pi/2$ and changes the size of the flooding zone with each angle. The checking on each angle helps in finding the node which is closest to the vertical line. The vertical and diagonal communication reduces the long propagation delays.

Along with reducing the dark shaded area, the presented approach also achieved performance targets evaluated by using the NS-2 simulator with the AquaSim package. Simulation results reveal that the angle adjustment technique provides high ratios of data delivery, reduces end-to-end delays, and also decreases the consumption of energy.

The results of the angle adjustment technique were compared with DBR which shows that the proposed technique works well than DBR in terms of data delivery, end-to-end delays, and energy consumption in the dense as well as sparse network conditions.

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