An Multi-level Clustering and Layer Based Guiding Network Routing Protocol for Underwater Wireless Sensor Networks

Soustab Haldar
Department of Computer Science and Engineering
Indian Institute of Technology (BHU) Varanasi
Varanasi, India
soustab.haldar.cse21@iitbhu.ac.in

Dr. Prasenjit Chanak
Assistant Professor
Department of Computer Science and Engineering
Indian Institute of Technology (BHU) Varanasi
Varanasi, India
prasenjit.cse@iitbhu.ac.in

Nuthan Chingeetham
Research Scholar
Department of Computer Science and Engineering
Indian Institute of Technology (BHU) Varanasi
Varanasi, India

Archana Ojha
Research Scholar
Department of Computer Science and Engineering
Indian Institute of Technology (BHU) Varanasi
Varanasi, India

***Abstract*—Researchers from all around the world have been interested in Underwater Acoustic Sensor Networks because of its wide range of applications. Because the network relies on acoustic sensor nodes that run on batteries, it is critical to create an energy-efficient routing strategy. One of the main causes of inefficient energy use is the uneven use of energy in various undersea regions, which results in hotspot problems. In this article, a Multi-level Clustering and Layer Based Guiding Network Routing Protocol (MCLBGNR) is proposed. In the underwater domain, segmentation into asymmetric layers according to Arithmetic Progression is a logical approach. The clustering solution suggested involves dividing the network into layers and sectors to enable efficient clustering. By considering residual energy and implementing node layer division, the hotspot issue can be alleviated, promoting balanced energy utilization throughout the network. Network void is avoided by an innovative layer-based routing path selection based on residual energy and distance, is presented in which the succeeding forwarder node is selected based on the layer division and in case of encountering void hole problem the forwarder node is selected by taking into account the hop count of the nodes established by the guiding network and further optimisation is done considering distance and the energy of the contestant heads.**

***Index Terms*—Multilevel Clustering, Underwater Acoustic Sensor Networks, Energy Efficient Routing, Sector Based Clustering and Routing, Void Avoidance.**

I. Introduction

The vast aquatic expanses, covering more than two-thirds of the planet, harbor valuable resources such as minerals, metals, gas, and oil, coveted by humanity [1].However, exploring these depths, often hundreds of meters below, poses significant risks and time constraints for human divers. Consequently, Underwater Acoustic Sensor Networks (UASN) are deployed to facilitate marine data collection and resource exploration. Acoustic waves emerge as the preferred communication medium for UASN, given their lower attenuation and broader reach compared to RF or optical waves. Submerged sensor nodes play a pivotal role in gathering diverse data, including temperature, acidity, pressure, chemical composition, conductivity, pH levels, dissolved methane gas, and aquatic pollution. [2]

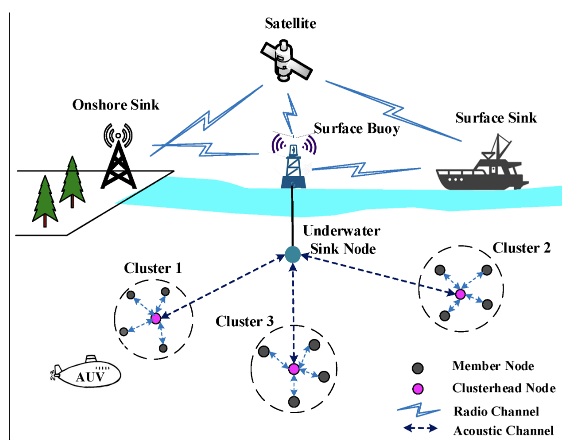

Fig. 1. Sample figure of an UWSN with cluster and Member nodes with Sinks.

A UASN is generally made up of three networking components: a Base Station (BS), a Surface Sink Node (SSN), and Ordinary Sensor Nodes (OSNs). OSNs are strategically placed across the water monitoring region to collect and transfer data to the SSN [3]. The SSN, placed atop the monitoring zone, sends this information to the ground station or BS for decision-making. Each OSN's internal architecture encompasses various hardware modules, such as an acoustic modem, sensors, interfacing circuitry, memory, onboard processing units, and batteries. As OSNs rely on battery power with finite energy [4], and battery replacement or recharging proves challenging in harsh aquatic environments, energy preservation emerges as a primary focus in designing algorithms for UASN Research. [5] .

The MCLBGNR Protocol described in this study is as follows:

- This research study presents a clustered routing system that uses arithmetic progression to partition the monitoring region into horizontal layers.
- Further, each layer is subdivided into sectors and clustering occurs within nodes of that particular sector leading to a distributed clustering scheme.
- To maximize network usability time and minimize energy consumption, a Guiding Network is established based on hop count. Packets are sent to sink via multi-hop transmission and the forwarding node is selected using layer division, distance and the energy of the nodes.
- In case a void is encountered, the guiding network is used to deliver the data packet via a different route as optimally as possible.

The rest of this paper is organized as follows. In Section II, Related Works are explored and in Section III, a Multi-level Clustering and Layer Based Guiding Network Routing Protocol (MCLBGNR) is designed, with the clustering and Guiding Network based Routing Phase. Section IV shows the simulation results and performance evaluations are presented. Section V concludes the paper.

II. Related Work

In this section, various modern routing protocols for Underwater Sensor Networks (UWSN) are critically analyzed, focusing on energy-efficient utilization. These protocols can be categorized into two groups: localization-based and localization-free.

The Localization-based Energy Efficient Routing Protocol includes a number of approaches. The Energy Efficient Layered Cluster Head Rotation suggests using an equal layered-based clustering strategy to decrease energy usage. Virtual layers are constructed between connected nodes, and packets are delivered by cluster heads in various hopping patterns. Similarly, the Multi-layer Cluster-based Energy Efficient protocol addresses uneven energy utilization on sensor nodes through multiple layering-based clustering techniques. Cluster heads are selected based on Bayesian probability and residual energy, with data packets transmitted via multi-hopping.An alternative method uses Ant Colony Optimization-based Routing in conjunction with K-Mean clustering to build clusters, with cluster heads selected according to distance from the sink and remaining energy. Using an event-driven strategy, Clustering-based Energy-efficient Routing (CBEER) [6] places many sink and sensor nodes in each tier and transmits data packets using a variety of hopping techniques. In an effort to minimize sensor node energy consumption, Clustered-Based Energy Efficient Routing [7] separates the sea depth into equal levels and chooses routing pathways based on the weight values of neighboring nodes. The Energy-balanced Unequal Layering comes last. By arranging clusters of varying sizes inside a layer and choosing routing pathways according to energy remaining and distance to the sink, clustering [8] reduces the energy consumption of inter-cluster communication.

Localization-free Energy Efficient Routing Protocol includes techniques such as the Dynamic Hierarchical Clustering Data Gathering Algorithm [9], which selects cluster heads based on node depth, residual energy, degree, link state, communication cost, and coverage factor. Energy Efficient Routing Protocol based on Layers and Unequal Clusters [10] proposes a layered architecture with smaller-sized clusters in deeper layers to prevent hot spot problems, with cluster head selection based on the waiting period and remaining energy. Using unequal-sized clusters with anchored nodes, a Hierarchical Routing Approach based on Q Learning Technique [11] uses Q-learning to find effective data routing pathways and increase UASN lifespan. Last but not least, the Intelligent Routing Protocol based on Deep Q-Networks selects routing pathways based on the Markov decision model (MDM), trained using DIQN to pick the forwarder node with the highest reward value. This approach seeks to balance energy consumption and extend network lifetime.

III. Multi-level Clustering and Layer Based Guiding Network Routing (MCLBGNR) Protocol

The proposed MCLBGNR Protocol comprises of several phases to establish the network structure and establishing sector-based clusters followed by Guiding Network Establishment Phase and then using the proposed routing mechanism to simulate the overall network. The phases are further discussed in detail as follows:

A. *Energy Model and Acoustic Propagation*

The utilization of the free space model and the multiple path fading channel model is essential in addressing the diverse information transmission distances between nodes and the Base Station (BS). This approach allows for the accommodation of the varying transmission distances that exist. The energy consumption model, which is outlined below, plays a crucial role in this context.

The energy expended by a transmitter to convey e bits of information is denoted as $E_t(e,d)$, whereas the energy utilized by the receiver to receive the same information is represented by $E_r(e,d)$. The distance separating the transmitter and the receiver is symbolized by d. The computation of these energy values is detailed in [15].

$$E_t(e,d) = \begin{cases} eE_{elec} \ + e\varepsilon_{fs}d^2, d < d_0 \\ eE_{elec} \ + e\varepsilon_{mp}d^4, d > d_0 \end{cases} \tag{1}$$

$$E_r(e,d) = e \times E_{elec} \tag{2}$$

Here, E_{elec} represents the energy utilization of the transmitter or receiving circuit per bits transmitted or received, and d_0

is the distance threshold. When $d < d_0$, the free space model is used to calculate $E_t(e, d)$, while the multiple path model is used otherwise. The value of d_0 is determined by:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{3}$$

The calculation of energy consumed by nodes when transmitting e bits of data to a Cluster Head (CH) can be determined using the following method:

$$E_{non-CH} = e \times E_{\varepsilon_{fs}} \times d_{toCH}^2 \tag{4}$$

Here, d_{toCH} represents the distance between the member node and the CH within a cluster. Assuming that the CH processes data transmission and receives e bits of information in each round, the energy consumption of the CH is calculated as:

$$E_{CH} = e \times \left((n - k + 1) \times E_{elec} + \frac{k}{n} \times E_{DA} \right) + E_r(e, d_{toBS}) \tag{5}$$

In the presented equation, the variable n is indicative of the quantity of active nodes, while the variable k is indicative of the quantity of segmented clusters. Moreover, the symbol E_{DA} is utilized to denote the energy expenditure of the Cluster Head during data processing, and d_{toBS} signifies the spatial separation between the Cluster Head and the Base Station.

B. Network Architecture and Layer and Sector Division Phase

The proposed Underwater Acoustic Sensor Network model exhibits a three-dimensional structure, illustrated in (figure). Comprising two distinct networking elements - the Surface Sink Node (SSN) and the Ordinary Sensor Nodes (OSN) - the network architecture is delineated. Positioned at the apex of the water surface, the SSN is equipped with two modems: an RF modem for communication with the onshore monitoring station, and an acoustic modem for communication with the OSNs submerged underwater. OSNs, dispersed randomly throughout the underwater networking region, serve the purpose of gathering environmental data and relaying it to the SSNs. These OSNs are assumed to be homogeneous ordinary sensor nodes, each equipped with a built-in acoustic modem facilitating communication with neighboring OSNs.

The SSNs are distributed in an pre-planned equispaced [20] manner on the surface of the network for maximum network efficiency and to reduce energy consumption of OSNs from any part of the network. The distribution of OSNs within each logical layer is maintained through a buoyancy control system, ensuring equitable and random deployment. Initial energy reserves of SSNs are considered unlimited and easily replaceable, whereas OSNs possess limited energy reserves that cannot be replenished [14].

The underwater monitoring region is partitioned into logical layers [16], where each layer corresponds to an increasing depth. The width of each layer expands according to an arithmetic progression, ensuring unequal layer widths. This progression is mathematically represented as follows in Equation (6):

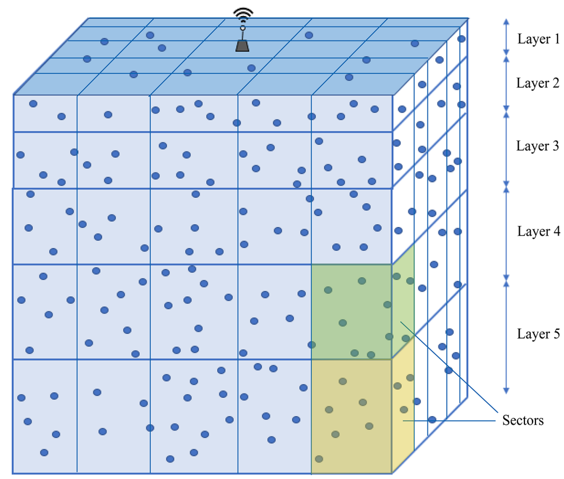

Fig. 2. Layer and Sector based Division of UWSN

$$\lambda_n = L_w + (n - 1) \cdot C, \tag{6}$$

where λ_n denotes the thickness of the n-th layer, L_w represents the thickness of the first layer, n signifies the layer number, and C stands for the layer incremental constant [3].

For instance, if the monitoring region has a depth of 1000 meters:

$$\begin{aligned}
\lambda_1 &= 100 + (1 - 1) \cdot 50 = 100\,\text{m}, \\
\lambda_2 &= 100 + (2 - 1) \cdot 50 = 150\,\text{m}, \\
\lambda_3 &= 100 + (3 - 1) \cdot 50 = 200\,\text{m}, \\
\lambda_4 &= 100 + (4 - 1) \cdot 50 = 250\,\text{m}, \\
\lambda_5 &= 100 + (5 - 1) \cdot 50 = 300\,\text{m}.
\end{aligned}$$

Hence, the depth limit of each layer exceeds that of the previous layer, i.e., $\lambda_1 < \lambda_2 < \lambda_3 < \lambda_4 < \lambda_5 = 100 < 250 < 450 < 700 < 1000\,\text{m}$. As OSNs closer to the SSN typically engage in more forwarding tasks compared to those deeper in the underwater network, a networking structure with equal layer widths may lead to energy utilization imbalances. Therefore, the proposed network structure aims to achieve energy utilization balance among OSNs.

Each layer is further subdivided into equal sectors, where the dimensions of each sector follow equations (7) and (8):

$$S_{width} = L_{width} / \sqrt{C_{layer}}, \tag{7}$$

$$S_{length} = L_{length} / \sqrt{C_{layer}}, \tag{8}$$

where L_{width} and $L_{;length}$ are the layer length and layer width respectively, and C_{layer} is the number of clusters per layer given by

$$C_{Layer} = C_{Total} / |L| \tag{9}$$

where C_{total} is the total number of clusters in the network and $|L|$ is the total number of layers the network is divided into.

C. Sector-Based Clustering Phase

The phase of clustering consists of two sub-phases, namely the phase of cluster formation and the process of selecting cluster heads (CHs) also known as Cluster Heads. The explanations of both sub-phases are detailed as follows.

The cluster formation phase starts with taking the layer division and sector division into account and the nodes located within each sector of a particular layer is considered to be a Cluster. Thus the Sector division serves as a way of evenly distributing the clusters in the network.

Typically, OSNs located in deeper water levels tend to undertake fewer forwarding tasks compared to those near the SSN, leading to an imbalance in energy utilization among OSNs. Therefore, achieving energy consumption balance throughout the monitoring area is crucial for extending the network's lifetime. The residual energy ζ_{Res} of any OSN can be calculated using Eq. 10.

$$E_{Res} = E_{Init} - E_{Con} \tag{10}$$

Here, E_{Init} represents the initial energy of the OSN, and E_{Con} denotes the consumed energy of the OSN, calculated as:

$$E_{Con} = E_{\text{Trans}} + E_{\text{Rec}} + E_{\text{Agg}} \tag{11}$$

E_{tx}, E_{rx}, and E_{da} represent the energy spent on transmission, reception, and data aggregation respectively as in Equations (1)and (2) .

The size of clusters C_{Size} is taken to be a cuboid cluster formed by the nodes in the layer and the cluster division.The process of selecting Cluster Heads (CHs) is subsequently carried out. CHs bear the responsibility of collecting data from cluster members (C_Members) as well as other CHs or the Sink Sensor Node (SSN). Each Online Social Network (OSN) has the potential to serve as a CH, and within each cluster, OSNs evaluate their expenses in order to assume this role.

The assessment of the Cluster Head's (CH) fitness value is conducted autonomously at individual nodes, taking into account factors such as distance, remaining energy, and hierarchy. A Cluster Head exhibiting the shortest distance and the greatest residual energy is associated with a heightened level of fitness. Assuming v represents the node within the ith cluster, the fitness value of CH_i in relation to v is calculated as:

$$F(v, \text{CH}_i) = \alpha \times (1.0 - \frac{D_{CH,i}}{max(D_{CH,i})}) + (1.0 - \alpha) \times \frac{E_{Res}}{E_{I}nit} \tag{12}$$

where α is a fitness-function parameter and $0 \leq \alpha \leq 1$. The OSN with the maximum fitness value function is chosen to be the Cluster Head. CHs are re-elected if the energy of a CH falls below a threshold limit in order to preserve node's energy by the same Equation (12). The fitness-based CH selection method results in an even energy distribution of nodes among the clusters in extended rounds of simulation.

D. Guiding Network Establishment Phase

The Guiding Network Establishment Phase is set up by the CHs starting from the sink assigning itself a hop count(HC) [17]. The hop count off the sink is equal to zero, the CHs which are in the transmission range of the sink in Layer 1 are assigned a hop count equal to one, and this establishment phase continues from each cluster head passing it's hop count plus one to all other cluster head within its transmission range. If a cluster head receives the guiding network establishment signal from two or more surrounding cluster heads the hop count assigned to that cluster head is equal to the minimum of all the received hop counts.

Algorithm 1: Guiding Network Establishment Phase

Input : Initialize sink with hop count $HC_{\text{sink}} = 0$
Output: Hop Counts assigned to all Cluster Heads (CHs)

foreach *CH traversed Layer-Wise* **do**
  Assign hop count $HC_{\text{CH}} = \min(HC_{\text{received}}) + 1$ to CHs;
  Broadcast guiding network establishment signal with hop count = HC_{CH} ;

while *Hop Counts for all CHs are not assigned* **do**
  Receive guiding network establishment signal from neighboring CHs;
  Update hop count as minimum of received hop counts + 1: $HC_{\text{CH}} = \min(HC_{\text{received}}) + 1$;
  Broadcast updated hop count to neighboring CHs;

The Guiding Network thus established can then be used when a void is encountered to pass the data packet to a surrounding node with the Hop Counts establishing the most optimal alternative delivery route. The complete routing mechanism is discussed in next subsection.

E. Routing Phase

The Cluster Member (C_Member) is tasked with the responsibility of detecting and producing data packets destined for its respective Cluster Head (CH). The CH then follows the MCLBGNR Protocol to transmit the data through a multi-hop technique to pass the packet to the layers above the current layer and subsequently sending it to a Surface Sink Node(SSN).

The Routing Protocol states that from a CH located in $Layer_{\text{i}}$, a pool of CHs are selected who are within the transmission range of the CH and belong to $Layer_{\text{i}} - 1$. If no such nodes are found then it fetches all CHs which have depth less than the transmitting CH and within its transmission range. For each such receiver, its Evaluation Value is calculated by the following Evaluation Function(EF),

$$\text{EF} = \alpha \times \frac{E_{Con}}{E_{Init}} + \beta \times \frac{D_{CH_i,CH_i+1}}{max(D_{CH_i,CH_i+1})} \tag{13}$$

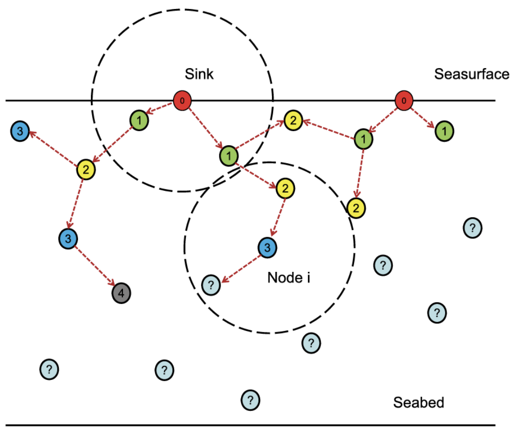

Fig. 3. Guiding Network in Multi-Sink Networks

Here α and β are weighted values where $\alpha + \beta = 1$, and D_{CH_i,CH_i+1} is the distance between the transmitting CH and each of the receivers and $|z|$ is the depth of the network region.

The routing receiver from the pool of receivers is selected based on the residual energy ($_{Res}$) and the distance between them. The forwarding CH selects its successor CH based on the highest residual energy (minimum consumed energy) and minimum distance. Higher RSS values indicate closer proximity between CHs, while lower values indicate greater distance. Choosing a CH with higher residual energy prolongs network lifetime, while selecting one with lower distance enhances signal quality, reducing the likelihood of transmission errors and packet loss. Together, these factors improve routing path selection. CH of Layer 1 - Layer closest to the sink, transmits directly to the nearest sink. This EF is recursively called until a void is encountered in the network or the sink is reached.

In case no valid receiver is found, a void is encountered whereby no nodes are present in its transmission range at a lower depth than the transmitting node. In such a case, we use the guiding network established along with the hop count to transmit the packet to a suitable node. A set of CHs which are possible receivers are taken who have Hop Count(HC) equal to or lesser than HC of the current CH. A modified Evaluation Function(mEF) 14is used to get the most optimal node to act as the receiver for this function.

$$\text{mEF} = \gamma \times \frac{E_{Con}}{E_{Init}} + \delta \times \frac{D_{CH_i,CH_{(i+1)}}}{max(D_{CH_i,CH_{((i+1)}})} + \epsilon \times \frac{|(depth_{CH_i} - depth_{CH_{(i+1)}})|}{tx_range} \quad (14)$$

Here γ , δ and ϵ are weighted values where $\gamma+\delta+\epsilon = 1$, and D_{CH_i,CH_i+1} is the distance between the transmitting CH and each of the receivers and $depth_{CH_i}$ is the depth of the CH_i. This mEF ensures that the most optimal relay node in case of a void is selected on the basis of depth difference, residual energy and distance between the relay nodes. The receiving CH then transmits according to the previous protocol and if the nodes are still in a void region this process is repeated.

In case of an extreme void region, where the only nodes the CH can transmit to is one with a higher HC than the node itself, then the initial pool consists of CHs which have HC greater than HC of the current CH.

All possible scenarios are listed as follows:

1) **Scenario (a):** The CH forwarder (A) is located within layer n and identifies several CHs in layers n and $n-1$ that are qualified to send data packets. The CH forwarder (A) has a preference for selecting a CH from layer $n-1$ according to the formulation provided in Equation [13].
2) **Scenario (b):** The forwarder CH (A) is located within layer n and identifies a single CH in layer $n-1$ that is suitable for transmitting data packets. Consequently, the forwarder CH (A) opts for the sole CH available in layer $n-1$.
3) **Scenario (c):** Similarly to scenario (a), the forwarder CH (A) is situated in layer n and identifies several CHs in layer n that are deemed eligible (in the absence of any eligible CH from layer $(n-1)$. The optimal recipient CH is selected utilizing Equation [13].
4) **Scenario (d):** This scenario demonstrates the occurrence of a void. The forwarder CH (A) is situated in layer n and detects several CHs in layer n with shallower depth. Under these circumstances, the forwarder CH selects the subsequent CH utilizing Equation [14].

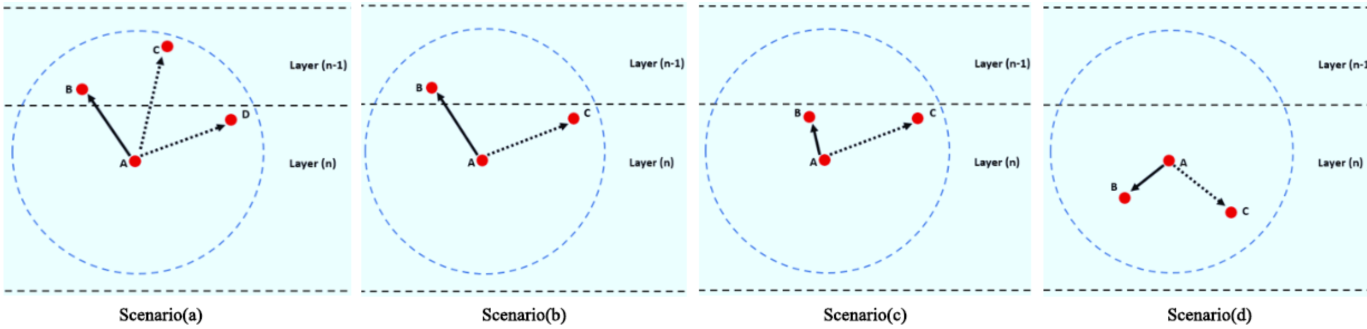

Fig. 4. Possible Locations of CHs

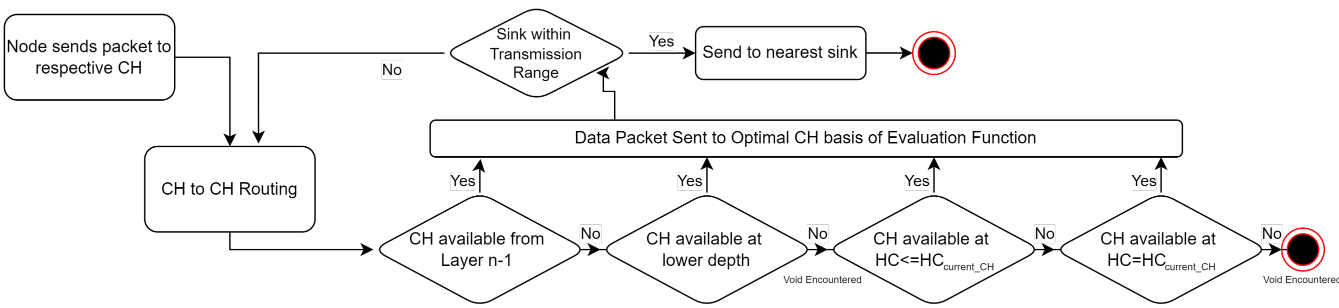

Fig. 5. Flowchart of Routing Phase

IV. Performance Evaluation

In this section, simulation results are provided to demonstrate the performance of our proposed model and Python is used to simulate a distributed underwater sensor network of N sensor nodes randomly deployed. Assuming the network model is as follows: random distribution of sensor nodes with equal performance and limited energy in the given area, and that the geographic location of each sensor node is available. SSNs are assumed to have a large amount of energy which is comparatively very large to the OSNs.

A. Simulation Parameters

For simulation N = 500 nodes are randomly deployed in a 500 m × 500 m × 500m 3D Cubical Network. The parameters used for the equations used are as follows:

TABLE I
Simulation Parameters

Parameter	Value
n	500
x_{range}, y_{range}, z_{range}	(0, 500), (0, 500), (-500, 0)
Sink coordinates (Uni-Sink Networks)	250, 250, 0
Sink energy (sink˙E)	10,000 J
Transmission range (tx_range)	100 m
Frequency (freq)	10,000 Hz
Data rate (data_rate)	35,000 bytes/s
f_{kHz}	10
Data packet size	200 bytes
Hello packet size	4 bytes
Number of layers	5
Layer heights(in m)	80, 90, 100, 110, 120
ff_alpha	0.5

B. Simulation Results

The various protocols are evaluated based on factors such as the Number of Alive Nodes, the Residual Energy of the Network, and the Average End to End Delay within the network. The energy levels of the nodes will gradually diminish over time while the UWSNs are operational, ultimately resulting in node depletion and subsequent reduction in network coverage.

Figures 7 and 8 shows the variation of the network longevity with various layer divisions. The results show that for a network depth of 500 metres, the layer division of 80m, 90m, 100m, 110m, 120m gives us the optimal results with the number of dead nodes being 309 out of total 500 nodes over a 750 round simulation, which is **11.32% decrease in the number of dead nodes** and **2.1 % increase of residual energy** of the network. The nodes have an initial energy of 2J, and the simulation has 9 SSNs and 20 Cluster Heads in the network. However, a more extreme unequal layer division such as with layer divisions of 50m, 75m , 100m, 125m ,150m and 20m, 60m, 100m, 140m, 180m show that such extreme cases leads to uneven node distribution in the network which leads to increased energy usage in the course of the simulation.

In this part our proposed MCLBGNR Protocol is compared with four existing protocols EEGNBR [17], EECRAP [3], DVOR [18] and DBR [19] against three parameters - number of dead nodes after each round, total residual energy of the network and average end to end delay (per round). For each

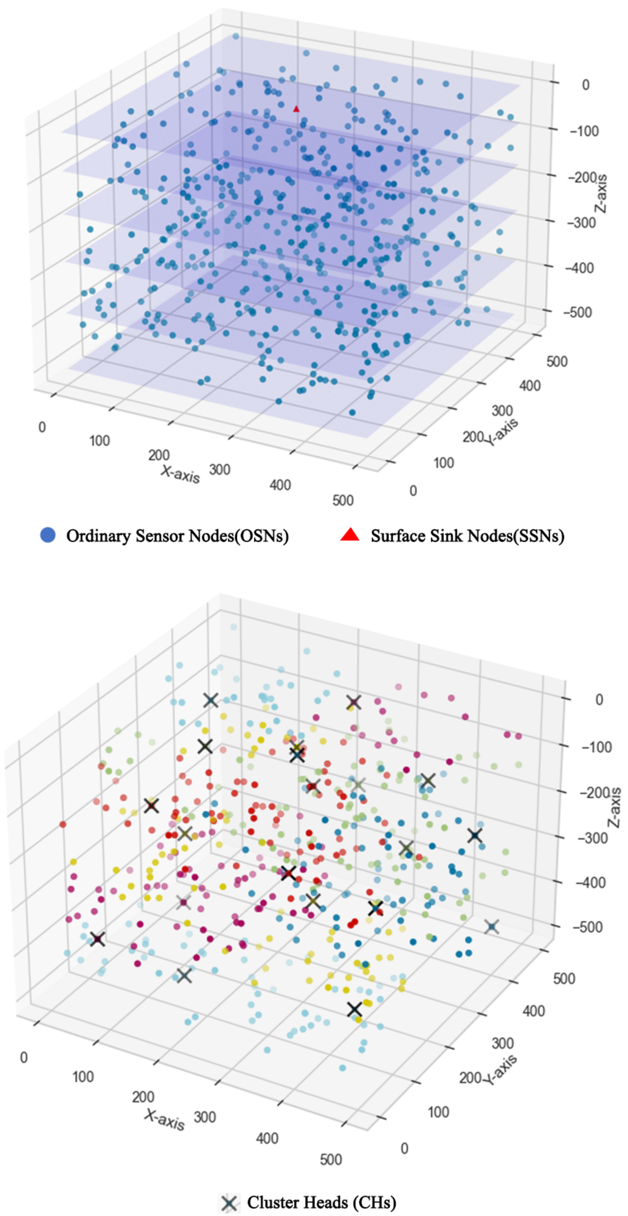

Fig. 6. UASN Network Structure with Layer Division and CHs

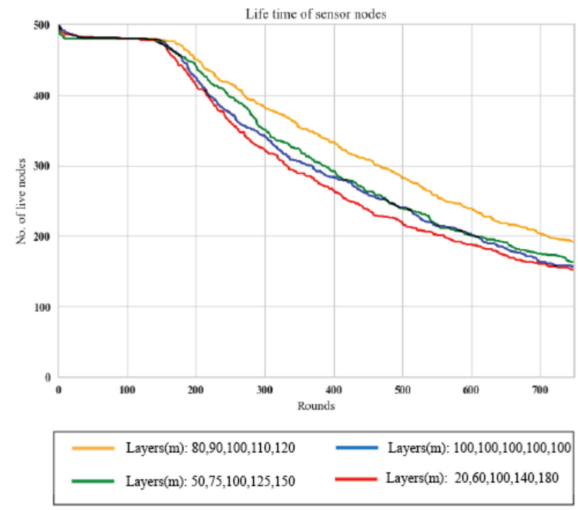

Fig. 7. Number of Alive Sensor Nodes v/s Rounds for different Layer Divisions

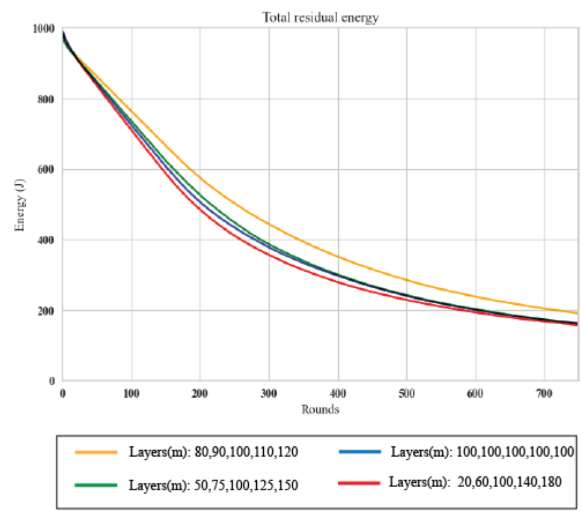

Fig. 8. Residual Energy in J of Sensor Nodes v/s Rounds for different Layer Divisions

of the protocols, the number of sinks is set to 9, and the initial energy of each node is set to 15J for a fair comparison. Figures 9 , 10, 11 after 750 rounds of simulation with 500 OSNs, figures 9 and 10 shows the variation of the network longevity with these different protocols. MCLBGNR has the least number of dead nodes at 42, followed by EECRAP with 132 dead nodes and EEGNBR with 143 dead nodes, DVOR and DBR have 216 and 311 dead nodes respectively. Thus our proposed MCLBGNR Protocol has **68.18% fewer number of dead nodes** when compared to EECRAP which gives the best result out of the comparing protocols. The residual energy of the network after 750 rounds (rounded to 3 decimal places), for **MCLBGNR is 6174.695J, for EECRAP is 3726.322J, and for EEGNBR, DVOR and DBR is 4171.564J, 3687.167J and 1686.690J** respectively. The sector based cluster division, along with the layer based data routing leads to efficient energy consumption among all the nodes. When comparing average End-to-End (E2E) Delay, when the network reaches a stable transmission phase (¿= 500 rounds) the proposed MCLBGNR protocol is outperformed by only DBR Protocol where DBR has an E2E delay of 4.95% lesser than MCLBGNR. But compared to EECRAP and EEGNBR, MCLBGNR has a 11.57% and 1.34% lesser E2E Delay. The data packet processing time is set to 0.1s for

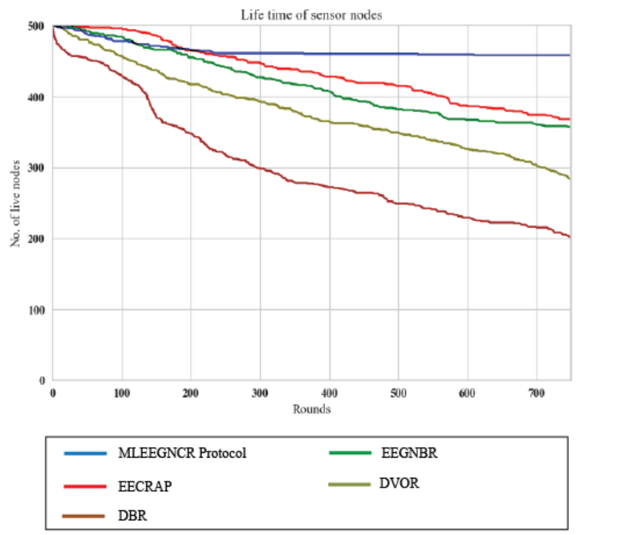

Fig. 9. Number of Alive Sensor Nodes v/s Rounds for different protocols

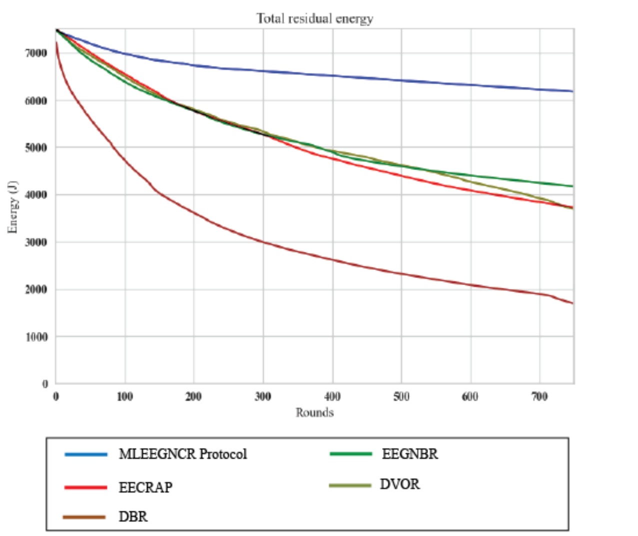

Fig. 10. Residual Energy in J of Sensor Nodes v/s Rounds for different protocols

each of the protocols.

In order to compare our proposed MCLBGNR Protocol for different network sizes with varying number of nodes with four existing protocols EEGNBR, EECRAP, DVOR and DBR against three parameters - number of dead nodes after each round, total residual energy of the network and average end to end delay (per round). The protocols are compared for networks having 250,500,750 and 1000 nodes. MCLBGNR shows an increase from 42 to 45 dead nodes in a network size from 250 to 1000 nodes, whereas for EECRAP the number of dead nodes increases from 85 to 272, for EEGNBR it increases from 62 to 231, for DVOR it increases from 65 to 374 and for DBR it increases from 146 to 452 nodes.

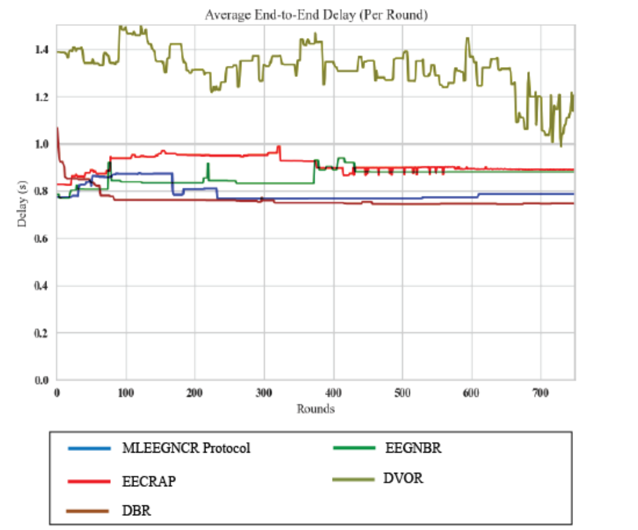

Fig. 11. Residual Energy in J of Sensor Nodes v/s Rounds for different protocols

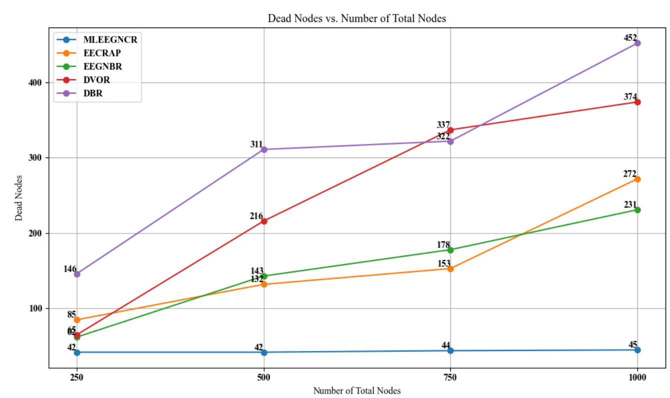

Fig. 12. Residual Energy in J of Sensor Nodes v/s Rounds for different protocols

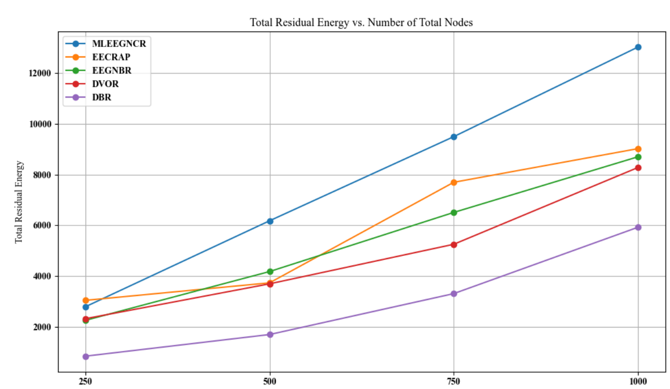

Fig. 13. Residual Energy in J of Sensor Nodes v/s Rounds for different protocols

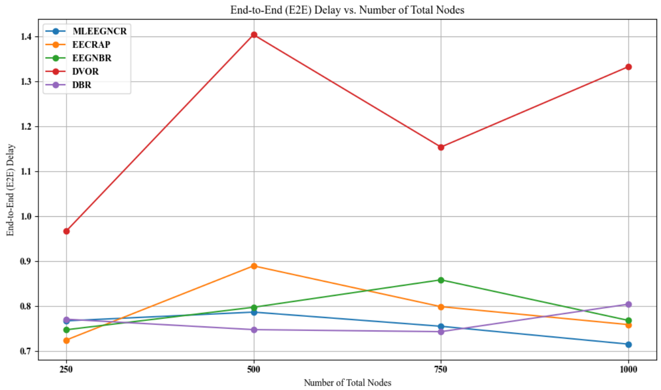

Fig. 14. E2E Delay (per round) v/s Rounds for different protocols

A similar trend follows for residual energy of the network where MCLBGNR consistently outperforms other protocols, The proposed protocol performs best for networks having a large number of nodes, here when tested for 1000 nodes in a 500m by 500m by 500m simulation area, MCLBGNR had 44.24% more residual energy when compared to EECRAP, thereby providing a significant increase in overall network longevity. In terms of E2E delay, MCLBGNR performs the best out of all protocols for a large network size of 1000 nodes. MCLBGNR outperforms EECRAP by 5.72% and DBR by 11.04% .Whereas for other networks of variable sizes the results vary as different routing mechanisms are chosen by different protocol.

V. Conclusion

The present study introduces MCLBGNR as a solution to the issue of energy consumption in Underwater Acoustic Sensor Networks (UASNs). MCLBGNR, a clustering and routing protocol with a multi-layer and sector-based approach, aims to overcome the constraints imposed by the non-rechargeable characteristic of OSNs in UWSNs. The primary strength of MCLBGNR is its capacity to equilibrate energy usage by utilizing asymmetric layers and achieving balanced energy consumption through sector-based clustering, where cluster heads are strategically chosen based on the remaining energy and depth metrics of the OSNs. Furthermore, it deals with scenarios involving void regions by employing an Evaluation Function that considers depth variance, energy levels, and inter-node distances to identify the most suitable node for data packet transmission. Comparative analysis with other protocols like EECRAP, EEGNBR, DVOR, and DBR demonstrates the superior performance of the proposed MCLBGNR in terms of reduced dead nodes and enhanced residual energy within the network, while maintaining comparable levels of Average E2E Delay as the aforementioned protocols.

References

[1] M. Cicioglu and A. Calhan, "Performance Analysis of Cross-Layer Design for Internet of Underwater Things," IEEE Sens. J., vol. 22, no. 15, pp. 15429–15434, 2022, doi: 10.1109/JSEN.2022.3187372.

[2] U. Draz et al., "Energy Efficient Proactive Routing Scheme for Enabling Reliable Communication in Underwater Internet of Things," IEEE Trans. Netw. Sci. Eng., vol. 8, no. 4, pp. 2934–2945, 2021, doi: 10.1109/TNSE.2021.3109421.

[3] Khan, M.U., Otero, P. and Aamir, M., 2024. An Energy Efficient Clustering Routing Protocol based on Arithmetic Progression for Underwater Acoustic Sensor Networks. IEEE Sensors Journal.

[4] M. Y. I. Zia, J. Poncela, and P. Otero, State-of-the-Art Underwater Acoustic Communication Modems: Classifications, Analyses and Design Challenges, vol. 116, no. 2. Springer US, 2021.

[5] H. U. Yildiz, "Joint Effects of Void Region Size and Sink Architecture on Underwater WSNs Lifetime," IEEE Sens. J., vol. 23, 10,pp. 10.1109/JSEN.2023.3264159.

[6] Y. Yuan, M. Liu, X. Zhuo, Y. Wei, X. Tu, and F. Qu, "A Q Learning-Based Hierarchical Routing Protocol with Unequal Clustering for Underwater Acoustic Sensor Networks," IEEE Sens. J., vol. 23, no. 6, pp. 6312–6325, 2023, doi: 10.1109/JSEN.2022.3232614.

[7] L. Chen, Y. Hu, Y. Sun, H. Liu, B. Lv, and J. Chen, "An Underwater Layered Protocol Based on Cooperative Communication for Underwater Sensor Network," Proc. 32nd Chinese Control Decis. Conf. CCDC 2020, pp. 2014–2019, 2020, doi: 10.1109/CCDC49329.2020.9164029.

[8] R. Hou, L. He, S. Hu, and J. Luo, "Energy-Balanced Unequal Layering Clustering in Underwater Acoustic Sensor Networks," IEEE Access, vol. 6, pp. 39685–39691, 2018, doi: 10.1109/ACCESS.2018.2854276.

[9] H. Khan, S. A. Hassan, and H. Jung, "On Underwater Wireless Sensor Networks Routing Protocols: A Review," IEEE Sens. J., vol. 20, no. 18, pp. 10371–10386, 2020, doi: 10.1109/JSEN.2020.2994199.

[10] F. Zhu and J. Wei, "An energy efficient routing protocol based on layers and unequal clusters in underwater wireless sensor networks," J. Sensors, vol. 2018, 2018, doi: 10.1155/2018/5835730.

[11] G. Tuna, "Clustering-based energy-efficient routing approach for underwater wireless sensor networks," Int. J. Sens. Networks, vol. 27, no. 1, pp. 26–36, 2018, doi: 10.1504/IJSNET.2018.092114.

[12] A. A. A. El-Banna, K. Wu, and B. M. Elhalawany, "Opportunistic Cooperative Transmission for Underwater Communication Based on the Water's Key Physical Variables," IEEE Sens. J., vol. 20, no. 5, pp. 2792–2802, 2020, doi: 10.1109/JSEN.2019.2953277.

[13] E. M. Sozer, M. Stojanovic, and J. G. Proakis, "Underwater acoustic networks," IEEE J. Ocean. Eng., vol. 25, no. 1, pp. 72–83, 2000, doi: 10.1109/48.820738.

[14] W. Khan, H. Wang, M. S. Anwar, M. Ayaz, S. Ahmad, and I. Ullah, "A Multi-Layer Cluster Based Energy Efficient Routing Scheme for UWSNs," IEEE Access, vol. 7, pp. 77398–77410, 2019, doi: 10.1109/ACCESS.2019.2922060.

[15] Zhao, Z., Shi, D., Hui, G. and Zhang, X., 2019. An energy-optimization clustering routing protocol based on dynamic hierarchical clustering in 3D WSNs. IEEE Access, 7, pp.80159-80173.

[16] Chinnasamy, S., Naveen, J., Alphonse, P.J.A., Dhasarathan, C. and Sambasivam, G., 2022. Energy-aware multilevel clustering scheme for underwater wireless sensor networks. IEEE Access, 10, pp.55868-55875.

[17] Liu, Z., Jin, X., Yang, Y., Ma, K. and Guan, X., 2022. Energy-efficient guiding-network-based routing for underwater wireless sensor networks. IEEE Internet of Things Journal, 9(21), pp.21702-21711.

[18] Guan, Q., Ji, F., Liu, Y., Yu, H. and Chen, W., 2019. Distance-vector-based opportunistic routing for underwater acoustic sensor networks. IEEE Internet of Things Journal, 6(2), pp.3831-3839.

[19] Yan, H., Shi, Z.J. and Cui, J.H., 2008. DBR: Depth-based routing for underwater sensor networks. In NETWORKING 2008 Ad Hoc and Sensor Networks, Wireless Networks, Next Generation Internet: 7th International IFIP-TC6 Networking Conference Singapore, May 5-9, 2008 Proceedings 7 (pp. 72-86). Springer Berlin Heidelberg.

[20] Mhemed, R., Comeau, F., Phillips, W. and Aslam, N., 2021. Void avoidance opportunistic routing protocol for underwater wireless sensor networks. Sensors, 21(6), p.1942.