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Energy Harvesting in Clustering-based Routing Scheme for UWSNs (EH-CDBR)

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***Abstract*—Underwater Wireless sensor networks (UWSNs) contains number of sensor nodes deployed in predefined region of interest for specific purpose of natural and environmental events like temperature, pressure, humidity etc. Nodes are battery operated and loaded with specific purpose sensor. Low bandwidth, high bit error ratio, large propagation delay and more specifically the limited available supply of energy to the sensor nodes in UWSNS are all time hot topics for researchers. A new routing approach EH-CDBR has been presented in this paper. Routing in EEDBR took place through a node having low depth, thus energy of those very specific nodes drains off early, creating a communication hole. Although CDBR have rationalized the load on the nodes near to the sink by introducing clustering approach but the issue remains up to some extent. We in our work have considered both depth and residual energy of the nodes for the Cluster Head (CHs) selection. Similarly a Best-Fit function has been introduced to select a suitable relay CH node to forward data towards the sink located at the surface of water. Moreover, an energy harvesting mechanism has been devised with sensor nodes. We have compared our scheme with current state of art UWSNs routing protocols of "Energy Efficient Depth Based Routing Protocol (EEDBR)" and "Clustering Depth Based Routing Protocol (CDBR)". Simulation results shows that our proposed approach have efficient results in End-to-End delay, Number of Alive Nodes and Transmission loss as compared to EEDBR and CDBR.**

KeyWords: Underwater Wireless Sensor networks, Design issues, Routing protocols, Energy Consumption, Energy Harvesting

I. Introduction

Water comprises 71 % of the planet earth. This demands the need to investigate the underwater world. UWSNs as a subclass of WSN are considered to be suitable technologies for this purpose .UWSNs have many potential applications like mine reconnaissance, disaster prevention, assisted navigation, seawater and environment supervision for tsunamis monitoring, oil pollution, and other seismic activities [1].

A very basic UWSN comprises of certain number of sensor nodes, which are anchored at the ocean floor or distributed at some height from it. These are battery-powered, small size node which can cover or monitor up to some range [2].

Unlike terrestrial networks, nodes in UWSN use acoustic channel for communication while sinks at the surface of water also called *sonobuoys* are equipped with acoustic as well as radio modems. Sinks are connected to one another and with onshore data storage house via radio channel, while nodes are accessed through acoustic channel. Sinks are considered to have no issue of power constraints. Because of the rapid attenuation and absorption, electromagnetic (radio) waves are not favorable to use in underwater environment thus acoustic channel is considered a best option for underwater communication [2].

Figure 1 depicts architecture of a very basic UWSN. Battery operated SNs are installed in a region of significance equipped with specific event sensors i.e temperature, turbidity or submarine structures monitoring etc. Nodes can communicate with each other and with sink through acoustic channel for data transmission. Sink node forward the assembled data to offshore data center through radio links. Data received at anyone of the sink node is considered received at all nodes. Sinks placed at the surface of water acts like a mediator between the submarine nodes and offshore data center.

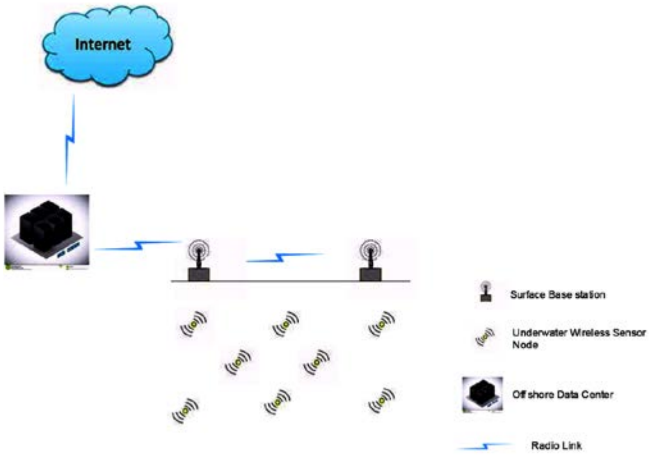

Figure 1: UWSN Architecture

Sink and SN may be static or mobile depending on the application. Nodes lying near to the surface of the water deplete more energy due to high traffic load while node installed or located in depth sense and forward data towards these nodes.

The paper is arranged into following sections. In Section II some of the current state of art routing schemes has been studied. Section III provides motivation towards this research work. Section IV of the paper presents a flow chart of the proposed routing scheme. In section V Proposed model of (EH-CDBR) is presented. Section VI discusses results of Simulation. In last portion of section VII conclusion and future work has been presented.

II. Related Work

To increase the performance and stability of the network, various schemes and protocols has been designed. Categorized summary of some of such protocols are presented here.

LEACH [3] is considered as block cluster based routing protocol and assumed as pioneer of clustering principle, with the purpose to distribute the energy evenly in the network. In clustering the entire network is divided in small groups called “clusters”. Among the CM of each cluster arbitrarily a node is selected as CH. All the information collected by SN is forwarded towards the CHs for forward communication.

LEACH involves two steps, setup step and steady step. In first step clusters are formed and in second step data transfer is initiated. Each node in LEACH has a chance to be a CH. Each node in the network picks an arbitrary numeral figure which is then compared with the threshold value of the network. If the arbitrary number is smaller compared to set threshold one, this node becomes the CH. CH then propagate an advertisement message to other nodes in its vicinity.

PANEL [4] is a grid cluster based WSN routing protocol. In PANEL Aggregator is determined on the basis of geographical position information. Similar to other clustering protocols, in PANEL too every node has equal chances of selection as cluster head or aggregator. PANEL has the distinguished characteristic which differentiate it from other clustering protocols is its features to support and provide platform to both synchronous and asynchronous applications.

Authors in [5] presented advanced version of Vector-Based Forwarding Routing Protocol for UWSN which they called Clustering Vector Based Forwarding algorithm (CVBF): A clustering approach. It is the extension of Vector base forwarding protocol, VBF. They have divided the network space into number of clusters where one sink is identified as virtual sink in each cluster. All other nodes within the cluster make way towards this virtual sink, which in turn communicate the main sink in the network. The simulated results are compared with Hop-by-Hop VBF (HHVBF), VBF, Energy Saving VBF (ES-VBF) and Vector-Based Void Avoidance (VBVA) routing protocols. It has been found that the said algorithm is better than aforementioned ones in packet delivery ratio especially in sparse condition, over all power consumption specifically in dense network environment and average end-to-end delay (in both sparse and dense networks).

DBR [6] explains routing based on depth. DBR is the localization-free protocol designed for UWSNs which doesn’t need geographical information for sensor location in routing procedure. Depth information is sufficient for routing purpose, collected from the depth sensor installed with each node in UWSN. Running the network without taking into consideration the location information service and manifold sink architecture deployment having minimum or no extra cost charges are the major advantages of this protocol.

EEDBR [7], Energy Efficient Depth-Based Routing protocol, is the modified form of DBR [6]. During the course of study the researcher utilize depth for data packet forwarding while residual energy is too considered to improve overall lifetime of the network and stability. After running extensive simulations they have observed that EEDBR is far better in performance then DBR in network stability, end-to-end delay and energy consumption.

CDBR [8] may be recognized an enhanced edition of DBR (Depth Based Routing protocol) an UWSN protocol with additional features of clustering. In DBR approach the data is forwarded toward the less depth node, hence these low depth nodes consume more energies and eventually died. To minimize the power consumption and divide the traffic load evenly in all the nodes, a clustering approach has been introduced in cDBR. Nodes have been divided into small subgroups (clusters) where all the nodes have equal chances of electing as CH.

In paper [9] Opportunistic routing in WSNs powered by surrounding Ambient Energy Harvesting (WSN-HEAP) namely Energy Harvesting Opportunistic Routing Protocol (EHOR) is illustrated. Unlike the traditional WSN routing protocols, nodes in energy harvesting based routing protocols has no precise schedule for awake and sleep. So the predefined WSN protocols are not compatible to the situation of WSN-HEAP. As the nodes asleep when their energy is depleted, EHOR considers the energy constraints of the nodes. Environmental factor directly influence the rate of charging, hence it is very difficult to predict the identities of nodes which will awake. EHOR accepts this challenge through selecting optimal forwarder by dividing the network into the regions on the bases of the distance between the sender and sink. EHOR exhibit increases efficiency and throughput in comparison to the other WSN and WSN-HEAP routing protocols.

DUCS (Distributed Underwater Clustering Scheme) [10], a UWSN routing protocol that doesn’t require the geographical information position. DUCS utilize the data aggression technique to suppress the redundant data traffic and hence ignore the flooding techniques, reduce the message switching caused by proactive routing. DUCS enjoys the assumption of mobile nodes. To reduce the information loss, sustain the better quality of communication and to face the high propagation delay in underwater communication channel a continuous adjusted timing advance together with guard time values are used. For the purpose to overcome nodes mobility issue, after the data frame transmission a time slots is scheduled to maintain cluster. A distributed algorithm is utilized for cluster formation in self-organization mode.

III. MOTIVATION

From the literature survey it is obvious that in UWSN routing, researcher has focused on energy consumption and stability period of the network. To deal with these issue number of protocols has been developed, but still there remain some deficiencies. DBR relies on depth information for routing. Thus low depth nodes face high traffic load resulting in earlier death of these nodes. Likewise EEDBR addressed two parameters i.e residual energy and depth of the node. In both algorithms, low depth nodes forward all the traffic towards the sink, hence die earlier and create holes in the network. Packet transmission towards high depth nodes is waste of energy. This results in decrease network life. Both of the protocols do not have clustering mechanism. Recently a protocol CDBR has been proposed with a clustering mechanism. It is the improved version of both protocols DBR and EEDBR.

We have focused our work to improve network's life and scalability by introducing clustering and energy harvesting techniques, to limit the high energy consumption and energy harvesting procedure to enhance the battery life and hence the network life time.

IV. FLOWCHART OF PROPOSED WORK

Figure 2 depicts the flow chart of the proposed protocol. It mainly consists of 2 phases. Cluster setup phase and Data forwarding phase. Nodes placement, probability weight calculation, residual energy check for energy harvesting, CH and normal node selection took place in first phase. While TDMA frame formation, data events sensing, data transmission, Energy harvesting, Best-Fit function calculation for relay CH selection took place in second phase of data forwarding.

V. PROPOSED PROTOCOL

This portion includes the proposed work of a clustering-based routing protocol for UWSNs with consideration on energy harvesting (EH-CDBR).

A. *Network Architecture*

In the predefined area of interest two hundred and fifty nodes were deployed randomly with initial energy Ei. Each SN has certain number of sensor modules which are capable of sensing specific phenomenon (temperature, turbidity, and rustiness). Acoustic modems are used for communication. Nodes required more energy in transmission of data rather than receiving it.

Ten Sinks at the top of the network i.e at the surface of water are deployed. Each one equipped with two types of modems. Radio modem used for communication between other sinks and on shore data centre. Acoustic modem collects data from CH.

B. *Cluster Establishment Phase*

After deployment every node first makes a decision itself either it will be a normal node or a CH. Each SN "i" picks a arbitrary number between "0" & "1" and match it with

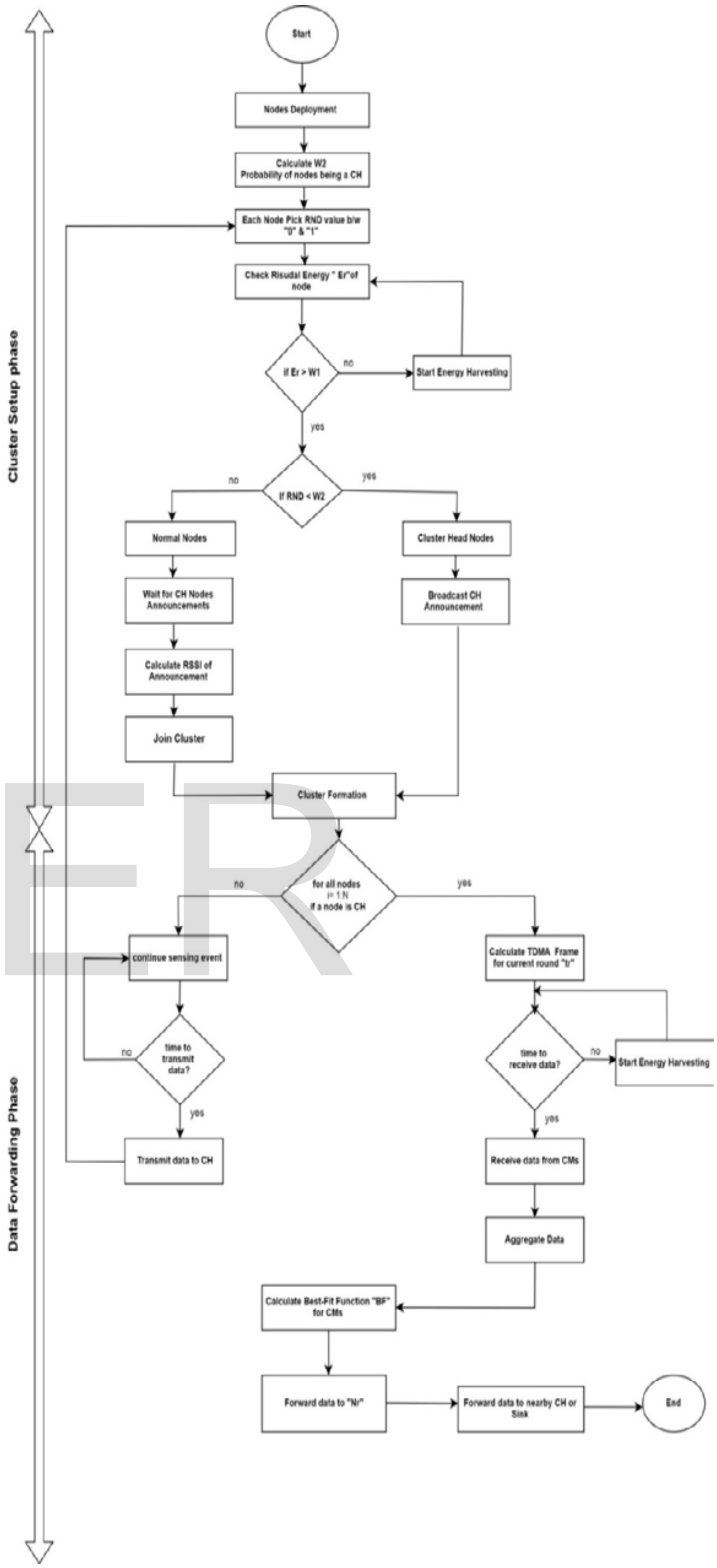

Figure 2: Flow chart of the Proposed Protocol

a threshold W_2, calculated as below. In a present round, when a number selected is found lower compare to the threshold, the node is selected as CH [3].

$$W_2(i)=\begin{cases} \frac{P}{1-P*\left(r \bmod \frac{1}{P}\right)*\frac{Er}{\sqrt{DeptH}}} & \text{for } i \in A \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

such as:

P = Predefined percentage of CHs (i.e P= 0.10)

i = individual node

A= set of nodes which had not a chance of being a CH for the last 1/P rounds.

r = round under consideration (current node)

E_r = remaining energy of a node under consideration

Depth= Depth of node under consideration, each node is equipped with depth sensor.

At the beginning every node has “P” probability of being a CH. Each node will must be once a CH at any instant during 1/P rounds. Node once selected a CH for one round, will not be a cluster head for coming 1/P rounds. Thus chances of remaining nodes of being CH increases. This self selection method of CH selection decreases the processing time being wasted while exchanging the communication overhead messages. Also the low bandwidth and high error rate environment perfectly suits this technique.

After cluster creation, each CH advertised itself using CSMA MAC protocol with the normal nodes for joining cluster. Each normal node calculates RSSI of various signals received from various CHs and join a CH having high signal power [3].

For” N” total number of nodes in a network, each cluster have N/Z members node, where “Z” is the number of cluster in a network.

C. Data Forwarding

Once the CH creation process is over, each CH generates a TDMA frame having a definite time slot for every member node of cluster. At the stipulated time slot, each node turns on its radio transmitter and transmits its data towards the CH. After receiving data from all nodes, CH aggregates it and forwards it towards the sink at the surface of water. Each CH calculates Best-Fit function for all other CHs in its range as:

$$BF = \frac{Er}{\sqrt{DeptH}} \quad (2)$$

CH having higher value of Best-Fit function and high residual energy is selected as next forwarder of cluster aggregated data towards sink for current round.

In a cluster total time taken by the nodes and cluster head to complete a round is estimated as:

$$T_{rd} = T_{cl} + N \times \frac{h_{CH}}{S} \quad (3)$$

whereas:

T_{rd} = Total time consumed in one round

T_{cl} = Time consumed by a cluster in cluster set up, data aggregation and transmission

h_{CH} = Transmission range of CHS.

S = Speed of sound waves in under water (1500 m/sec).

N = Total Number of Node

D. UWSN Channel Model

Modeling acoustic propagation in UW environment is of great importance for communication between nodes for data transfer. Numbers of models have been devised ranges from simpler one to complex in the literature. Features which must be considered in the modeling of UWA transmission are:

i.Attenuation

Sound waves travels with very slow speed in water which makes it distinguished as compared to EM waves. Water features like pressure, turbidity, temperature and salinity directly influence sound waves propagation. Sound waves travel with the speed of 1500 m/sec just below the surface of water in oceans. It is five times smaller compared to the speed of light, but four times greater of magnitude to the speed of sound in air. This speed varies with increase in depth, concentration of dissolved chemicals, salinity and temperature. Near the surface of water this change is due to the variation of temperature.

Sound waves propagate very well in warm water compared to the cold water. For 1 degree rise in temperature, the speed of sound waves increases by 4 m/sec [11].

Attenuation function in the case of EM wireless communication is presented as $A(d) \propto d^{-\alpha}$, for α as constant decay factor. In acoustic communication, attenuation function is associated with both the frequency and distance and estimated as A(d, f) [12].

Where “*f*” is the carrier frequency of transmitted signal. Absorption loss and spreading loss are also two major reasons which produce attenuation in UWA communication channel.

Urick [13] defined the attenuation as:

$$A(d,f)=A_0 d^k \alpha(f)^d \quad (4)$$

such as:

d = Distance (km) from source to destination

f = frequency (in kHZ)

A_0 = Normalized Constant

k = Spreading Constant

The value of spreading constant k is 1 for cylindrical area whereas for the spherical space its value is 2. While in practical spreading its value is 1.5.

In UWA channel medium may absorb some of the wave’s energy and transform it to heat energy. This loss of energy is directly influenced by the material imperfection

through which the sound waves are physically propagating. “Inelasticity “is the material imperfection in the case of sound waves. For EM waves “conductivity “is imperfection.
Thorps Formula is devised for absorption coefficient α(f) [13] as:

$$10\log\alpha(f)=\frac{0.11\,f^2}{1+f^2}+\frac{44\,f^2}{4100+f^2}+\frac{2.75\,f^2}{10^4}+0.003[\text{dB/km}] \quad (5)$$

ii. Ambient Noise

Surrounding ambient noise is produced by multiple sources like waves (N_w), shipping (N_s), thermal (N_{th}) and turbulence (N_t). These different types of noises are modeled by Power Spectral Density (PSD) and Gaussian statistics and expressed in the units of dB re μ (decibel relative to micro Pascal) in kHz.

General terms and functions which estimate the UW ambient noises are [12].

$$N(f)=N_w(f)+N_s(f)+N_{th}(f)+N_t(f) \quad (6)$$

and

$$10\log N_w(f)=50+7.5\sqrt{w}+20\log f-40\log(f+0.4) \quad (7)$$

$$10\log N_s(f)=40+20(s-0.5)+26\log f-60\log(f+0.03) \quad (8)$$

$$10\log N_{th}(f)=-15+20\log f \quad (9)$$

$$10\log N_t(f)=17-30\log f \quad (10)$$

such that w = Speed (velocity of winds) having range 0 to 10 m/sec and s = shipping activity factor, for low activity having value “0” and “1” for high activity.

Functions above shows that level of noise is dependent on frequency, thus while selection of frequency band for communication, noise must be considered.

iii. Signal-to-Noise Ratio (SNR)

According to Urick [13] acoustic signals propagating in UW has Signal to Noise Ratio (SNR) at the receiver side (passive sonar) which can be expressed as:

$$\beta=D_i+(S_l-T_l-N_l) \quad (11)$$

Whereas:

S_l = Source Level (level of noise produced by the source)

T_l =Transmission Loss (due to UW atmosphere)

N_l = Noise Level (level of noise produced by receiver + the surrounding)

Di = Directivity Index of (the hydrophone)

All the above terms are calculated in dB reμPa. whereas 1μPa has the reference value 0.67×10^{-22} Watts/cm^2 [13].For practical purpose at receiver side the SNR is indicated with $\beta(d,f)$, which is estimated as:

$$\beta(d,f)=\frac{P_{Tx}}{A(d,f)N(f)\varphi} \quad (12)$$

whereas P_{Tx} is transmission power in Watt, N(f) is the noise in the transmission channel in Watt/Hz, φ is the bandwidth of the channel in Hz, A(d, f) shows UWA channel attenuation.

iv. Multipath

From source to destination a wave arrive via different paths. In larger transmission region usually in shallow water, acoustic waves reflect from bottom as well as from surface and arrive at destination through multiple paths. In deep sea water speed of acoustic waves vary spatially which results in multipath occurrence.

Let suppose there are “M” distinctive paths leading from source towards destinations and Tm presents the delay in propagation through path mth. Then the total channel delay spread “D” in our case will be equal to the delay in propagation time of first and last multipath.

$$D=T_{m-1}-T_0 \quad (13)$$

As sound waves have very low propagation speed, the channel delay spread “D” is remarkably large. In practical scenario, if two distinct paths have 15 meter difference in length then it will results in 1ms difference in time (for 1500 m/s speed of sound waves). Generally this delay spread ranges from 50 to 100 ms [10].

E. Radio Model

For our work we have used the same radio model suggested in [14]. For data transmission within a cluster energy dissipated is proportional to the d_0^2, where as for data transmission over distinct range like CH to sink energy dissipated is proportional to d_0^4.Where d_0 represents the distance between two nodes.

Energy dissipated during transmission (at transmitter side) of a message of “z” bits over a distance of d_0 is calculated as:

(For data transmission inside the cluster)

$$E_{Tx}(z,d_0)=z(E_{Tx\text{-}elec}+E_{fs}*d_0^2) \quad (14)$$

(For data transmission in between Sink and CH)

$$E_{Tx}(z,d_0)=z(E_{Tx\text{-}elec}+E_{amp}*d_0^4) \quad (15)$$

While energy consumed during reception (at receiver side) of a message of z bits is calculated as:

$$E_{Rx}(z)=E_{Rx\text{-}elec}*z \quad (16)$$

In this very specific radio model a transmitter and receiver circuitry operates on energy of $E_{Tx\text{-}elec}=E_{Rx\text{-}elec}=50$

nJ/bit, while transmitter amplifier dissipates an energy of E_{amp} = 0.0013pJ/bit/m^2 and E_{fs} = 10 pJ/ (bit m^{-2}). Energy consumed in data collection and aggregation from all the members of the CM is assumed to be E_{agg} = 5 nJ/bit .

F. Energy Model

In this study, SNs are having energy harvesting mechanism. The surrounding ambient energy is variable at different spots. Usually the charging time is much lower as compare to the energy consumption by an individual SN. Different nodes have different rate of energy harvesting at some very specific moment.

We suppose that each node has P_{EH}, n > 0 energy harvesting rate. Stored energy at individual node is symbolized as E_S,i and E_M,i as maximum storage capability. BSs are supposed to have no power issues.

For each individual node "i" the energy model will be like:

$$P_i(t)=Min(P_i(t-1)+P_{EH,i}(t-1),E_{Max,i})-(E_{Tx}+E_{Rx}) \quad (17)$$

For a node i "t" shows discrete time slot, P_i(t-1) is energy remained from the previous time slot, $P_{EH,i}$(t-1) is the energy harvested after previous time slot. To keep the node alive the power must be $P_i(t) > 0$ before energy harvesting initialization. In designing the protocol we have taken this into consideration by checking the residual energy at the start and end of the operation.

G. Energy Harvesting in UWSN through Triboelectric Effect

Triboelectric effect is an electrification phenomenon primarily based on contact-induction, through which an object is charged electrically when being brought in contact to some dissimilar object. The charge convention (positive or negative sign) of the bearing object totally relay on the analogous polarity of the object being contacted. The transmitting charge may be neutrons, electrons, ions or molecules. When two dissimilar objects touch each other, an adhesion phenomenon occur, in which a chemical bond is created between contacting surfaces.

We have used the same experimented result as that of authors calculated in [15]. TENG under consideration exhibit various result to different incident frequencies in underwater environment.

From the above Table 1 it is obvious that higher the frequency of incident ultrasonic waves higher the output voltage. The output power of TENG at 80 Khz frequency is sufficient to operate a water–resistant watch and climate sensor in UW environment [16]. The size of TENG can be enlarged according to the power requirements.

VI. Simulation Results

For the performance evaluation of the proposed protocol sequence of simulations have been performed.EH-CDBR protocol has been compared with current protocols of EEDBR and CDBR.

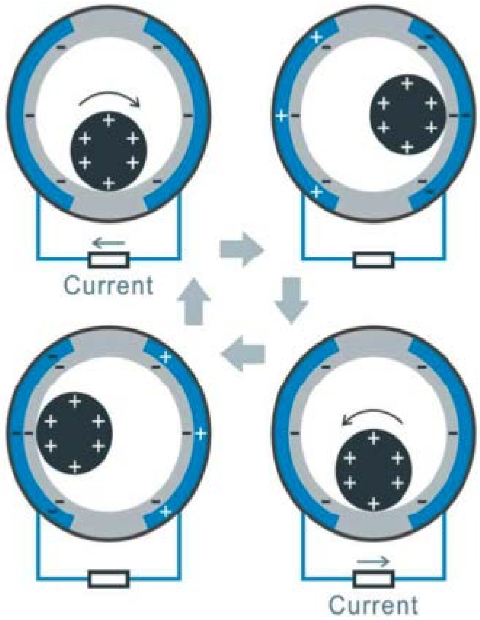

Figure 3: Working Principle TENG

Table 1: Output Voltages of TENG for Different Incident Ultrasonic Waves [15]

S.no	Incident frequency (kHz)	Output Voltage (mV) after 60 Sec	Equivalent galvanostatic current (mA)
1	28	91.4	0.21
2	80	134.6	0.45
3	100	0 to 367	1.43

Network of randomly deployed 250 nodes in the dimension of 500m x 500m x 500m were simulated for 2000 rounds for each scheme.

A. End-to-End delay

Results in figure 4 shows that EEDBR has 300%, CDBR has 200.16 %, EH-CDBR has 100 % delays. Thus our proposed protocol has 200 % reduced end-to-end delay compared to EEDBR. In EEDBR increased number of hopes, while in CDBR lack of channel noise and attenuation factors estimation cause huge end-to-end delay. In EH-CDBR along with depth information of nodes, numbers of channel factor like attenuation, signal-to-noise ratio have been taken into account which reduce the chances of packet loss and end-to-end delay. Also the increased number of sinks reduces the transmission distance which enhances the overall performance.

B. *Number of Alive Nodes*

From the figure 5 it is obvious that performance of our protocol EH-CDBR is better than CDBR and EEDBR. The improved performance of EH-CDBR is the result of less number of hops transmission and increased number of sink nodes. CH forward data to another relay CH having high residual energy and low depth. CH located near to the surface of water forward data to sink directly. Moreover the energy harvesting process prolongs the life of node.

C. *Transmission Loss*

Transmission loss is the degradation in the intensity of waves while travelling from source towards destination. Figure 6 clearly depicts the lowered transmission loss in the case of EH-CDBR compared to EEDBR and CDBR. This is the result of perfect modeling of SNR of the network. Also the relay forwarding has prominent effects to enhance the performance. EEDBR exhibits long distant transmission in which data is prone to high transmission loss, at the start of the network operation there is greater loss because of dense environment ,later on when the network became sparse the losses gets reduced. In CDBR there is poor noise modeling, While in EH-CDBR the Thorps attenuation and Urick formulation model hint out all the available losses during the transmission in the process of data transfer from sender to receiver. Efficiency of bandwidth, carrier frequency and effects of noise are the parameters which are considered in EH-CDBR. In the other two schemes no noise factors have been considered. In figure 6 EH-CDBR and CDBR show some resemblance which is the result of clustering mechanism usage in both of the schemes.

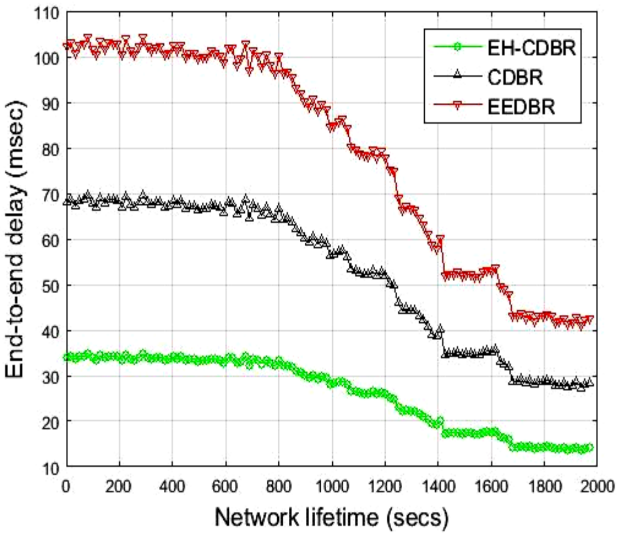

Figure 4: End-to-end Delay

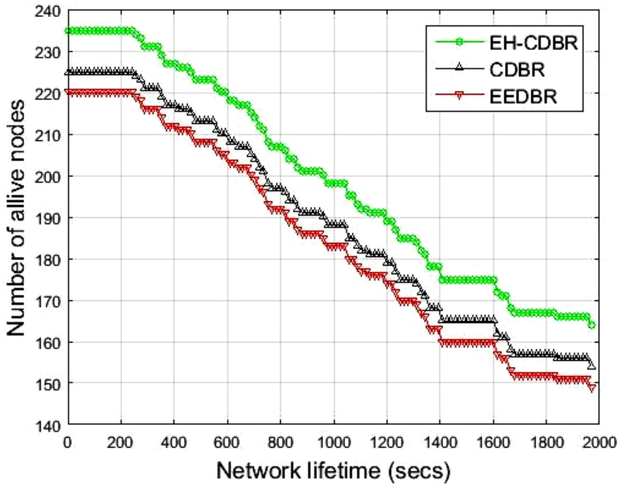

Figure 5: Number of Alive Nodes

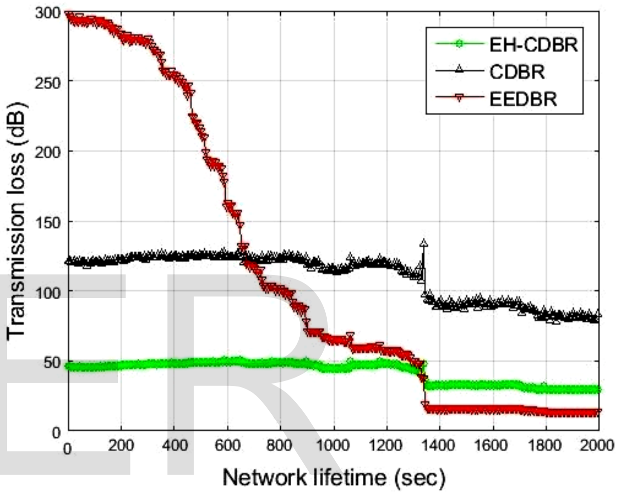

Figure 6: Transmission Loss

VII. COCLUSION AND FUTURE WORK

In this paper we have presented energy harvesting routing scheme for UWSN, EH-CDBR. We compared this routing scheme with current state of art routing protocols of UWSN which are EEDBR and CDBR. Results shows that EH-CDBR is 300.7% efficient compared to EEDBR in the case of end-to-end delay. Our protocol shows improved performance in increased number of alive nodes having 108% improved results on the scale compared to EEDBR and CDBR. Likewise EH-CDBR has only 35% transmission loss compared to EEDBR and CDBR which has these results 84.4% and 100% respectively.

In UWSN energy supply is main issue. Although in our research work, we have gained some efficient results in maintaining residual energy of the nodes through energy harvesting but in future we will try to implement enlarged sized TENG with greater output voltage /power. It will improve the performance of network up to greater extent.

In future we will implement cooperation technique. Cooperation may be defined as group of entities having common goal and share each other resources while working together. In cooperation the sender node forward a copy of data to relay node. The relay nodes amplify or decode the data for onward transmission.

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