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SIMULATION AND ANALYSIS OF GREEDY ROUTING PROTOCOL IN VIEW OF ENERGY CONSUMPTION AND NETWORK LIFETIME IN THREE DIMENSIONAL UNDERWATER WIRELESS SENSOR NETWORK

SHEENA KOHLI*, PARTHA PRATIM BHATTACHARYA

College of Engineering and Technology, Mody University of Science and Technology, Lakshmangarh, Rajasthan, India
*Corresponding Author: sheena7kohli@gmail.com

Abstract

Underwater Wireless Sensor Network (UWSN) comprises of a number of miniature sized sensing devices deployed in the sea or ocean, connected by dint of acoustic links to each other. The sensors trap the ambient conditions and transmit the data from one end to another. For transmission of data in any medium, routing protocols play a crucial role. Moreover, being battery limited, an unavoidable parameter to be considered in operation and analysis of protocols is the network energy and the network lifetime. The paper discusses the greedy routing protocol for underwater wireless sensor networks. The simulation of this routing protocol also takes into consideration the characteristics of acoustic communication like attenuation, transmission loss, signal to noise ratio, noise, propagation delay. The results from these observations may be used to construct an accurate underwater communication model.

Keywords: Attenuation, Network lifetime, Propagation delay, Signal to noise ratio, Transmission loss.

1. Introduction

Underwater Wireless Sensor Networks (UWSNs) find a wide diversity of applications like underwater exploration, tsunami and other seismic sea wave detection, aquatic life and oil field monitoring, etc. [1]. Being so vast, most of the underwater environment is still uncharted. But this unexplored area offers a lot of opportunities for research in the field of UWSNs. Figure 1 depicts the basic skeleton of an Underwater Wireless Sensor Network. UWSNs have some common characteristics when compared to the Ground or Terrestrial Wireless Sensor Networks (TWSNs), but at the same time, have certain distinctness too. The differences are mainly because of the medium of communication, node deployment, routing, communication speed, energy consumption, frequencies, etc. [2]. Designing of the routing protocols is a challenging task, because of the harsh and coarse environment of water. UWSNs are generally deployed in a three-dimensional environment, which eventually brings on new challenges, such as long transmission delay, deployment of sensors at different depths, node mobility caused by water currents, etc. [3]. This paper describes the greedy routing in underwater environment, with the simulations been conducted on MATLAB [4].

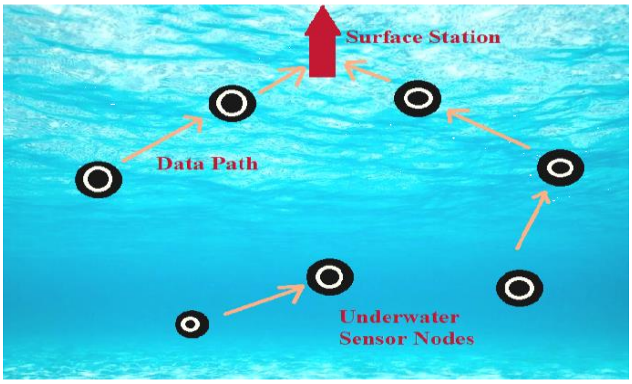

Fig. 1. Underwater wireless sensor network.

2. Routing in Underwater Wireless Sensor Networks

Designing a routing protocol is the basic requirement involved with the operation of any network. If the network is deployed under the water, the same task becomes more difficult and challenging because of the not so friendly medium. The same needs considering the factors like large propagation delay, low communication bandwidth and dynamic topology [3].

A large number of routing protocols have been proposed for chalking out path from source node to destination node or sink in the wireless sensor networks. A common category of the routing protocols is the geographical routing. It assumes that each node knows its destination position. Geographical routing is based on the information of the location of source and destination. It also helps in choosing the next hop nodes easily, making geographical routing a promising method for acoustic channels [5, 6].

Greedy routing is a kind of geographical routing [7]. Greedy routing tries to send the message to the destination node with the fewest number of hops. The source node sends message to the node which is closer to the destination node. When greedy routing is used as a packet forwarding scheme, each node sends data to the neighbours and most suitable neighbour finds the minimum distance to the destination node. Due to different characteristics of the acoustic channel, greedy hop-by-hop routing is a suitable routing method for underwater applications. The base stations or sinks in UWSNs are generally deployed on the surface of the water, near the shore and ordinary nodes are deployed in the different depths of the underwater environment. Accordingly, greedy routing can be implemented in UWSNs because the neighbour nodes with positive headway have less depth than the current forwarder node [6].

The paper deals with the implementation of greedy routing protocol in the three-dimensional underwater sensor network, while considering the effects of different acoustic channel characteristics such as attenuation, transmission loss, signal to noise ratio, noise, propagation delay. We consider that sensor nodes are deployed at different depths in a 3D network. A generic model for a 3D UWSN has each sensor node assigned with a triple of coordinates (x, y, z). The function (u,v) defines the distance between two nodes in a 3D Euclidean space as:

$$\delta(u,v) = \sqrt{(u_x - v_x)^2 + (u_y - v_y)^2 + (u_z - v_z)^2} \tag{1}$$

Underwater wireless sensor nodes are equipped with sensing units, capable of detecting data from the external environment and transmitter/receiver units for data communication.

3. Acoustic Channel Characteristics

The various acoustic channel characteristics which need to be considered in routing of Underwater Wireless Sensor Networks are:

3.1. Attenuation

Attenuation occurs due to the transformation of acoustic energy into heat. Energy absorbed by the water is proportional to the frequency of the signal. The Thorp model proposed in 1967 [8] involves the simplest equation for attenuation, taking into account the effect of the frequency utilized. The Thorp equation is formulated as:

$$\alpha = 0.11\frac{f^2}{1+f^2} + 44\frac{f^2}{4100+f^2} + 2.75\times10^{-4} f^2 + 0.003 \tag{2}$$

where, f is frequency in kHz.

3.2. Transmission loss

Transmission loss is the abatement in sound intensity through the path from transmitting node to receiving node in the network [9]. It is dependent on the transmission range and attenuation. The transmission loss in *dB* is expressed as:

$$TL = SS + \alpha \times 10^{-3} \tag{3}$$

where, SS is spherical spreading factor expressed as:

$$SS = 20\log r \tag{4}$$

α is attenuation factor in *dB*, calculated from Thorp formula as given in Eq. (2). r is transmission range in meters.

3.3. Signal to noise ratio

Signal to Noise Ratio is stated as the signal strength relative to the background noise. In UWSNs, Signal to Noise Ratio of a transmitted signal by a node is expressed in the terms of Source Level (*SL*), Transmission Loss (*TL*), Ambient Noise or Noise Level (*NL*) and Directivity Index (*DI*) [10]. *SNR* in *dB* is expressed as:

$$SNR = SL - TL - NL + DI \tag{5}$$

The Source Level (*SL*) depends upon Transmission Power Intensity (I_t) and Transmission Power (P_t), expressed as:

$$SL = 10\log\left(\frac{I_t}{0.067\times 10^{-18}}\right) \tag{6}$$

Given the Transmission Power (P_t), Transmission Power Intensity (I_t) of an underwater signal at 1 m from the source can be obtained for the shallow water in Watts/m^2 through the following expression:

$$I_t = \left(\frac{P_t}{2\pi \times 1m \times d}\right) \tag{7}$$

where, *d* is depth in meters.

TL or Transmission Loss is same as expressed in Eq. (3), *DL* or the Directivity Index is set to zero (because we assume omni-directional hydrophones). *NL* or the Noise Level i.e. the ambient noise of underwater wireless sensor networks is expressed in terms of summation of Turbulence noise, Shipping noise, Wave noise and Thermal noise [11], summing up into:

$$N(f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f) \tag{8}$$

In the equation (8), tturbulence noise is:

$$10\log N_t(f) = 17 - 30\log(f) \tag{9}$$

Shipping noise is:

$$10\log N_s(f) = 40 + 20(s - 0.5) + 26\log(f) \tag{10}$$

where, *s* is the shipping factor which ranges from 0 to 1 for low to high activities, respectively.

Wave Noise is:

$$10\log N_w(f) = 50 + 7.5\sqrt{w} + 20\log(f) - 40\log(f + 0.4) \tag{11}$$

where, the parameter *w* is the wind speed.

Thermal noise is:

$$10\log N_{th}(f) = -15 + 20\log(f) \tag{12}$$

In all the above equations for noise components, *f* is the frequency in kHz.

3.4. Propagation delay

Propagation delay is the time taken by the signal to transmit from sender to receiver node in the network. As depicted in Eq. (13), propagation delay depends upon the distance between two nodes and speed of sound in underwater [12].

$$T_p = \frac{d}{c} \tag{13}$$

where, d is distance between two nodes in meters. c is speed of sound in meters/second.

Speed of sound in underwater acoustic communication is calculated by Eq. (14). A sound wave can be considered as the mechanical energy that is transmitted by the source. A sound wave travels from one particle to another, being propagated through the ocean at the sound speed. The propagation speed can be expressed by the following nine term equation [13]:

$$\begin{aligned} c &= 1449 + 4.6T + 0.055T^2 - 5.304\times10^{-2}T^2 + 2.374\times10^{-4}T^3 \\ &+ 1.340(S-35) + 1.630\times10^{-2}D + 1.675\times10^{-7}D^2 \\ &- 1.025\times10^{-2}T(S-35) - 7.139\times10^{-13}TD^3 \end{aligned} \tag{14}$$

where, T is temperature in degrees Celsius, D is depth in meters and S is salinity in parts per thousand.

Table 1 shows the relation between depth, temperature and salinity for sound speed. As the depth of sea is varied from 0 meter to 1500 meters, the temperature and salinity of water decreases, along with the sound speed [14].

Table 1. Relation between depth, temperature and salinity for sound speed.

S. No.	Depth (meters)	Temperature (T) in degree Celsius	Salinity (S) in ppt	Sound speed (c) in meters/second
1	0	18	0.03745	1475
2	50	15	0.03602	1466
3	100	10	0.03534	1448
4	500	8	0.03511	1447
5	1000	6	0.03490	1446
6	1500	4	0.03405	1446

4. Energy Model for Underwater Wireless Sensor Networks

To transmit data from one node to another node over a distance d, the energy dissipation in underwater channel is [15]:

$$E(d) = E_t(d) + E_r(d) \tag{15}$$

$$E_t(d) = l(E_{elec} + E_{amp}) + P_t \times \frac{l}{h \times B(d)} \tag{16}$$

$$E_r(d) = l(E_{elec} + E_{DA}) + P_r \times \frac{l}{h \times B(d)} \tag{17}$$

Here, P_t and P_r are the transmission and reception powers for transmission energy E_t and reception energy E_r of the network respectively, l is packet size and $B(d)$ is the bandwidth available. h is the bandwidth efficiency of modulation in bps/Hz, given by the equation:

$$h = \log_2(1 + SNR) \tag{18}$$

E_{elec} is the energy consumed by the electronics to process one bit of message, E_{amp} is the energy consumed by amplifier and E_{DA} is the energy for data aggregation.

5. Simulation & Analysis

5.1. Approach methodology

1. Deploy a three-dimensional network with random topology.
2. Initialize all parameters with their respective values.
3. Implement all acoustic characteristic equations.
4. Apply Greedy Algorithm
    4.1. Decide source and destination nodes.
    4.2. Each node sends data to its neighbours.
    4.3. Find the most suitable neighbour finds the minimum distance to the destination node.
5. Calculate energy consumption and network lifetime.

5.2. Simulation parameters

The network of 50 nodes is deployed using random topology in 100 m x 100 m × 100 m environment. In every single simulation run, all the nodes of the network sense data and transmit to neighbour nodes. We have applied greedy routing for homogeneous Underwater Wireless Sensor Network.

For this routing protocol source node and destination node are considered to be node-1 and node-7 respectively. Initially all nodes have equal energy of 5J. Table 2 shows the simulation parameters used in the implementation [15]. Figure 2 depicts the random deployment of nodes in the three-dimensional Underwater Wireless Sensor Network of 100 m x 100 m × 100 m size.

Table 2. Simulation parameters.

Parameter	Value
Network Size	100 m x 100 m × 100 m
No. Of Nodes (n)	50
Source Node	1
Destination Node	7
Initial Energy of Every Node (E_0)	5 J
Amplifier Energy (E_{amp})	0.0013 pJ/bit/m^4
Electronics Energy (E_{elec})	50nJ/bit
Energy for Data Aggregation (E_{DA})	5nJ/bit
Number of Simulation Rounds (r_{max})	6000
Data packet size (l)	240 bytes
Bandwidth (B(d))	4Hz
Frequency (f)	10kHz
Distance (d)	20m
Range (r)	50m
Transmission Power (P_t)	70mW
Reception Power (P_r)	16mW
Shipping Factor (s)	0.5
Wind Speed (w)	6 m/s

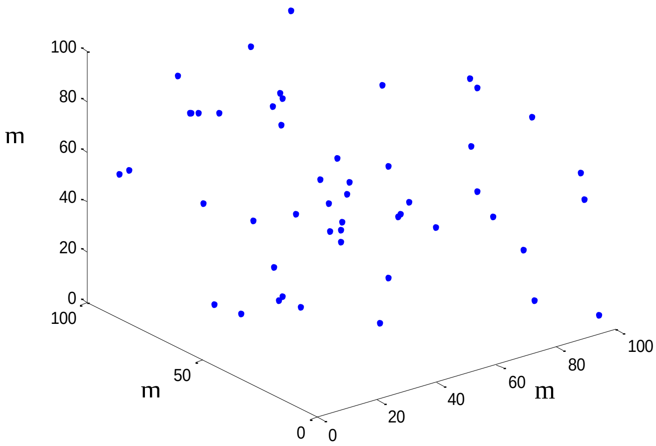

Fig. 2. Random deployment of nodes in underwater network.

Figure 3 illustrates the network after applying topology. Each node sends data to its neighbour node for finding a path from source to destination node. The red dotted line shows the path from node no 1 to node no 7, i.e., the path from source to destination is as: Path= 1,4,5,12,13,9,2,10,8,6,3,7.

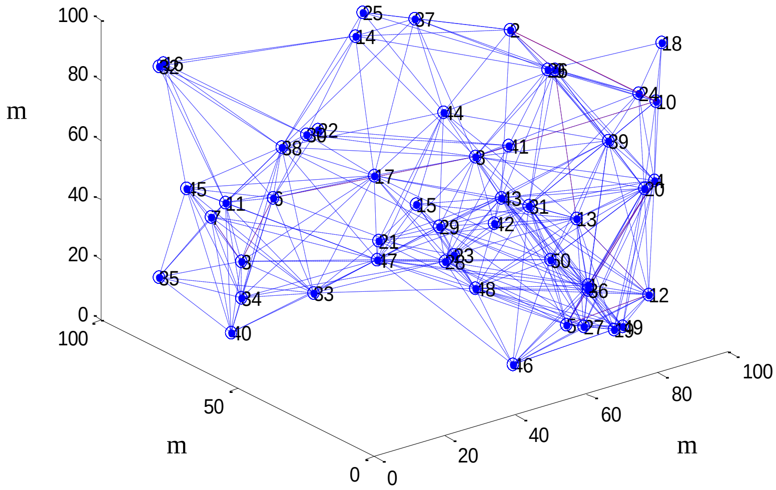

Fig. 3. Underwater wireless sensor network topology.

6. Results

The results obtained from the simulation are as follows:

6.1. Energy consumption

From the simulation, the transmission and reception energy at different depths in the network has been observed. Table 3 shows the results for the same. The results have been obtained from Eq. (16) and (17).

Table 3. Variation of transmission and reception energy with depth.

S. No.	Depth (meters)	Transmission energy (J)	Reception energy (J)
1	20	22.64	10.87
2	40	22.78	10.94
3	60	22.88	10.98
4	80	22.94	11.01
5	100	22.99	11.04

It is observed from the energy model that transmission energy E_t is dependent upon transmission electronics, transmission power and amplifier energy. The reception energy E_r depends upon the reception electronics, reception power and data aggregation energy. Both the energies in case of Underwater Wireless Sensor Networks, may vary with the Bandwidth (*B(d))* available and the bandwidth efficiency of modulation (*h*). The value of *h* depends upon signal to noise ratio (SNR) which can be calculated as per Eq. (5). SNR indirectly depends upon Transmission Power (P_t), Reception Power (P_r), distance between two nodes (*d*), frequency (*f*), shipping factor (*s*), wind speed (*w*), attenuation (α), range (*r)*.

Figures 4 and 5 show the transmission and reception energy varying at the different depths. Both the energies increase with the increasing depth of the water. As we go down the sea or ocean, energy consumption increases. Moreover, the change in *the* above said parameters on which h or SNR depend, leads to the variation in energy consumption.

It may be illustrated from the results that the transmission energy is more when compared to reception energy. The reason may be easily justified from the energy model shown in Fig. 6, being used for communication in the network. The transmission energy E_t depends upon the distance from source to the destination. More distance means more dissipation of energy. The electronics energy is used at both transmission and reception circuitry. The amplifier energy is needed at the transmission end only as for sending the signal at a distance may lose its strength and hence requires amplification. While at the reception end, the extra energy consumed is for the aggregation of data, removing duplicate data or fusing of data, combining of data received from different sources, if any.

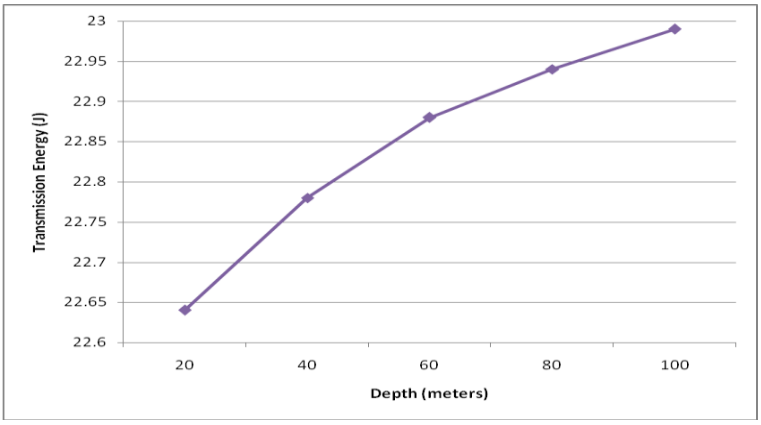

Fig. 4. Transmission energy vs. depth.

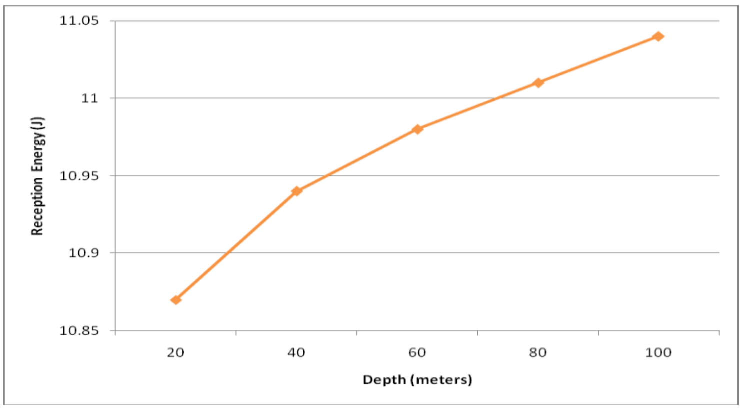

Fig. 5. Reception energy vs. depth.

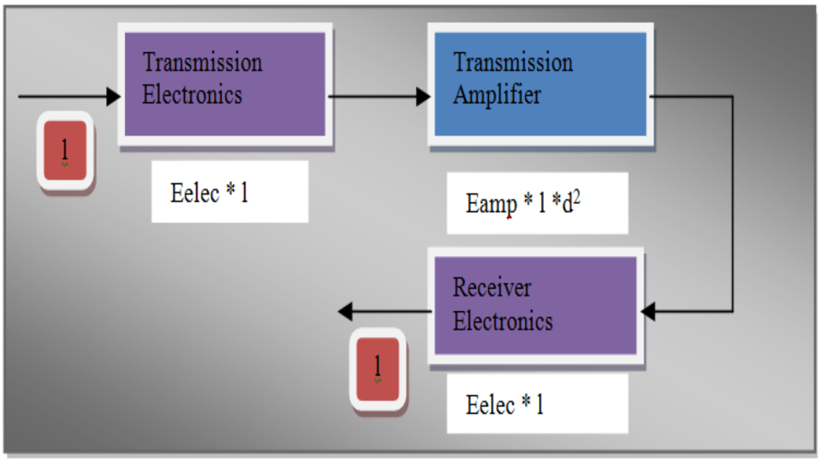

Fig. 6. Transmission and reception energy model.

Further, the total energy consumption of underwater wireless sensor network is calculated for greedy routing protocol. Table 4 shows the relation between total energy consumption by the network at different depths. The results of same are depicted in Fig. 7, showing the increase in total energy with the increasing depth under the water. Figure 8 depicts the amount of change in values on incrementing the depth of water.

Table 4. Variation in energy consumption with depth.

S. No	Depth (meters)	Energy consumption (J)	Difference in values with change in depth (J)
1.	20	33.50	-0.22
2.	40	33.72	-0.13
3.	60	33.85	-0.09
4.	80	33.94	-0.09
5.	100	34.03	-

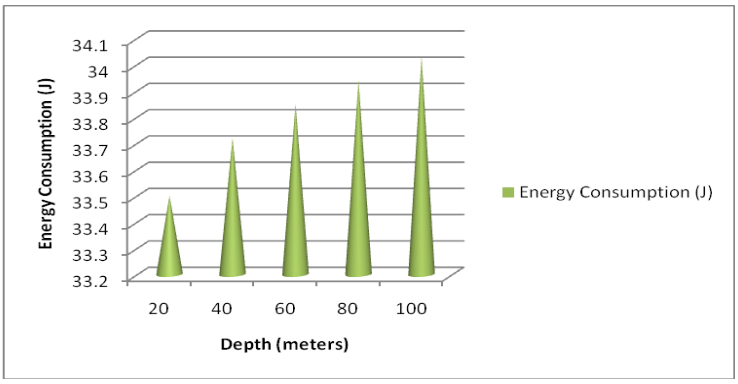

Fig. 7. Total energy consumed by the network vs. depth.

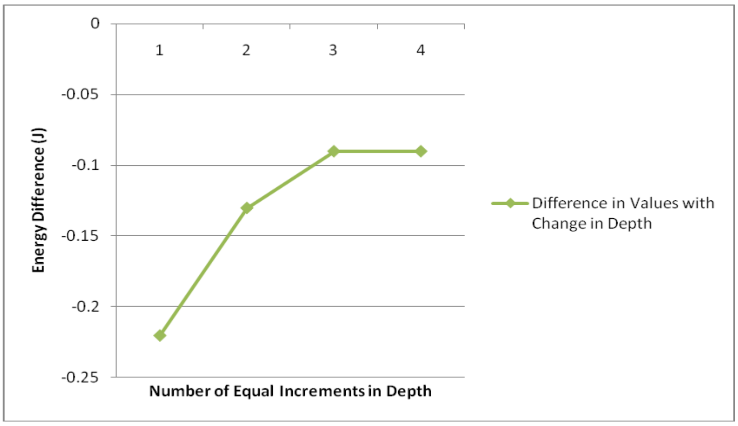

Fig. 8. Difference in energy consumption at each increment of depth.

6.2. Network lifetime

Figure 9 illustrates the trend of nodes dying, with the increasing round numbers. As shown in Table 5, first node dies in 304 rounds and all nodes become dead at 5563 rounds. Therefore, it may be computed that the network lifetime on applying greedy protocol with the defined parameter values is of 5563-304 = 5259 rounds approximately. The exact point when the first and the last node dies can be visualized with the help of Fig. 10.

A typical problem of Wireless Sensor Networks occurs due to failure of one or more nodes, i.e. when some part of the network is isolated from the remaining network. This is stated as network partitioning problem [16]. The solution for the same has been described in [17, 18].

Table 5. Round number when nodes die.

S. No.	1
Round number when first node dies	304
Round number when last node dies	556

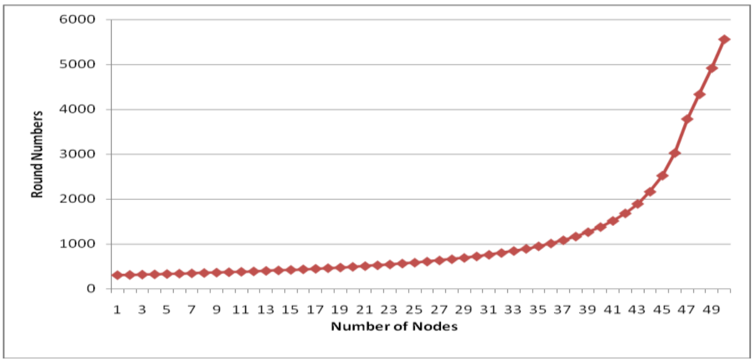

Fig. 9. Round number v/s number of dead nodes.

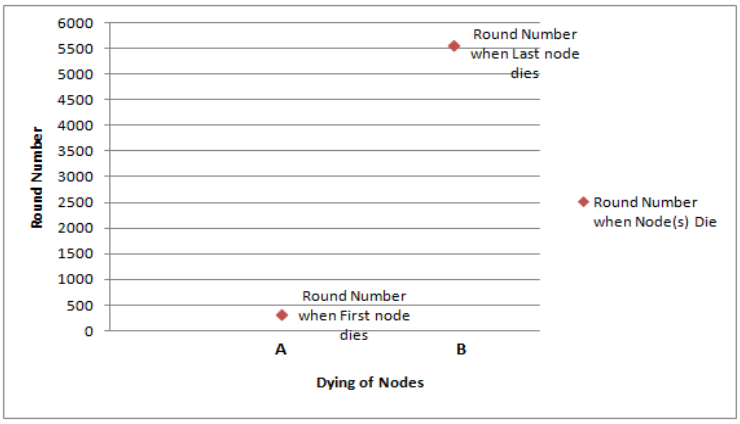

Fig. 10. Dying of first and last node.

6.3. End to end delay

End-to-end delay refers to the time taken for a packet to be transmitted across a network from source to destination. It may be computed as [19]:

$$\mathrm{TE-E} = (\mathrm{k}+1)(\mathrm{Ttx}) + \mathrm{k}(\mathrm{Trx}) + \mathrm{Tp} \quad (19)$$

Here, *Ttx* and *Trx* are the consumed transmission and reception time of a packet, *k* is the number of hops for a specific packet, whereas, *Tp* is the overall propagation delay of packet, which can be calculated from Eq. (13). Table 6 shows the relation between end to end delay and depth.

Table 6. Variation of end to end delay with depth.

S. No	Depth (meters)	End to end delay (seconds)	Difference in values with change in depth
1	20	380.012	0.013
2	40	380.025	0.011
3	60	380.036	0.016
4	80	380.052	0.009
5	100	380.061	-

Figure 11 shows end to end delay of the network varying with depth. As shown, end to end delay increases with the increasing depth in the water. The amount of change in the end to end delay with increase in the depth is depicted in Fig. 12.

Besides these simulation results, changing the topology of the deployed network or including the case of segmented networks may be considered as an extension to the current work. The recent trends like [19 - 21] encourage to explore this area further.

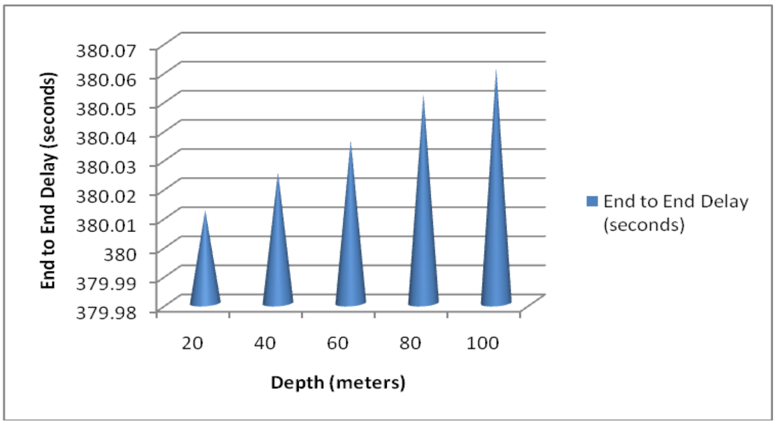

Fig. 11. End to end delay v/s depth.

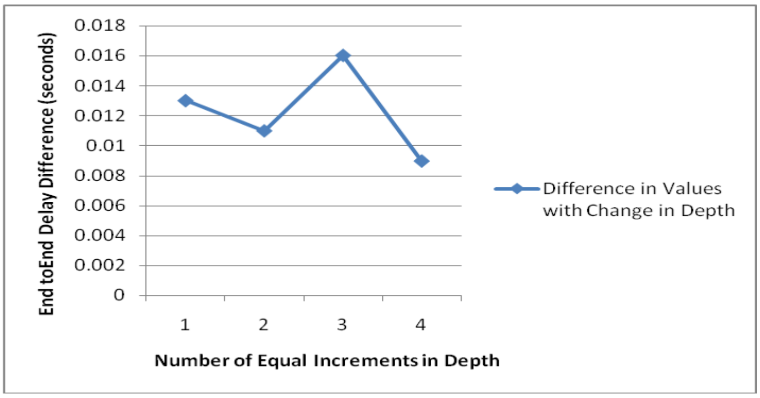

Fig. 12. End to end delay difference with each increment of depth.

7. Conclusion and future scope

This paper includes the analysis of transmission and reception energy consumption, network lifetime and end to end delay in three dimensional UWSN, considering greedy routing. From the simulation, it has been observed that there is a large difference between transmitting energy and receiving energy of nodes. The total energy consumption increases with the depth of water, due to factors such as attenuation, transmission loss, signal to noise ratio and ambient noise under the water. The trend of dying of nodes in the network with respect to the round numbers gives the idea about the network lifetime. The end to end delay of network is also calculated, which depends upon the propagation delay. It also increases with the increasing depth of the water. The propagation delay is inversely proportional to the sound speed, that is related to the temperature, depth and salinity of water in which the sensor network has been deployed. The future scope includes application of the same protocol in real scenario. The results from these observations may be used to construct an accurate underwater communication model.

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