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A Multi-Layer Cluster Based Energy Efficient Routing Scheme for UWSNs

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ABSTRACT Underwater Wireless Sensor Networks (UWSNs) have emerged as a remarkable interest for scholars worldwide in terms of various applications such as monitoring offshore oil and gas reservoirs, pollution, oceans for defense, and other applications such as tsunami. Terrestrial Wireless Sensor Networks (TWSN) and UWSNs share many characteristics apart from having different communication medium and working environment as UWSNs face the challenges of low-bandwidth, long latency, and high bit error rate. These have caused for UWSNs many problems such as low reliability, packet retransmission, and high consumption of energy. To alleviate the aforementioned issues, many techniques have been proposed. However, most of them merely consider the issue of hotspot which occurs due to the unbalanced transmission of load on sensor nodes near the surface sink. In this article, we propose a multi-layer cluster-based Energy Efficient (MLCEE) protocol for UWSNs to address the issue of hotspot and energy consumption. There are different stages in MLCEE, first of which is the division of the whole network in layers, the second is clustering of the nodes at same layers. In the last stage of transmission, the cluster head (CH) selects the next hop among the CHs based on greater fitness value, small Hopid and small layer number. To mitigate the issue of hotspot, the first layer remains un-clustered and any node in the first layer transfers data to the sink directly while cluster heads (CHs) are selected based on Bayesian Probability and residual energy. The simulation results of the proposed technique, done using MATLAB, have revealed that MLCEE achieves superior performance than the other techniques with regard to the network lifetime, energy consumption, and data transmission amount.

INDEX TERMS Underwater wireless sensor networks (UWSNs), BN Bayesian probability (BN), network lifetime, dynamic clustering, cluster head (CH) selection, energy efficiency.

I. INTRODUCTION

Recently, UWSNs are fascinating more considerations from industry and academia due to their comprehensive application fields, for example, auxiliary navigation, ecological observing, resource exploration, and calamities avoidance, etc. Underwater nodes are mostly deployed sparsely in the monitoring area from surface to bottom and these nodes are equipped with an acoustic modem. Communications through optical signals in underwater are not adequate due to absorption loss and rapid attenuation. Therefore acoustic signals are used for underwater communication [1].

The sensor nodes follow a specific routing mechanism to forward the sensed data to sinks while facing a major limitation of power source as sensor nodes are furnished with small size batteries [2]. Once underwater sensor nodes are arranged, the recharging or replacing of their batteries is a very difficult task due to the harsh underwater environment. However, acoustic waves themselves have some limitations like low bandwidth, high bit error rate (BER) [2], [3], long propagation delay, and multi-path fading [4]. Therefore, these challenges motivated researchers to develop energy efficient routing protocols for UWSNs.

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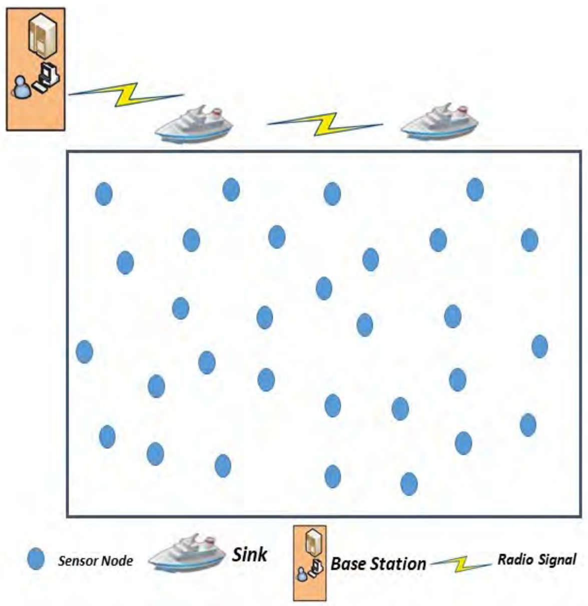

FIGURE 1. Basic architecture of UWSNs.

The basic architecture of UWSNs is shown in Figure 1, in which sensor nodes are randomly deployed and static sink is placed on the surface of the monitoring area. The sensor nodes send their sensed data to static sink either by means of multi-hop communication or through direct communication. In multi-hop communication, sensor nodes forward the sensed data to their one-hop neighbors until the data reached the sink (surface). Due to noise and link impairments, there is an excessive chance of data corruption during multi-hop communication [5]. Moreover, a hot-spot problem occurs in multi-hop communication because sensor nodes near sink deplete their energy very quickly [6] and these nodes die earlier, therefore the area of interest remains unobserved. To cope with the hot-spot problem, mobile sinks are used in many routing protocols [7] for data collection from sensor nodes in their vicinity. Furthermore, in existing protocols [8] sensor nodes near sink are often nominated for data sending, such unstable load of transmission on these nodes cause initial death of sensor nodes and produce energy holes in the network [9]. As a result of these energy holes, some areas in the network remain un-sensed. Whereas in direct communication, nodes at distant positions in the network also send their sensed data directly to surface sink which causes quick consumption of energy of those nodes. The nodes at a distant position die earlier and cause coverage hole problem. The mobile sinks are better to collect information from sensor nodes at minimum distance in order to avoid coverage hole problem [10].

In this article, we present an MLCEE routing protocol for UWSNs. This protocol aims at mitigating the issues of hotspot, high error rate and high consumption of energy. In this scheme, the entire network region is divided into different layers from surface to bottom and in every layer, nodes are clustered. According to Ekman [11], [12] from the surface, the stream of water is very high and sensor nodes will change its position quickly. Therefore, taking energy balance into consideration in first layer due to the high stream of water, clustering will not be formed and the nodes in the first layer will directly transfer data to the sink node. So other than the first layer, clusters will be formed at each layer for the purpose to balance the energy consumption. In this scheme, we present different algorithms such as an algorithm for assigning Hopid and clustering. Data aggregation performed by CHs and transfers the aggregated data to sink node by utilizing hop by hop route from one CH to another.

II. RELATED WORK

UWSNs has been under study since last one decade and researchers have proposed different routing algorithms in order to reduce the high consumption of energy and long end-to-end delay. In literature [13], the authors proposed a depth based routing (DBR) protocol, it is also known as the localization free protocol. In a dense network, DBR selects the forwarder node with the greedy forwarding approach. As DBR utilizes only information of depth and In any case, information of depth isn't sufficient to limit the data to be sent inside a specific territory. Data might be sent through different ways which may cause a high consumption of energy. This protocol achieves high data delivery ratio for the dense network. However, in the sparse network, the packet delivery ratio is relatively low and end to end delay is high. In literature [14], the author suggested a routing protocol named as Energy-efficient depth-based routing (EEDBR) in order to mitigate the DBR's consumption of energy issue. The performance was improved by EEDBR in term of consumption of energy, end to end delay and enhanced network lifetime.

In literature [15], the author suggested H2-DAB (Hop-by-hop dynamic addressing-based routing protocol). In H2-DAB, a HopID assigned to each node by means of hello packet from the sink node. The HopID of each node describes the number of hops away from the sink node. As the source node selects the next relay node which has small HopID, if such node is not found which have small HopID that may in turn reasons the issue of void region. It also causes extra consumption of energy and long end to end delay. To reduce delay and consumption of energy in the system, the authors introduced ranging technique [16], which is named as energy efficient depth-based routing (EE-DBR) protocol and directional depth-based routing (D-DBR) protocol for UWSNs. By using ToA ranging technique, the space between two sensor nodes is measured by the data packet's propagation time from one sensor node to another. For the purpose to diminish the consumption of energy in the system, EE-DBR reduces redundant transmissions by using ToA ranging technique. Next forwarding node which have least distance to sink is also selected through this TOA ranging technique. For the calculation of two sensor nodes distance, the ranging technique has been used by D-DBR. Through an optimal route the packet to be progressed for the purpose to diminish delay. However, ToA ranging technique cannot perform well in sparse regions and it causes coverage holes in the sparse region. The authors in the literature [17] proposed channel-aware depth-adaptive routing protocol (CDRP) for UWSNs to evade void regions and achieve increased PDR (packet delivery ratio). For the purpose of successful transmissions and reduction of delay, CDRP considers the deviation of noise and sound speed in underwater. The source node constructs a virtual ideal path for forwarding of data packets to sink through the ideal path table. Each sensor node then selects relays based on one-hop neighbor information for forwarding of data to the destination. It sends neighbor information along with data packet in order to diminish control packet overhead. CDRP uses backward transmissions for successful data delivery to sink in order to avoid void holes which results in increased consumption of energy in the network.

A channel aware routing protocol (CARP) for UWSN have been anticipated in literature [18], to prolong the delivery ratio by considering link quality and hop count as a forwarding metrics. A node nominated as a relay node, if it has high residual energy and history of successful delivery of packets to its neighbors, CARP also exploits a simple mechanism to avoid loops such that using hop count of a node to be selected as a next forwarder. To send a data packet, a node first broadcasted a control packet PING in its neighborhood. After sending PING, sender node then waits for PONG replies from its neighbor nodes. If a node does not receive any PONG reply within a specific time, then it will again send PING. After times, if there is no PONG reply from any neighbor node then the sender node drops the packet. CARP increases the transmission power of a node in order to select farther relays which reduce end-to-end delay. It also achieves high PDR by considering link-quality of relay nodes. In CARP, packets overhead increasing network communication cost, which in turn increases the consumption energy of the network.

To reduce the consumption of energy in the network, the authors proposed a weighting sum of two hop depth difference based WDFAD-DBR routing protocol [19]. The depth of existing hop and following estimated hop is considered as a forwarding metric for data forwarding to effectively reduce void holes. A mechanism to reduce duplicate packets, the transmission is incorporated by dividing the forwarding area which in turn decreases energy consumption in the network. This technique considered two hopes to direct data. However, in sparse regions, the second hop without adjustment could not find next forwarding hop to directs data, which causes the second hop in the void region. In GEDAR [20], a packet advancement metric is used to determine the next forwarder node for a forwarding data packet to the destination. In GEDAR, in case of void regions, a recovery mode process which is based on depth adjustment is used for sending the data packet to the destination. If it has no neighbors in its transmission range, then the node is considered in the void region and it announces its condition as a void node. It then identifies its new depth based on the position information of neighbor nodes to resume the greedy forwarding strategy. With node adjustment technique, maximum network throughput is accomplished at the cost of high end-to-end delay in the system. In GEDAR, the communication cost of the network is also high due to control packet overhead.

Clustered routing protocol based on improved K-means (CBK) algorithm is suggested for UWSNs in literature [21]. In order to evade the unbalancing of energy, CBK utilizes K-means algorithm for the formation of clusters. Based on clustering, some other location-free routing protocols are suggested in literature [22]–[25].

III. OUR PROPOSED SCHEME

A. MOTIVATION

For UWSNs, the primary target of routing protocol is the reduction of high energy consumption and end-to-end delay. In an environment like underwater, the acoustic signal is embraced as correspondence medium for communication, that prompts more consumption of energy. The sensor nodes energy is constrained and difficult to be provided. Consequently, in a routing protocol, energy balance and energy efficiency are essential design goals. It has been demonstrated that protocols based on clusters are viable with respect to sparing energy. UWSNs consumed much energy on transmitting of data as compared to receiving of data. In this way, decreasing the number of transmissions is valuable in diminishing the consumption of energy. Fusion and aggregation of data by CHs can viably diminish the quantity of transmission. Since communication at long distance prompts more consumption of energy, to spare the energy in our scheme multi-hop routing is implemented by means of CHs. CH directed data towards sink by means of another CHs. Consequently, in this scheme we intents to plan a routing technique based on clusters which is more appropriate for UWSNs.

For UWSNs [26]–[29], different clustering schemes have been presented. However, none of them considers the hotspot issue. CHs particularly which are close to the surface forward information more as often as possible than others, which in turn causes the early demise of these sensor nodes and causes the issue of hotspot. The lifetime of the whole network is influenced by the hotspot issue. Hence, MLCEE technique plans to enhance the strategy of clustering to take care of the hotspot issue. In this scheme, the nodes in the first layer will not be clustered which are closer to the surface and any node can be chosen as a next sending node to sink. At a similar period to evade the issue of a hotspot, technique of clustering is applied after the first layer.

In UWSNs, the ratio of delivery is low and bit error is high because of the harsh condition. Therefore, links with high quality can reduce energy consumption and enhance the ratio of delivery. Accordingly, the imperative issue is the determination of routing routes which have links with high quality. Amid the choice of next sender, residual energy and link quality are considered in MLCEE scheme.

B. MODEL FOR CONSUMPTION OF ENERGY IN THE NETWORK

Our considered network is a three-dimensional (3D) and there are numerous nodes conveyed randomly beneath the water and the situation of every node varies with an ocean water stream while the sink is fixed. The sensors are outfitted with acoustic modems that can transmit data using acoustic signals. Every node has a unique ID and is introduced with even transmission range and initial energy. Submerged acoustic networks are demonstrated as a regular Power flow condition [30] without thought of divergence of the beam, and consequently, the power transmitted $P(t)$ is communicated as:

$$p(t) = p_R e^{c(\lambda)r} \tag{1}$$

p_R is the power which has been received, r is the range of transmission, λ is the attenuation coefficient of ocean water. In light of accepting antenna's viable region and the impact of the acoustic framework and the external environment, equation (1) can be rewrite as:

$$p(t) = p_R e^{c(\lambda)r} / \delta \eta t \eta r \tag{2}$$

In the above equation δ is accepting antenna's viable region, ηr is the acoustic transmittance of receiver and ηt is the acoustic transmittance of emitter.

The consumption of energy on transmitting data from node k to node e is:

$$Ut^{ke} = Uelec + \frac{p_R e^{c(\lambda)r}}{\delta \eta t \eta r Zb} \tag{3}$$

In the above equation $Uelec$ demonstrates the consumption of energy to route 1-bit data, among node k and node e, r is the distance separation and Zb indicates the information rate of submerged acoustic communication. The node on handling and receiving of 1bit data, the consumption of energy is:

$$Ut = Uelec + \frac{p_R}{Zb}.L(M) \tag{4}$$

$L(M)$ denotes the energy loss, at the point when the information is communicated underwater at M (distance).

$$L(M) = l^k \alpha(f)^l \tag{5}$$

usually k is the factor of spreading which generally uses factor for both spherical, cylindrical 2 and 1 respectively. By means of Thorp's equation the α(f) absorption coefficient can be determined as:

$$\alpha(f) = .011\frac{f^2}{(1+f^2)} + 4.4\frac{f^2}{(41*10^2+f^2)} + 2.75*10^{(-6)} + .003 \tag{6}$$

In the above equation carrier frequency f is determined in kHz and absorption coefficient α(f) will be measured in dB/km.

TABLE 1. Notations used in model for consumption of energy in the network.

Notation	Definition
$p_{(t)}$	$p_{(t)}$ is the power transmitted
p_R	The received power
$c(\lambda)$	Attenuation coefficient of sea water
r	Transmission range
δ	viable region of Receiving
ηr	acoustic transmittance of receiver
ηt	acoustic transmittance of emitter
$Uelec$	consumption of energy to route 1-bit data
Zb	The information rate of acoustic communication
$L(M)$	energy loss at a distance (M)

C. ASSUMPTION AND STRUCTURE OF NETWORK

We assume a multi-sink network architecture consists of sensor nodes and sink nodes. The sink is static and is positioned on the surface of the water. The static sink includes both acoustic and radio modems. Sink communicates with sensor nodes using acoustic links and for connection to another sink it utilized radio links. Packet accumulated at one sink is assumed to be received at all sink. Sensor nodes are furnished with acoustic modems to communicate with one another. For the purpose of more effective clustering, sensor nodes from top to bottom are arranged in layers. Using Buoyancy control mechanism underwater nodes are conveyed at various layers. The number of layers relied upon layers communication range and water depth. If we consider that the sea average depth is about 2.5 to 3 km [31] and 500 m is the range of communication, then round about 5 to 6 layers are required. In underwater for communicating with one another, every sensor node is outfitted with an acoustic modem. Sensor nodes float horizontally with water stream, their movement in a vertical direction can be negligible.

According to Ekman [11], [12] up to 100m from the surface, the stream of water is very high and sensor nodes will change its position quickly. Therefore, while taking energy balance consideration in the first layer, due to the high stream of water clustering will be not formed and the nodes in the first layer will directly transfer data to the sink node. Other than the first layer, in all other layers, clusters will be formed and member node of each cluster will forward data to the CH. CH will aggregate and sends the data to another CH. The data will be reached at sink by utilizing hop by hop route from one CH to another.

In this article, we consider the sink node energy unlimited, because the sink node battery can be substituted as it is placed on the water surface. In the interim, we consider the same initial energy for all the sensor nodes which is one time and the node's battery cannot be substituted. We also conclude that all the sensors have the same range of communication and every node is outfitted with the depth sensor. The delivery of data will be determined as successful if any of the sinks collects the data.

As already discussed the nodes are divided into different layers. For instance, if we consider 1000m is the monitoring area and 250m is the node communication range, then a total of 4 layers we required. Equal or less than 250m is the distance among two layers. At every layer, the nodes are deployed randomly and only at the same layer the CH will be selected.

D. LAYERING AND ASSIGNING HOPID

To expand the efficiency of the proposed scheme, the whole monitoring area is divided into layers which have equal size. The number of layers can be calculated by M_{area}/W, where M_{area} is the depth of monitoring area and W is the width of layer. The sensor nodes embedded with pressure gauge [32], using this pressure gauge every node determines its own depth. For the purpose to know to which layer sensor node belongs to, every node calculated its layer number using the following equation:

$$N_{\mathrm{ln}} = \frac{N_{dpt}}{W} \bmod (LN). \tag{7}$$

N_{ln} is the layer number of node N, N_{dpt} is the node N depth and LN is the total number of layers in network.

Algorithm 1 Hopid Assigning by Broadcasting Inquiry Message

```
Sink broadcasts Inquiry message (IM)
Default Hopid for SINK is N00
Maximum Sink Hop Count r = 5
inquiry Message received
if Type of inquiry Message = Sink-IM then
    Received Sink-Hopid N_KL from Sink-IM
    Own Sink-Hopid N_MN
    if K & L = 0 and r=0 where r is the hop count from sink then
        N ← r + 1
        Update Sink-IM own Sink-Hopid
        broadcast further
        if inquiry Message recieved from sensor node,where N & r < 5 then
            N ← r + 1
            broadcast further
        else
            Drop inquiry Message Already have Hopid
        end
    end
    if N & r = 5 // Max Hop Count then
        Stop further broadcasting Sink IM
    end
end
```

As described in Algorithm 1, each node will be assigned their Hopid by means of inquiry Message (IM) from the sink node. The procedure is as per the following. Towards nodes, an inquiry Message (IM) broadcasted from the sink node. Every node will get a Hopid from the inquiry Message which is received, so as to allocate Hopid to every node in the entire network, every node will rebroadcast the IM by an increment of one in the field of Hopid and add layer number which is computed by every node using equation (7). This procedure will carry on until every node got Hopid and determined the layer number to which it belongs. The format of inquiry Message is presented in Table 2. The first portion is the type of inquiry message which means that whether the inquiry message is received from sink or another sensor node. The second portion is the Sinkid portion which is unique. For the purpose of recognizing the destination, the sensor node utilized the Sinkid. The last portion is layer count; at first, the layer count portion is zero but after receiving the inquiry message the sensor nodes add its layer number in this portion which it computes by using equation (7).

TABLE 2. Inquiry message from sink.

Type of inquiry Message	Sinkid	Layercount

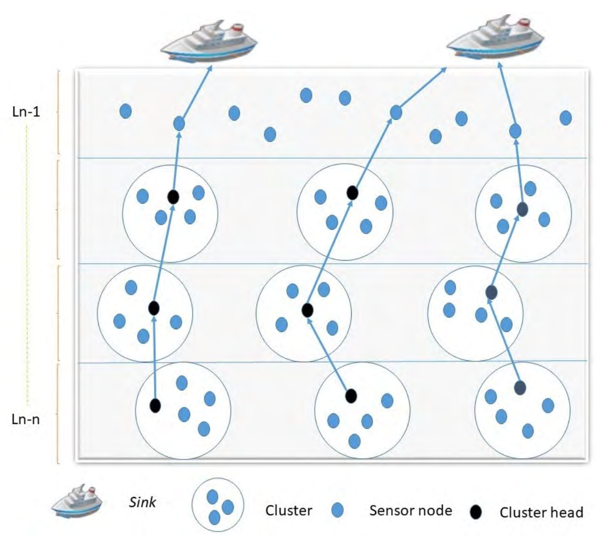

FIGURE 2. Structure of network.

E. CLUSTERING

Different factors are taken into account for the selection process such as residual energy, distance to sink and rate of energy consumption. In this scheme formation of clusters and selection of CHs are dynamically conducted according to the unique underwater conditions at runtime. A consistent setup is established between cluster member and CH for collection of data and making decisions. The anticipated scheme of clustering is shown in Figure 2. We further divide clustering into two phases.

1) FINDING NEIGHBOR INFORMATION

In this phase, every node will broadcast a query Message in neighbor nodes, which include the layer number, node id and the residual energy of node. After receiving the query Message every node will only save the same layer neighbor nodes information and will drop the query Message of other layer nodes. The query Message format is presented in Table 4.

TABLE 3. Inquiry message rebroadcast by sensor node.

Type of inquiry Message	Nodeid	Hopid	Layercount

TABLE 4. Query message for identifying neighbor nodes.

Type of Message	Nodeid	Residual energy	Layer Number

TABLE 5. Competition message for the selection of CH.

Type of Message	Nodeid	Residual energy	Layer Number	Probability (Pi)

2) CLUSTER HEAD (CH) FORMATION

In this phase, every node will calculate their holding time H_t using the following equation. Every node has a different H_t.

$$H_t = S_2 + \rho \times \left(\frac{residualenergy}{Initialenergy}\right) \tag{8}$$

where H_t is the holding time of a node, S_2 is the time of duration and ρ [1, 0.5] is any value for avoiding the confliction if nodes have similar residual energy. From Equation (8), we can determine that if a node residual energy is high, then the node will have smaller holding time and the nodes will have a better chance to elect as a CH. After expiring of holding time, the nodes send a competition message in neighbor nodes, the format of competition message (COM_P Msg) is shown in Table 5. If for example, a node received a message before expiring of its holding time (H_t) then the node will be directly dropped itself from the competition and become a cluster member. If nodes received too many competition messages from other nodes, then the node will select the CH which has high probability. We further explained in Algorithm 2.

Many scholars have used Bayesian probability (BN) for different purposes [33], [34]. We are using Bayesian spam filtering [35] for our scheme which is much allied to our problem domain. The BN probability is calculated for every node based on remaining energy, energy consumption rate, and Link quality. For the CH selection, we apply the Bayesian spam filtering, since we have two possible outcomes. A node can either be a CH *(H)* or member node *(H')*. We find out the probability of becoming a head node for each node in a cluster, and the one with maximum probability, which is also based on its attribute values becomes the CH.

The two possible classification outcomes are the head node*(H)* or member node*(H')*. Consider m nodes in a cluster. All the clusters have their own set of values for attributes.

States: H and *H'*

Set of Nodes: $N = (n_1, n_2, n_3 \ldots.., n_m)$

Set of attributes for node i:$X_i = x_{i1}, x_{i2}, x_{i3} \ldots., x_{ia}$

To apply Bayesian probability, we need to know the conditional probability concept. The probability of an event B to occur given event A has already occurred is given by:

$$P(A|B) = P(AandB)/P(B) = [P(B|A) * P(A)]/P(B) \tag{9}$$

Algorithm 2 Formation of Cluster and Selection of CH

```
for every node Nj do
    broadcast Query Message
    for every node Nj received Query Message do
        if layer number of Node in received Query
        Message Ln = Nj's LN then
            save and record the Query Message of
            neighbors
        else
            drop Querry Message
        end
    end
end
for every node Nj do
    if layer number LN ≠ 1 //nodes not in layer one then
        Nj compute H_t (holding time)
    end
end
for every node Nj do
    while H_t (holding time) does not expire do

    end
    if did not obtain COM_P Msg within H_t then
        broadcast COM_P Msg within neighbors after
        Expiring H_t
    else
        send the JOIN_M Msg
    end
end
for every node obtained COM_P Msg do
    compute Pi value
    Select CH which have greater Pi
    send the JOIN_M Msg
    for each Cluster Head do
        record the information of member nodes
    end
end
```

P(A) is the prior probability that *A* occurs, while *P(A|B)* is the posterior probability that *A* occurs knowing that *B* has already occurred. Similarly, *P(B)* is the prior probability that *B* occurs, while *P(B|A)* is the posterior probability that *B* occurs knowing that *A* has already occurred.

In our case, let the prior probability(without the knowledge of attributes) of a node x_i to be head node H be denoted by $P(n_i = H)$. If x_{ij} represents the value of jth attribute for ith node, the posterior probability (knowing the attribute values) of a node x_i to be head node H is denoted by $P(n_i = H/x_{ij})$. Similarly, the prior and posterior probability of a member node are given by $P(n_i = H')$ and $P(n_i = H'|x_{ij})$ respectively. $P(x_{ij}|n_i = H)$ is the posterior class probability of an attribute value to occur at a node given it is a cluster head, while $P(x_{ij})$ is the prior probability of an attribute value to occur.

In order to find the posterior probability of a node to have a possible set of attribute values, given that it is a cluster head, we use the rule that if A and B are independent events,

$P(AandB) = P(A) * P(B)$. Hence, if the event of individual attribute values to occur is independent of other attribute values, then $P(x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ia}|n_i = H)$, our required probability is given by the product of $P(x_{ij}|n_i = H)$ for each attribute value of the specific node.

$$\begin{aligned} P(x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ia}|s_i = H) &= P(x_{i1}|s_i = H) \\ &\quad * P(x_{i2}|s_i = H) * P(x_{i3}|s_i = H) \ldots . P(x_{ia}|s_i = H) \\ &= \prod_{j=1}^{a} P(x_{ij}|s_i = H) \end{aligned} \tag{10}$$

Now from equation (9)

$$P\left(x_{ij}|s_i = H\right) = \left(P\left(s_i = H|x_{ij}\right) * P\left(x_{ij}\right)\right) / P\left(s_i = H\right) \tag{11}$$

So, (10) becomes

$$P(x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ia}|s_i = H) = \prod_{j=1}^{a} \frac{P(s_i = H|x_{ij}) * P(x_{ij})}{P(s_i = H)} \tag{12}$$

Since the denominator doesn't depend on j,

$$\begin{aligned} P(x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ia}|s_i = H) &= \frac{\prod_{j=1}^{a} P(s_i = H|x_{ij}) * P(x_{ij})}{(\prod_{j=1}^{a} P(s_i = H))} \\ &= \frac{\prod_{j=1}^{a} P(s_i = H|x_{ij}) * P(x_{ij})}{[P(s_i = H)]^a} \end{aligned} \tag{13}$$

Now, since there are only two possible states for a node to be in, H and H'.

$$\begin{aligned} P\left(s_i = H|x_{ij}\right) + P\left(s_i = H'|x_{ij}\right) = 1 P\left(s_i = H'|x_{ij}\right) \\ = 1 - P\left(s_i = H|x_{ij}\right) \end{aligned} \tag{14}$$

Also,

$$P\left(s_i = H\right) + P\left(s_i = H'\right) = 1 P\left(s_i = H'\right) = 1 - P\left(s_i = H\right) \tag{15}$$

Now, the posterior probability of a cluster to have a possible set of attribute values, given that it is not a cluster head is:

$$P(x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ia}|s_i = H') = \frac{(\prod_{j=1}^{a} P(s_i = H'|x_{ij}) * P(x_{ij})}{[P(s_i = H')]^a} \tag{16}$$

Now, $x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ia} = X_i$ be set of attributes for ith attribute, then

$$P(X_i|s_i = H') = \frac{\prod_{j=1}^{a} P(s_i = H'|x_{ij}) * P(x_{ij})}{[P(s_i = H')]^a} \tag{17}$$

From equation (14) and (15)

$$P(X_i|s_i = H') = \frac{\prod_{j=1}^{a} [1 - P(s_i = H|x_{ij})] * P(x_{ij})}{[1 - P(s_i = H)]^a} \tag{18}$$

Also,

$$P(X_i|s_i = H) = \frac{\prod_{j=1}^{a} P(s_i = H|x_{ij}) * P(x_{ij})}{[P(s_i = H)]^a} \tag{19}$$

Now, given the set of attributes X_i, the probability of a node to be head is:

$$P\left(si = H|Xi\right) = \frac{\left(P\left(X_i\ |s_i = H\right) * P\left(s_i = H\right)\right)}{P\left(X_i\ \right)} \tag{20}$$

Since given a set of attributes about a node, it can be either in H or H' state:

$$\begin{aligned} P\left(X_i\right) = P\left(X_i\ |s_i = H\right) * P\left(s_i = H\right) \\ + P\left(X_i\ |s_i = H'\right) * P\left(s_i = H'\right) \end{aligned} \tag{21}$$

$$\begin{aligned} P(s_i = H|X_i) &= \frac{\frac{\prod_{j=1}^{a} P(s_i=H|x_{ij}) * P(x_{ij})}{[P(s_i=H)]^a} P(s_i = H)}{\frac{\prod_{j=1}^{a} P(s_i=H|x_{ij}) * P(x_{ij})}{[P(s_i=H)]^a} P(s_i = H) + \frac{\prod_{j=1}^{a} [1-P(s_i=H|x_{ij})] * P(x_{ij})}{[1-P(s_i=H)]^a [1-P(s_i=H)]}} \\ &= \frac{[\prod_{j=1}^{a} P(s_i = H|x_{ij}) * P(x_{ij})] * [P(s_i = H)]^{(1-a)}}{[\prod_{j=1}^{a} P(s_i = H|x_{ij}) * P(x_{ij})] * [P(s_i = H)]^{(1-a)} + [\prod_{j=1}^{a} [1 - P(s_i = H|x_{ij})] * P(x_{ij})][1 - P(s_i = H)]^{(1-a)}} \end{aligned} \tag{23}$$

$$P(s_i = H|X_i) = \frac{([\prod_{j=1}^{a} P(s_i = H|x_{ij})] * [P(s_i = H)]^{(1-a)})}{\prod_{j=1}^{a} P(s_i = H|x_{ij}) * [P(s_i = H)]^{(1-a)} + \prod_{j=1}^{a} [1 - P(s_i = H|x_{ij})][1 - P(s_i = H)]^{(1-a)}} \tag{24}$$

$$P(s_i = H|X_i) = \frac{([\prod_{j=1}^{a} P(s_i = H|x_{ij})] * [P(s_i = H)]^{(1-a)})}{\prod_{j=1}^{a} P(s_i = H|x_{ij}) * [P(s_i = H)]^{(1-a)} + \prod_{j=1}^{a} [1 - P(s_i = H|x_{ij})][1 - P(s_i = H)]^{(1-a)}} \tag{25}$$

$$\begin{aligned} P(s_i = H|X_i) &= \frac{(\prod_{j=1}^{a} P(s_i = H|x_{ij}))}{([\prod_{j=1}^{a} P(s_i = H|x_{ij})] + [\prod_{j=1}^{a} [1 - P(s_i = H|x_{ij})]][\frac{(1-P(s_i=H))}{P(s_i=H)}]^{(1-a)})} \\ &= \frac{(\prod_{j=1}^{a} P(s_i = H|x_{ij}))}{([\prod_{j=1}^{a} P(s_i = H|x_{ij})] + [\prod_{j=1}^{a} [1 - P(s_i = H|x_{ij})]][\frac{P(s_i=H')}{P(s_i=H)}]^{(1-a)})} \end{aligned} \tag{26}$$

So, (20) becomes:

$$P(s_i=H|X_i)=\frac{(P(X_i|s_i=H)*P(s_i=H))}{(P(X_i|s_i=H)*P(s_i=H)+P(X_i|s_i=H')*P(s_i=H'))} \quad (22)$$

Now, putting values from (15), (18) and (19), (23) is obtained, as shown at the bottom of the previous page. Since we are not really considered about the probability of a certain attribute to occur, eliminate $P(x_{ij})$ (24), as shown at the bottom of the previous page. Now, putting values from (15), (18) and (19), (25) is obtained, as shown at the bottom of the previous page. Dividing numerator and denominator by $[P(s_i = H)]^{(1-a)}$, (26) is obtained, as shown at the bottom of the previous page. If all the nodes have an equal probability of being a head if we have no information about their attributes,

$$P(s_i=H)=P(s_i=H)\,1=\frac{P(s_i=H)}{P(s_i=H)} \quad (25)$$

Putting the values of (26) in (25),

$$P(s_i=H|X_i) = \frac{\prod_{j=1}^{a} P(s_i=H|x_{ij})}{[\prod_{j=1}^{a} P(s_i=H|x_{ij})]+\prod_{j=1}^{a}[1-P(s_i=H|x_{ij})]} \quad (26)$$

Let P_i be the probability of head given its attributes and P_{ij} be probability given a specific attribute.

$$P_i=\frac{\prod_{j=1}^{a}(P_{ij})}{\prod_{j=1}^{a}[P_{ij}]+\prod_{j=1}^{a}[1-P_{ij}]} \quad (27)$$

Taking reciprocal

$$\frac{1}{P_i}=\frac{\prod_{j=1}^{a}P_{ij}+\prod_{j=1}^{a}[1-P_{ij}]}{\prod_{j=1}^{a}(P_{ij})} \quad (28)$$

Subtract 1 from both sides

$$\frac{1}{P_i}-1=\frac{\prod_{j=1}^{a}P_{ij}+\prod_{j=1}^{a}[1-P_{ij}]}{\prod_{j=1}^{a}(P_{ij})}-1 \quad (29)$$

$$\frac{1}{P_i}-1=\frac{\prod_{j=1}^{a}P_{ij}+\prod_{j=1}^{a}[1-P_{ij}]-\prod_{j=1}^{a}P_{ij}}{\prod_{j=1}^{a}(P_{ij})} \quad (30)$$

$$\frac{1}{P_i}-1=\prod_{j=1}^{a}\frac{[1-P_{ij}]}{(P_{ij})} \quad (31)$$

Now taking ln on both sides

$$\ln(\frac{1}{P_i}-1)=\ln(\prod_{j=1}^{a}[\frac{1}{P_{ij}}-1]) \quad (32)$$

Now since logarithm of a product of terms is equal to the product of logarithms of individual terms, hence:

$$\ln(\frac{1}{P_i}-1)=\ln(\prod_{j=1}^{a}[\frac{1}{P_{ij}}-1])$$

$$\ln(\frac{1}{Pi}-1)=\sum_{j=1}^{a}\ln[\frac{1}{P_{ij}}-1] \quad (33)$$

So, Pi can be

$$P_i=\frac{1}{e^{\sum_{j=1}^{a}\ln(\frac{1}{P_{ij}}-1)}+1} \quad (34)$$

For simplicity let $n=\sum_{j=1}^{a}\ln(\frac{1}{P_{ij}}-1)$

Then, Pi can be calculated as:

$$P_i=\frac{1}{e^n+1} \quad (35)$$

After the formation of cluster heads, the cluster member will send the reply message (JOIN_M) for joining the cluster. CH will add the nodes in the list of cluster members. The format of JOIN_M is shown in Table 6.

TABLE 6. Message for joining cluster.

Packet type	CH id	Residual energy	source node id	next CH id	data number

TABLE 7. Maintaining of CHs information.

CH Hopid	Layer Number	Residual energy	Probability (Pi) of CH

F. FORWARDING OF DATA

After the formation of clusters, the TDMA schedule has been assigned to each cluster member. In which every member of the cluster will transfer data at a specific time interval to mitigate the issue of transmission interference in the network. After aggregation of data the CH transfer the data towards the surface sink. For example, If the source node is located at the first layer, then it will transfer data directly to the sink node. For other situation, if the source node is located other than the first layer then the data will be forwarded through CHs by means of hop by hop. When the CH hears the packet information from other CHs then every CH saves the information of other CHs in the form of an array as shown in Table 7. The information includes residual energy, probability, the CH Hopid at its own layer and at upper layer which has small layer number. CHs selects the next forwarder from the upper layer.

The forwarding next node is selected by considering the residual energy, Hopid and probability. The fitness value for the selection of next forwarder is calculated as:

$$f_C H=\left(\frac{Eres-H}{Eini-H}\right)\varsigma+p,\ \varsigma+\xi=1 \quad (36)$$

Eres-H is the CH residual energy, *Eini-H* is the initial energy of CH, ς and ξ are the coefficients of weight and P is the probability of CH.

From the saved information cluster head determines the fitness value of every CH for the selection of next forwarder. The source cluster head will transfer the packet information to the upper layer CH, which has high fitness value and less Hopid. Cluster head transfer packet information which includes CH id, source node id, residual energy, data number,

TABLE 8. Data packet format.

Packet type	CH id	Residual energy	source node id	next CH id	data number

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Algorithm 3 Selection of Next CH as a Forwarder

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for *Every cluster head CH-j* **do**
  for *Each CH-i ∈ neighbor nodes & CH-i LN < CH-j LN* **do**
    Compute f_CHi //fitness value
  end
end
Select next forwarder which has greater fitness value
Transfer data to next forwarder
for *Nj node obtained data packet* **do**
  if *In obtained packet the next CH id = Nj's id* **then**
    transfer the data packect
  else
    Drop the packet
  end
end

---

and next CH id as shown in Table 8. Data number and source node id denote a distinctive data in the entire network. CH id denotes the id of cluster head which is transferring this information packet and next CH id denotes the id of next CH forwarder which has high fitness value among CH nodes at layer less than its own layer. Residual energy denotes the present CH energy for transferring the data.

If the CH does not obtain the reply message from the CH having less layer number, then the CH will transfer data to a cluster head which have similar layer number. The receiving CH will compare its own id with the next CH id if it is similar then it will forward the data further and thus up to sink node. The CH will drop the data packet if the CH id is not similar to the next CH id. The forwarding mechanism is further explained in algorithm 3.

As UWSNs have a dynamic structure and the nodes drift with water flow due to which the nodes may change their location. When a cluster member fails to direct the information packets to its own CH, that implies that the node is out of range from its own cluster. For this situation, the node will monitor other cluster head's data packets. Upon receiving the data packets of other CH, the node will join that cluster as per the required information which is included in the received data packet.

After completion of one round, From the residual energy of cluster members, CH will determine its own cluster average energy if it is less than the network threshold energy then the clusters will have reconstructed at that layer and CH will be reelected. The information about routing will also be updated.

IV. DISCUSSIONS AND SIMULATIONS

In this portion, the results of MLCEE is assessed and contrasted with DBR and EEDBR. The implementation of the proposed scheme is done by utilizing MATLAB version R2016a. A similar number of nodes is utilized during all simulations for all the three schemes (MLCEE, DBR, and EEDBR). In 3D monitoring area, 500 nodes are deployed. For every node, the initial energy is 5 joules. 2W and 0.1W is the consumption of power for processing and reception of data. For every node the transmission range is 100m. In MLCEE simulations, 100m is the layer depth for each layer where 100 nodes are deployed randomly at every layer. In the horizontal direction, the nodes drift with water flow from 2-3 m/sec. Two sinks are arranged at the surface of the water and utilized as for the collection of data from sensor nodes. Two hundred bytes is the data size while inquiry message having a size of 5 bytes, 5 bytes is the size of competition message and 5 bytes is the size of joining. Acoustic signal frequency is 10kHz. The parameters are also shown in Table 9. An average of 6 distinct results has been taken into account for final results.

TABLE 9. Simulation parameters.

Parameter	Value
Dimensions of Network	500 m × 500 m × 500 m
Sink nodes	2
Sensor Nodes	500
Range of Transmission	100 m
Nodes Initial energy	5 J
Power consumption for processing of data	2 W
Velocity of acoustic waves	1500 m/s
Acoustic signal frequency	10 kHz
Power consumption for reception of data	0.1 W
ρ , ς , ξ	[1,0.5],0.5,0.3

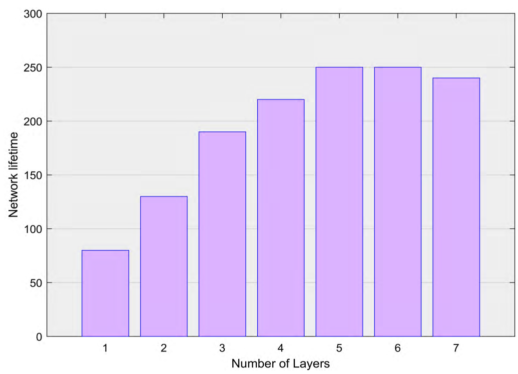

FIGURE 3. Effects of layering on network lifetime.

First of all, we observe the network layering effects on network lifetime. To validate that the network layering can successfully improve the unbalanced consumption of energy. We divided 500 sensor nodes within five layers, each layer having 100 sensor nodes. As appeared in Figure.3, the lifetime of the network is significantly improved when the number of division layers is between 1-5, but it does not affect too much by increasing the number of layers more than five layers. The whole network depth is 500 meters and 100m is the transmission range of sensor nodes. By increasing the number of layers more than five layers, then it will prompt overlapping of transmission range. This is the reason when the quantity of layers surpasses more than five layers, the lifetime of network stops developing and even starts to decrease. The lifetime of network increments up to 5 layers while comparing it with the network lifetime which has only one layer.

As we kept the width of layers equal but as shown in Figure 4 when we increase the width of layers then end-to-end delay also increases because nodes required more multi-hop transmission that's why end-to-end delay increases by increasing the width between layers. If we decrease less than 100m, then it causes overlapping of transmission range.

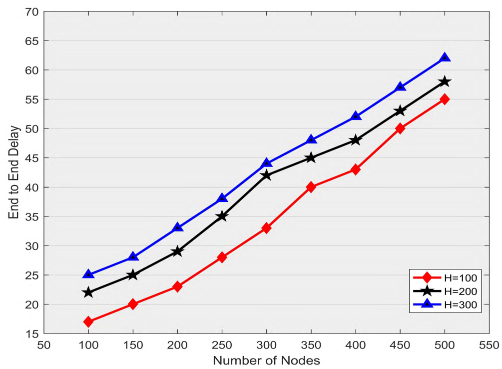

FIGURE 4. Layer width effects on end-to-end delay.

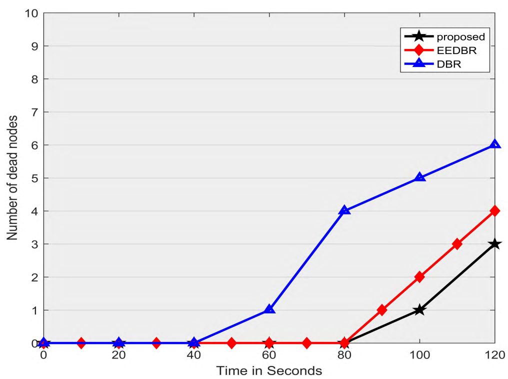

FIGURE 5. Comparison of stability period.

First sensor node dead time characterizes the network stability period. In Figure 5, the results are shown for different simulations. almost at the 60s, the primary nodes died in DBR routing protocol and in EEDBR routing protocol the primary nodes died at 90s while in MLCEE the primary nodes died at 100s. Without considering the nodes residual energy in DBR protocol, a large amount of redundant packets is produced That prompts unexpected demise of sensor nodes. Energy is a noteworthy concern factor in the MLCEE and EEDBR during the progressing of information to the destination. Particularly, to decrease the quantity of sending data MLCEE utilizes clustering approach. Subsequently, the demise time of primary node for DBR protocol is earlier than MLCEE routing protocol.

A lifetime of the network is characterized as the total period until the entire nodes die in the system. Figure 6 exhibits the lifetime of the network of three different routing schemes in arbitrary topologies. The results demonstrate that DBR lifetime is the 1500s, EEDBR having 1700, while the lifetime of MLCEE is 2000s. Because of the retransmitting and redundant data, in these three routing protocols DBR having the shortest lifetime of the network. Redundant data and issues of energy in EEDBR are enhanced to some degree, that's why EEDBR have extended lifetime than DBR. In MLCEE the approach of clustering is used which spares the energy. In this way, between these routing protocols, MLCEE has enhanced network lifetime.

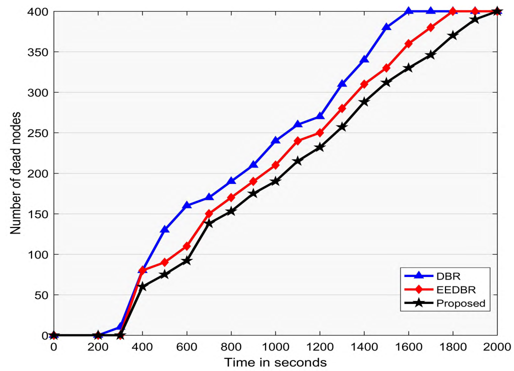

FIGURE 6. Network lifetime.

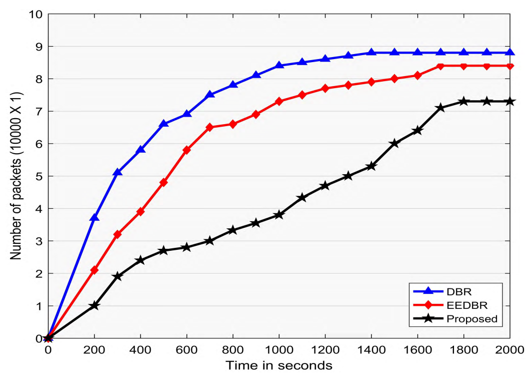

FIGURE 7. Throughput.

Throughput is characterized as the number of packets collected successfully at sinks which are deployed at the surface. Figure 7 exhibits the results of the throughput of DBR, EEDBR, and MLCEE routing protocols. The figure demonstrates that during 2000s MLCEE gets around 73,000 packets, EEDBR gets around 84,000, and DBR gets around 88,000. Because of the huge amount of redundant data DBR collected maximum data packets. EEDBR lessens the quantity of redundant data to some degree, so the EEDBR throughput is not as much of DBR. In MLCEE, due to the aggregation of data by the head nodes in clusters, the quantity of packets is

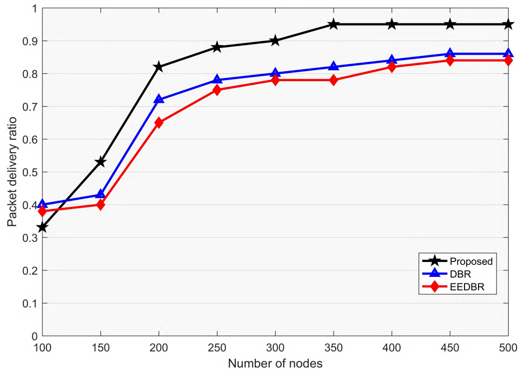

FIGURE 8. Packet delivery ratio (PDR).

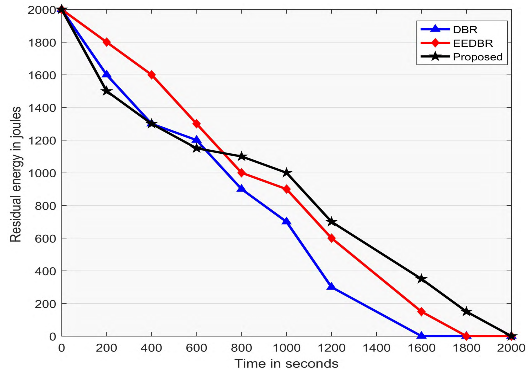

FIGURE 9. Consumption of energy.

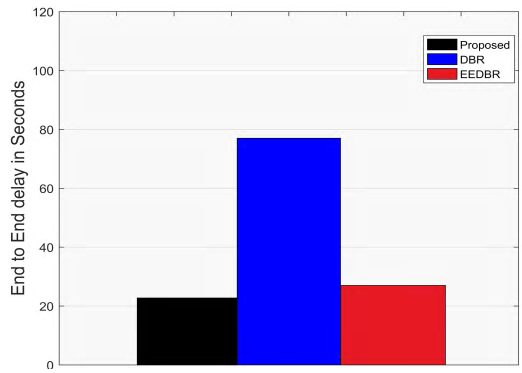

FIGURE 10. End-to-end delay.

decreased fundamentally. Henceforth the MLCEE throughput is not as much of EEDBR and DBR.

The delivery ratio is characterized as the proportion of the quantity of data effectively collected at the sink to the number of data transmitted from the source node. To assess delivery ratio performance in these three MLCEE, EEDBR and DBR routing protocols different simulations are executed. Figure.8 shows that PDR of MLCEE increases with the increase in node density. It is evident from the Figure.8 that PDR of MLCEE is 29% more than DBR and EEDBR routing schemes. However, in low node density DBR and EEDBR perform better than MLCEE. In sparse region, DBR shows 24% while EEDBR shows 21% better performance than MLCEE. The reasons are: in sparse region, fewer nodes contribute in cluster formation process due to high probability of void hole occurrence which in turn decreases successful delivery of data packets. While in high node density, high collision probability due to interference is avoided by selecting CHs having high residual energy and high probability for data forwarding, which results in improved PDR. However, due to high load on nodes which have low depth in DBR and EEDBR routing schemes increases packets drop due to which their PDR is less. Moreover, MLCEE performs better than EEDBR and DBR in terms of PDR as it selects CHs dynamically on basis of greater fitness value each time for data forwarding towards sink. Therefore, the results show that the PDR of MLCEE is higher than EEDBR, and DBR.

Consumption of energy indicates the performance of the network and certainly, it mirrors the network lifetime status. Less energy consumption reasons greater the network lifetime. Figure 9 exhibits the results of the energy consumption of DBR, EEDBR, and MLCEE routing protocols. Because of the redundant transmission of packets and overmuch sending nodes, DBR has the highest consumption of energy among these routing protocols. On the basis of residual energy and depth of the node, EEDBR chooses next forwarder which decreases the number of sending nodes. Additionally, in EEDBR, because of the priority procedure, considerably retransmissions of similar packets are diminished. Thus EEDBR has less consumption of energy than DBR. MLCEE utilizes the clustering approach to adjust the load of the entire system which leads to longer lifetime and balanced consumption of energy. MLCEE expends more energy for the formation of clusters during the starting stage of the network. Consequently, at the first 280 s, MLCEE has less residual energy than EEDBR. Though, after the starting stage, MLCEE has less consumption of energy than DBR and EEDBR.

End-to-end delay is characterized as the normal time taken by packets to reach from source to destination node. By means of different simulations, MLCEE, EEDBR and DBR routing protocols are compared. Figure 10 exhibits the results of end to end delay. From the comparison, we can see that DBR has the highest end to end delay due to a specific holding time which is required before sending. In EEDBR, during sending of data, the mechanism of priority is implemented. The next relay node which has the highest priority will immediately transfers the data. Hence, the delay is decreased. As in MLCEE the aggregation of data performed before sending of data, therefore, the propagation time is decreased by means of data packets reduction. Moreover, In the election of the next sending node link quality is also taken into account, therefore retransmissions are limited viably. consequently, among these three MLCEE, EEDBR, and DBR routing protocols, end to end delay of MLCEE protocol is minimum.

V. CONCLUSION

It is very difficult to substitute the batteries of submerged sensor nodes, hence, in UWSNs energy efficiency is the main research issue. To tackle this, in this article, we proposed a Multi-Layer Cluster based Energy Efficient routing protocol. This scheme intends to resolve the issues of high error rate, high consumption of energy, and end-to-end delay. There are different stages in MLCEE, first stage is the division of the whole network in layers, the second stage is cluster formation where sensor nodes are clustered at a same layer and the third phase is the forwarding of data towards sink. Further, to mitigate the issue of hotspot, the dynamic approach of clustering is suggested and also for the selection of CH, the probabilistic approach is introduced in which every node calculates its Bayesian Probability. In the phase of data forwarding, MLCEE exploits residual energy and Hopid as routing matrices. Simulation results demonstrate the adequacy of MLCEE which achieves superior results than DBR and EEDBR routing techniques in view of network lifetime, energy consumption and end to- end delay. In future work, we are looking forward to using AUV for data collection which can help further to reduce the end-to-end delay.

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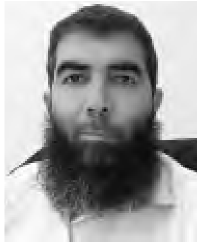

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