An efficient routing protocol based on polar tracing function for underwater wireless sensor networks for mobility health monitoring system application

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Abstract

In recent times, Underwater Wireless Sensor Networks (UWSNs) have involved various applications in oceanographic data collection, pollution revealing, environmental monitoring, offshore exploration, disaster prevention, military surveillance, etc. nevertheless the unique characterization of UWSNs are designed for the grid division on geographical system with polar tracing function to attain the shortest- path and minimizing the energy consumption for end – to – end transmission. In this paper, we proposed a Grid Division Polar Tracing (GDPT) routing protocol function using greedy algorithm for reducing the energy consumption by incorporating into cubic grids and polar tracing functions. The NS2 simulation results proved that the optimal distance of the found path, packet delivery ratio, network lifetime, energy consumption and propagation delay are the performance metrics in the routing protocols. In proposed case used for application of underwater sensor based health monitoring system for wireless in under water environment.

Keywords Underwater Wireless Sensor Networks · Routing · Network lifetime · Residual energy, health monitoring

Introduction

Underwater Wireless Sensor Networks (UWSN) is the most focusing point for the researcher due to its application like the oil industry, instrument monitoring, pollution control, climate recording, prediction of natural disturbances, search and survey missions, a study of marine life, and offshore investigation [1, 2]. The Acoustic sensor network consists of a large number of sink nodes in the surface called buoys. The sensor nodes collect the "raw" information from the seabed and transfer the data packets to the surface node for further transmission of data to the onshore node. Unlike Land base Wireless Sensor Networks (WSN), an UWSN is grounded in underwater environment and it is expected to enable applications in inshore and offshore. The main difference between WSN and UWSN in the acoustic channel is low radio frequency signal, low bandwidth, and more power consumption due to communication speed of sound in water is 1.5×10^3 m/s, which have a big difference with the speed of light in the water 3×10^8 m/s. It is difficult to develop the routing protocol due to the water current, which implies the dynamic network topology due to the node movement on water pressure which causes the path loss [3–5]. In UWSNs, all sensor nodes have easily drifted with ocean current, which results in active network configurations. Therefore the UWSN is typically considered to a dynamic change of dimensional (3D) network while contrast to the WSN is always designed as 2D network. The deployment of the node in seabed, which has limited power compare with WSN. The underwater sensor nodes are more expensive than normal

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sensor node [6, 7]. Based on the above constrains the routing algorithm in WSN is not accomplished to apply in acoustic sensor network.

The proposed work is on routing path algorithm for defining the shortest path with energy efficient strategies. The routing protocol is defined by the network layer with two phases in the routing schematics. First phase, describes that grid formation on geographical location of the nodes. The special grid is divided into tiny cubes space. With the least distance which covers the hoping node. The remaining nodes forms in between the spaces are assumed to be the anchor nodes which may act as a forwarder in mobility of the nodes. The greedy algorithms have been deployed on the forwarding of data packet from the source node to sink node through the routing protocol. Second phase, defines that the dimensional plane base on Cartesian system which selected according to the axial location of source and sink node with respect to time, the planer axis changes according to mobility of source node. This function defined by the polar tracing method in equating the degree of transmission. Based on the mobility of the nodes in in-shore, the definition of arrival and depart on cubic grid space is governed by the hash table function. The relative distance between the nodes is calculated with the Euclidean distance in the three dimensional space. The energy aware models have been taken in account with routing protocol which prolongs the node lifetime. The paper further deals with literature aspects of the various routing protocols, network models, energy consumption model, spatial division model and polar tracing function. In the final section the detailed GDPT algorithm is sorted out for the various protocols.

Related Work

In recent years many routing protocols have been proposed for UWSN. This section we surveyed the UWSN in many aspects which related to the geographical based protocols.

Geographic Forwarding based on Geospatial Division (GFGD) [6]

In the 3D underwater network, all the nodes are termed as big cubes. By segregating the big cube into small cubes, the adjacent nodes transmit the data packets from source to sink via hop-by-hop process. They proposed GGFGD and GFGD in 3D Geospatial Division, where all the nodes in the network are duty-cycled. The nodes can combine with each other to activate either sleep or wake-up mode, so that the energy consumption is more. The major drawback is the propagation delay due to static topology [8].

Actually in dynamic topology, energy consumption is inadequate and also it affects the routing performance in sparse network to decrease the network lifetime.

Vector – Based Forwarding (VBF) [9]

The VBF protocol was proposed to identify information regarding the location of the node, which transmit the packet and it is designed to solve the issues present in 3D space. VBF forwards the data in abandoned and scattered path. The VBF evolves a self-adaption algorithm to implement the packet distribution from current or source to sink node. Based on this algorithm, the nodes evaluate the position to forward the packets or otherwise discard the packet to improve the energy consumption. Once the transmission starts, it measures the distance and Angle of Arrival (AoA) by creating the "routing pipe" [10]. When compared with sparse network, VBF is inadequate in reliability, low bandwidth, high latency and packet delivery that leads to more energy consumption.

Improving the Robustness of Location-Based Routing (HH – VBF) [11]

The HH-VBF is developed from VBF to recover the sturdiness and energy efficiency in the form of the "routing vector" and the VBF approaches in the form of "routing pipe". Different virtual pipe is used by HH-VBF around the pre – hop vector for each forwarder to the sink. In this approach, packet forwarding by all the nodes are made adaptively based on their own location [12]. The major highlight of this protocol is to actuate the data delivery ratio in sparse network by increasing the pipe radius depending upon the transmission range. The main goal of HH-VBF is that each node has its own identical routing pipe and it leads to reduction in the packet discarding from sparse node.

The major shortcoming of this protocol is high energy consumption and packet forwarding is better in dense networks.

Depth Based Routing (DBR) [13]

The DBR protocol was proposed to accrue the depth information of each node and it does not mind about the full location information of the node. The DBR uses the greedy algorithm for packet delivery from seabed to buoys node. The node starts calculating the distance of sender node before transmitting a packet and within the threshold value otherwise the packet will be automatically discarded [7, 14]. All the nodes distribute their location information to their neighboring node to make

decision regarding the reduction in the energy consumption and to improvise the network lifetime. In DBR greedy approach is not performed well in sparse networks and never explores the "void" area. The performance of DBR increases more candidate node to forward the data packet.

Focused Beam Routing (FBR) [15]

FBR proposed a geographical based approach which makes the own location information of the nodes. It uses the control packets (RTS and CTS channel) to access the reservation and selection of the neighbor nodes based on the distance to sink. The FBR aims at performing packet loss, delay of packets, by which the energy gets exhausted due to control packet for each packet transmission. And also it assumes a distributed algorithm for least power consumption, average packet transmission, and end-to-end delay [16]. The broadcast range of the node is partial and they consider only the depth based not in sparse, so it fails in the multi-path construction.

Hop-by-Hop Dynamic Addressing Based (H^2-DAB) [17]

The H^2-DAB is uses multiple sink architecture to avoid the pack loss and energy loss.

It does not consider full dimensional location information, but it takes advantage of the multiple sink architecture and based on this, the performance of the routing protocols maximize the delivery ratio, low latency and reduction of the energy consumption. In underwater, the H^2-DAB holds many issues, firstly, the radio communications are replaced by acoustic communication due to low propagation speed and high latency. Secondly, energy consumption is dynamic in different networks like dense and sparse networks. Thirdly, some of the nodes are placed in surface area called sink node, some of the nodes are with anchor. These nodes are fixed, but some are positioned in undersea as they are not steady and they move with the water current. The main disadvantages of choosing forward node is that the sender may not have a response from its neighbor node especially in sparse network which is critical to monitor.

This fact restricted the scientific research operations. Nowadays there is a growing need of underwater monitoring (e.g. for exploration of natural undersea resources, gathering of scientific data or detection of marine incidents such as chemical pollution or oil spill). We have used Grid division polar tracing function. To address above stated issues, in this paper we propose a Grid division polar tracing (GDPT) protocol to reduce the energy utilization for end-to-end data delivery and works as follows: Initially, our system adaptively uses an prevailing geographic routing protocol to gain an anchor list

based on the projection distance of nodes in diversion mode. Then, our scheme employs geographic information, the uniqueness of energy utilization, and the metric of higher energy cost to make forwarding decisions. Finally, each forwarding node alters it transmission power so that it can just arrive at a chosen neighbor node and starts to forward data packets. Simulation results reveal that the proposed approaches show higher energy efficiency when matched up with other geographic routing protocols.

System Architecture

In UWSN, the nodes are deployed randomly in different depth from seabed to water surface. In addition, all the nodes move with water current. The proposed work of the network model is divided into three phases: firstly the calculation of energy consumption to avoid the node failure, secondly the inexactness in models for position estimation, self-localization errors, and drifting due to ocean currents, significantly increase the uncertainty in position of underwater nodes. These issues cause an ambiguity in deterministic routing. In order to address the problem caused by uncertainty issues, a grid based topology is proposed to localize the accuracy of node position on the network point of view. Finally, polar tracing function in consideration with 3D underwater environment helps in minimizing energy consumption and providing shortest path from source to sink with involvement of mobility. The polar tracing functions have been included for the shortest path defining from the source to sink straight to the planer nodes in the depth access.

Power Consumption

Through energy consumption of the network, we examine a simplified scenario in which "N" nodes and a cluster head node are arranged linearly along a stretch of length "r". The nodes are unvaryingly dispersed so that the distance between each two adjacent nodes, including the distance from the base station to the node closest to buoys, it is r/N. In our model, d is the transmission distance between sources and sink node, b is the bit length, T_p is the packet duration, depth of the node in ocean denoted as d_{th}, p_{ec} is the power consumption, and $f(x)$ is the frequency absorption. Thus, the utilization of energy for a node is calculated by transmitting m bit as E_{tx} [18].

$$E(d, b) = bp_{ec} + bT_b Cd_{th} de^{f(x)t} \tag{1}$$

$$E(d, b) = bp_{ec} \tag{2}$$

f(x) can be assume by

$$f(x) = 0.11 \frac{x^2}{1+x^2} + 44 \frac{x^2}{4100+x^2} + 2.75 \times 10^{-4} x^2$$
$$+ 0.003 \tag{3}$$

where f is the transmit channel center frequency, which determines the measure of central frequency between the high and low cutoff frequencies.

The UWSN is designed to calculate the propagation delay and path loss from the below equation the temperature of the sea water is denoted as K, the density of sea water is little higher due to salinity it referred as s. The atmosphere of underwater environment is calculated by [19, 20].

$$d_{delay} = 1449.05 + 45.7K - 5.21K^2 + 0.23K^3$$
$$+ \left(1.333 - 0.216K + 0.009K^3\right) \times (s-35)$$
$$+ (16.3 \times d_h) + 0.18d^2{}_h \tag{4}$$

$$l_{loss} = d^k exp\left(\frac{d*(x)}{10}\right) \tag{5}$$

where k is an energy propagation.

Now our aim is, to calculate the energy consumption of a node as given below equation, where E_r,

denotes the remaining energy of a node.

$$E_r = -(E_{rx} + E_{tx}) \tag{6}$$

where E_i is the initial energy of node.

Grid Based Division Model

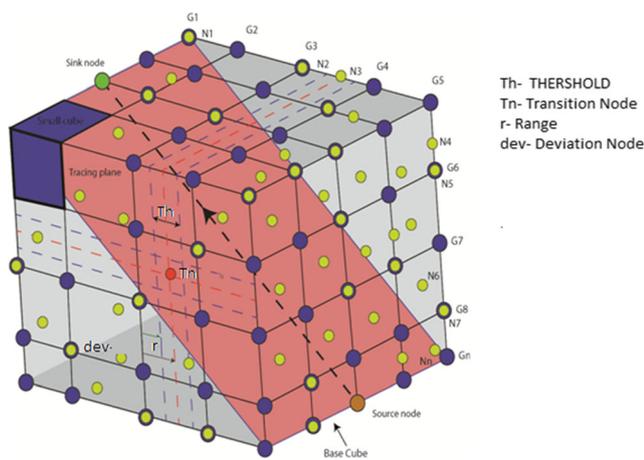A cubic space is drawn in 3D phases based on Geographic Positioning System (GPS). This space consider as Base

Th- THERSHOLD
Tn- Transition Node
r- Range
dev- Deviation Node

Fig. 1 Architecture view of the GDPT sensor networks

Cube (B$_c$). The surface of the water and seabed denoted as g$_n$, as shown in Fig. 1. The system architecture analysis of the GDPT sensor networks is exposed. N submit to numbers of acoustic sensor nodes with ultrasonic modems are indiscriminately deployed of node in B$_c$ with different depth d$_h$. Furthermore, all the nodes are in mobility which moves towards the water current under velocity v [21]. The faction of node in the cubical space division at time t = 1-k$_{sec}$ with constant velocity of v = 1.5×10^3 m/s. the node with the transmission range r = 50-100 m in underwater at 20–45 kHz by investigation study by Robotic Embedded Systems Laboratory (RESL) [22–24]. The positions of nodes in the cubic space are referred as edges. The number of edges is implicit to whole number of nodes. The divergence distance 'd$_{dev}$' among the two adjacent nodes initiate to be significance of transmission range 'r'. When a node enters the edges within the communication range with the divergence distance it is entered into the hash table with hash key function k$_i$ in order to avoid the collision between the adjacent node at the time of communication a threshold value have been set as 'th'. Initially all the nodes are in same level like energy, transmission range and propagation delay etc. In our investigation communication link of nodes are equal. A node is either source or sink which uses to provide required information to their neighbor nodes in the network. Actually a surface node with both acoustic and RF modem is placed on surface of the ocean to provide the feedback about the route. Generally, each node know their own location and also about the surface node. The communication range denotes as r of all the nodes present in the B$_c$ which shown in the fig. 1. The nodes scatter in the field which highly hard to connect each other's so we split the B$_c$ into multiple cube called tiny cube "TC". Now the node which starts the transmission first make trace from 0°-180° to find the vertex and adjacent node present in the TC as shown in Fig. 1. Based on that all the nodes know which cube belongs too. The length of the planar axial is P$_n$ which related to the transmission range r. We assume that all the nodes are in mobility and dynamic change of topology.

Polar Tracing Function

The polar tracing function is used to define the planar axis with respect to polar coordinates (r,). This creates the slop of axis in hypothesized from source to sink is shown in Fig. 2. Due to mobility of node the angle of incidence θ varies with the drifting of source from sink node at constant velocity. The moving speed and acceleration of the node N$_n$ with ID consisting of three field location frame and node ID (MAC address). The first field of location frame represent Cartesian coordinates (x,y,z) at polar angle with respect to (x,y) frame.

Fig. 2 Polar Tracing function on Grid based routing
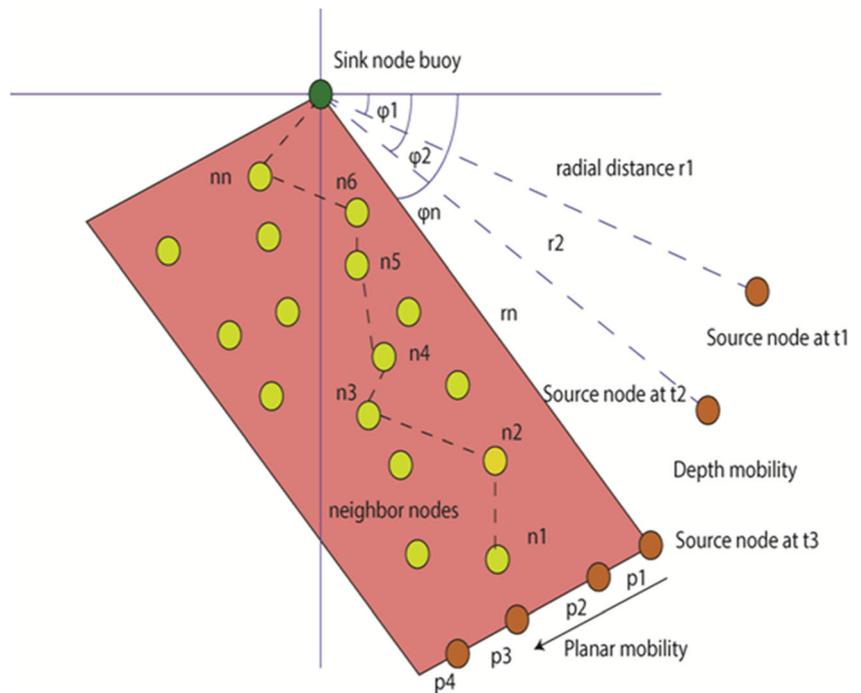
The proposed ID is divided into the following parameter using hash key function.

The polar transformation function at location S_0 (source) to S_i is derived with distance 'r' which can be calculated by the formula. The angular coordinate $\varphi \vee \theta$ $(r, \varphi \pm nx360°)$ denotes the definition of the distance, n is distance $(-r, \varphi \pm (2n + 1)180°)(0,2\pi) \vee (-\pi, \pi)$

$$x = r\cos\varphi \tag{7}$$

$$y = r\sin\varphi \tag{8}$$

$$r = \sqrt{x^2 + y^2} \tag{9}$$

$$\varphi = atan2(y, x) \tag{10}$$

$$t = 0 \rightarrow t_{(sec)} \tag{11}$$

$$d_x = (0 - d_x) \tag{12}$$

$$d_y = (0 - d_y) \tag{13}$$

$$d_z = (0 - d_z) \tag{14}$$

where dx.dy.dz are the Cartesian location at an angle incidence 휠with the mobility at time 't' the Cartesian coordinates can be derived using formula.

$$\frac{d_x}{d_t} = \sum_{n=1-\alpha}\left[r\cos\varphi\left[\frac{d_x}{d_{t_n}}\right]\right] \tag{15}$$

$$\frac{d_y}{d_t} = \sum_{n=1-\alpha}\left[r\sin\varphi\left[\frac{d_y}{d_{t_n}}\right]\right] \tag{16}$$

$$\frac{d_x}{d_t} = \left[\frac{\delta\sqrt{x^2 + y^2}}{d_t}\right] \tag{17}$$

Routing scheme of grid division polar tracing function (GDPT)

This section deals with the proposed work called Grid Division Polar Tracing Function (GDPT). In GDPT, each node can be directly communicated with all the neighboring nodes, edges and also the surface nodes of TC. The node 'u' is farthest case in which it can be associated that if and only if of r and d it satisfies the certain condition as shown in Fig. 1. The relation between r and d is

$$(2d)^2 + (2d)^2 + (2d)^2 = r^2 \tag{18}$$

the vital communication can be definite, thus when r is fixed, d are calculated by

$$d = \frac{\sqrt{x}}{y}r \tag{19}$$

In Fig. 1, the node 'n' is a normal node and is located accurately at the grid base point. We consider TC the inflexible axis as the synchronize derivation, as shown in Fig. 1. Since the node 'n' can directly transmit the data to sink node from the location at vertex-adjacent, edge-adjacent and surface-adjacent of TC's. The nodes n_1, n_2, n_3 to n_n are precisely located at the TC connection points

Table 1 Hash key function parameters

Location (x,y,z) 8bits	Angle (8bits)	Node intensity 4bits	Node velocity 4bits
01111011	01010100	1001	0011

which were in n's communication range and can directly commune with the grid node g_n. The surface node is the utmost node that the node 'n' can communicate with it. Thus the Euclidean distance among the node 'n' and the node g_n is considered to be the minimum value of node's transmission radius 'r'. If a TC is correctly located at the curve of B_c, either a TC contributes the same edge or surface with the B_c, the number of adjacent of TC is different. In this approach, the simulation shows that it makes no difference, in the algorithm which eliminates incompetent function of TC automatically during result.

Choose the adjacent TC

The source node is always needs to find the neighbor nodes to forward the data packet in TC. In the GDPT, the node which closer to the surface node with its own TC. Based on the deviation distance with the threshold value "th", the range 'r' can be estimated for the packet transmission. The hash entry function with the node entry and exit towards the grid locations $g_1, g_2, g_3 \ldots g_n$, will be estimated for the time $t = (1-k)$ sec. The entered node will be automatically assigned to a hash key format as shown in Table 1. The header format with node number and key slots with assigned bits in MAC address is used for node recognition for efficient routing in overcoming the location inaccuracy. The nodes in the inter transition range is defined to be the anchor nodes $a_1, a_2, \ldots a_n$. These anchor nodes acts as an intermediate hop node in case of shortest route definition.

Choose the next Hop Node

The nodes present in the TC are denoted as node density. In this phase, the most capable node deliberated as next hope node and each capability nodes, where define as 'ω' in node n. The polar tracing function is used to define the angle of incidence 'φ' for the location of sink node from source node. With the mobility of source node, the angle of incidence varies with time $t = (1-k)$ sec. The selected planar axis is considered to be the routing plane for hopping using greedy algorithm. The end-to-end delay referred as d_{delay}, the path loss referred as l_{loss}, and E_r is the residual energy of the present node. The water saline are interrelated with the above mentioned dealy d_{delay}, path loss l_{loss}, transmission distance 'd', channel frequency 'x', etc., All of these issues present to transmit the data packet from the present node α,

β and γ are constant values between 0 and 1, which represents on the environment, and they satisfy for example, if the water channel is completely free from contamination, β is set at 0, or if there is some energy increment strategy, γ can be set to a lesser value. Since the former process ensures that there is always at least node in the chosen adjacent TC, hence we choose a node with the high value to be the next hop node, and it must be awake node. Repeat the steps again in Phase I and Phase II until there is no more TC or nodes meeting the route discovery condition. Then, multiple node-disjoint routing paths can be achieved. Some TC can be reused for data transmission if there are several awakes nodes inside. We executed the simulation in NS2 to assess the execution of the GDPT [25], and our plan has a key factor to analyze the effect of water ebb and flow is overlooked in our model. Similarly, we investigated the dynamic topology and node mobility in the node level.

Results and Disussions

In this section, we discuss the performance of GDPT using greedy algorithm. We used the NS2 simulation to check the performance of GDPT and compared with GFGD protocol. We consider 100 to 1000 nodes were deployed in various depth and estimate the communication range of 300 m, in that all nodes are actualized the self-configuration and duty-cycled. The major parameters of our simulation are shown in Table 2. The supplementary executions of the sending scheme are measured uniquely.

In our simulation we consider the few metrics are packet delivery ratio, end-to-end delay and energy consumption are evaluating in GDPT protocol. In fig. 3 we

Table 2 Simulation parameters

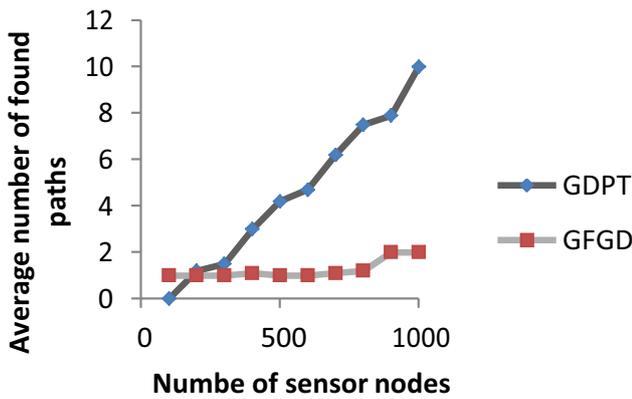| Parameters	Value
K	$10^o - 15\,°C$
r	50–100 m.
f	8–15 kHz
T_b	100 bit
Eelec	50^{-9} J/bit
E_i	10^{-4} J

Fig. 3 Average number of paths found

Fig. 5 Average end-to-end delay

examined the performance of both GDPT and GFGD. The discovering of efficient path to forward the data from S_o to g_n, the communication link between the node are increases the found path based on the function which accomplished GDPT protocol. By using the polar tracing function, which expands the adjacent node position in the 3D cube which increases the path. In this case, the GDPT have maximum possibility of route discovery and next hop by using the Euclidean theorem. The change of node and path will be considered at the time of node failure or link failure. In fig. 4 the impact of the packet delivery ratio performance the number of nodes in the network are convey the location information to neighbor node. According to that the increasing of the node density the automatically all node will drop in the axial path (polar axial). In our study, the GDPT consistently finding more path which leads to packet delivery ratio for both sparse and depth networks. Moreover, the GDPT exhibits that GFGD is drain the energy level and path loss. In this condition, we embrace the duty cycled for awake and sleep state of the node for packet transmission. Once duty cycle is either '0' means the node are activate for transmission or 'n' means not able to transmit the packets which results the GDPT to improve the packet delivery and successful in end-to- end delay. From Fig. 5 and
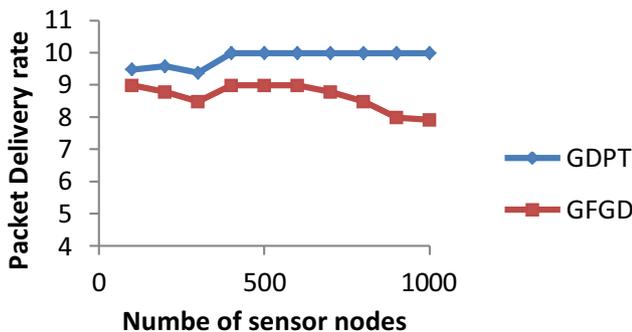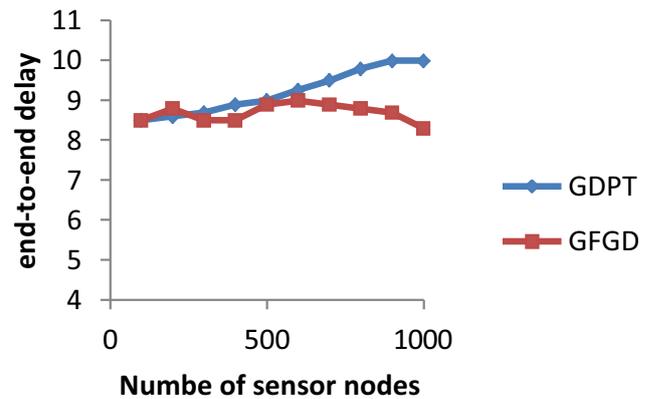
Fig. 6 show that the polar tracing function is increases the node density to find more path. Probably the source node and current node leads to find the next hop node for position absolutely by using Euclidean distance. We conducted the simulation for the end-to-end delay by varying the node movement from static to dynamic change of topology and node mobility which shows success rate (90% of packet delivery) for both sparse and dense network. In addition to that the polar tracing function uses more for light weight node to forward the packets to sink. The utilization of node is consumes less energy due to polar tracing function and also location and information packet easily conveyed to the entire adjacent node. Later we plan to expand the work for congestion control, quality of the packet and feedback session by using cross layer approach.

Conclusion

The major problem in UWSN is packet transmission between the nodes. In this paper, we propose a GDPT protocol by using the polar tracing function in underwater to find the shortest path and adjacent node for packet
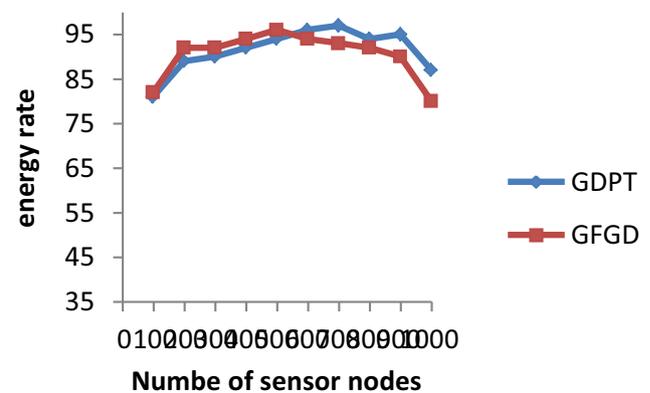

Fig. 4 Packet Delivery ratio

Fig. 6 Energy consumption

transmission. First, we split the 3D cube into tiny cube space and axial node selection for packet transmission. The procedure to select the node depends on energy efficiency, less packet loss, and low propagation. In addition, we presume that all the sensor nodes in the network are duty-cycled. In the duty-cycled model, the collaboration of nodes with each other is needed to switch their sleep or wake-up mode that helps one to save energy consumption. The simulation results show that our proposed function can attain 90% of packet delivery ratio, path found and less energy consumption than GFGD. The performance of GDPT is more beneficial to GFGD. Nevertheless, the GDPT attains the dynamic topology and mobility of node which is closer to surface node. The node or link failure does not come into the purview of our research. In future work, it is proposed to examine the congestion control and QoS by using the cross-layer approaches for various underwater situations.

Compliance with ethical standards

Conflict of Interest   This paper has not communicated anywhere till this moment, now only it is communicated to your esteemed journal for the publication with the knowledge of all co-authors.

Ethical approval   This article does not contain any studies with human participants or animals performed by any of the authors.

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