ABSTRACT The expansion of wireless sensor networks in the underwater environment resulted in underwater wireless sensor networks. It has dramatically impacted the research arena because of its widespread and real-time applications. But successful implementation of underwater wireless sensor networks faces many issues. The primary concern in the underwater sensor network is sensor nodes' energy depletion problem. In this paper, to improve the lifetime of the underwater wireless sensor network, an Energy-Aware Multi-level Clustering Scheme is proposed. The underwater network region is considered 3D concentric cylinders with multiple levels. Further, each level is divided into various blocks, representing one cluster. The proposed algorithm follows vertical communication mode from the sea bed to the surface area in a bottom-up fashion. Multiple levels with varying heights overcome the communication issues due to high water pressure towards the sea bed. Simulations are carried out to show the efficiency of the proposed algorithm, which performs better in terms of a prolonged network lifetime and average residual energy. The simulation result shows significant improvement in the network lifetime compared with current algorithms.

INDEX TERMS Energy-Aware Clustering, Underwater Wireless Sensor Networks, UWSN, Clustering Algorithm

I. INTRODUCTION

Underwater Wireless Sensor Network (UWSN) is the emerging technology used to sense and detect changes in the aqueous environment. UWSNs are used in many real-time applications in different fields. They are useful in collecting oceanographic data, environmental monitoring, disaster prevention, aquatic animal's habitat monitoring etc. [1],[2],[3],[4] UWSNs are different from Terrestrial Wireless Sensor Networks (TWSN) in many aspects. The mode of communication in TWSN is through radio transmission. Since radio communication is not feasible for UWSN, it relies on acoustic communication. The sensor nodes in UWSN are prone to the harsh environment of water, the salinity of water, turbulence, attenuation of signals, noise etc. Apart from the problems stated above, the primary concern in UWSN is the lifetime of the network. All the sensor nodes are battery powered and are deployed in an unattended manner. Replacing the battery or charging the battery is not possible. The energy consumption should be optimised [5],[6] to prolong the network lifetime. Much research focuses on this area of energy efficiency.

Energy consumption is mainly due to the transmission of data between nodes. In literature, many techniques are proposed to deal with energy conservation: radio optimisation, data reduction, sleep/wakeup schemes, energy efficiency routing, and battery depletion methods. Since radio transmission consumes more energy, energy-efficient routing helps more in prolonging the network's lifetime. The different approaches proposed in energy efficiency routing are clustering architectures, using energy as a routing metric, multi-path routing, relay node placement strategies, and sink mobility mechanisms. [3],[6] The proposed scheme in this paper is an energy-efficient clustering architecture that considers the network region a three-dimensional concentric cylinder. The paper's main objective is to achieve energy efficiency, thereby prolonging the lifetime of underwater wireless sensor networks.

The remaining section of the paper is organised as follows: Section 2 gives a survey of the existing literature. Section 3 describes the energy model, network model and clustering mechanism. Section 4 discusses the simulation setup and results.
Section 5 concludes the paper and talks about the future scope.

II. LITERATURE SURVEY

There are so many challenges that need to be addressed in UWSN compared with TWSN. The main challenges can be classified broadly as underwater noise, channel attenuation, limitation on the bandwidth, the speed of acoustic waves, shorter network lifetimes etc. Research is progressing in different dimensions to address all the above issues. [3][7][8][9][10][11].

The limited battery power of the nodes is the key challenge that affects the UWSN lifetime badly. It needs immediate attention, so most research progresses in this area. Routing protocols for UWSN have been considered the essential factor in the energy management of sensor nodes since data transmission consumes more power. Routing protocols for UWSN can be broadly classified into two types: localisation based and localisation free protocols. Further, it can be classified based on the parameter used for routing purposes. This paper deals with energy efficiency for UWSN and the related work of this paper is limited to the energy efficiency protocols available for UWSN.

The balanced energy adaptive routing protocol (BEAR)[12] proposed by SAMAN et al. in 2016 considers the underwater region as a hemisphere. Further, this region is divided into sectors. The nodes are considered stationary and randomly distributed among hemispheres. All the nodes are aware of its location, the distance from the sink, and its sector information. BEAR has three phases: the neighbour finding phase, the searching energy-efficient path, and the transmission phase. Even though BEAR balances energy consumption effectively, it is suffered by high interference nearer to the sink.

Jiming et al. proposed reliable and energy balanced routing REBAR for UWSN.[13] It considers the sphere energy depletion model. The space is considered as n adjacent spheres. Further, each sphere is divided into n layers with the same thickness. Each node is deployed in such a way that it has a constraint radius with the sink. The source node obtains the routing direction information with the help of directional vector v from source to sink. It also proposes an enhanced REBAR. It achieves energy efficiency because the restricted cylindrical path for routing the number of packets received at the sink is compromised.

Renfei et al. [14] proposed an improvised fuzzy logic vector algorithm based on forwarding routing protocol FVBF for UWSN. It considers a random topology with n number of nodes deployed in a 3D area. The position of each sender is known. It has a central sink, and a random walk 2D model is considered for nodes movement. It also considers thrp's transmission model for communication. It uses projection, i.e. the shortest path to reach the sink is taken as an energy optimisation parameter. It also considers the residual energy and fuzzifier, which describes the fuzzy logic inference system. Even though the protocol achieves energy efficiency, nodes in the selected cylindrical vectors die rapidly.

Ahmed Raza Hameed et al. proposed Balanced Energy-Efficient Circular BEEC [15] routing protocol for UWSN. BEEC mainly focuses on energy efficiency. The network field is considered as ten circular regions—each circle formed with eight sectors. Two mobile sinks are placed in such a way that each mobile sink caters to five circular regions. Initially, all the nodes are provided with the same amount of energy. Transmission between nodes is achieved through acoustic communication. Sinks are equipped with acoustic as well as radio modems. Mobile sinks traverse in the assigned regions and collect the nodes' data. Nodes have to send a ‘hello’ message when a mobile sink comes to its vicinity. The sinks move in a fixed pattern, but the nodes' locations are not prioritised. The nodes' movement is independent of the network condition. This protocol is suitable for dense conditions where nodes are close.

Kun Wang et al. proposed a reliable data transmission scheme for monitoring complex environments (EGRCs) [16] in UWSN. It considers the network as 3D cubes. Further, each one is divided into small cubes (SCs). The base station is equipped with an uninterrupted power source, and its location is identified using positioning algorithms. It is equipped with both acoustic and radio modem. The geographical area is classified as top and bottom surfaces. The water's surfaces are referred to as the top surface, and seabed is the bottom. The base station is located on the surface monitoring area. Each small cube will select the cluster head node, and all other nodes will send the information to its cluster head. The cluster is selected based on the residual energy as a vital parameter. The energy consumption model used in Low Energy Adaptive Clustering Hierarchy LEACH is assumed here. K-neighbourhood Sleep Scheduling algorithm is used to switch nodes from sleep-wake up mode. The protocol achieves less end-to-end delay and reduced energy consumption, but the early energy depletion of the cluster head degrades the system performance.

Tavakoli, Javid et al.[19] proposed A fuzzy-based Energy Efficient Clustering Routing protocol in UWSN, considering sensor energy limitation and link quality status. It follows three steps Fuzzy logic phases. Step one determine the cluster, step two discovers the possible routes and step three selects the most delicate route among the possible routes in step two. The protocol claimed better performance and packet delivery ratio among compared algorithms.

Subramani, Neelakandan et al.[20] proposed an optimisation based MCR routing approach for UWSN, consisting of two stages. Clusters formed in stage one, and optimisation techniques were used to find multi-paths between cluster heads to sink in stage two.

Wadud, Zahid, et al. [21] proposed an Energy Balanced Efficient and Reliable Routing (EBER) protocol for
UWSNs. It considers the residual energy of nodes for energy balancing and the number of Potential Forwarding Nodes (PFNs) among forwarder nodes to achieve data reliability. It also divides the transmission range into power levels based on the distance between forwarder nodes. Moreover, the data redundancy is reduced by considering the node’s depth, residual energy and PFNs among the neighbours. Multiple sinks are deployed over high traffic density areas to reduce network latency.

In 2021, Xiao et al. proposed a data fusion and genetic algorithms based energy-efficient clustering routing protocol (EECRP) for WUSN [22], which reduces energy consumption with the help of improved data fusion methods and eliminates the data redundancy and the number of data transmission. EECRP achieves a better life when compared with other classical routing algorithms.

III. ACOUSTIC PROPAGATION AND ENERGY MODEL

The underwater environment is affected by various parameters, and these factors have to be considered while sensing the aqueous environment. The significant factors that influence underwater communication are attenuation (path loss) and noise in the ocean due to various components.

In the year 2000, Milica Stojanovic [17][18] proposed methodologies to calculate the path loss, absorption coefficient a(f).

Attenuation depends on the distance of the channel and frequency. If a signal of frequency f travels over a distance of acoustic channel l attenuation is given by

\[ A(l, f) = l^k \cdot a(f) \cdot l \quad (1) \]

where k represents the spreading factor, and a(f) represents the absorption coefficient. Equation (2) is used to calculate the acoustic path loss. It is usually expressed in dB.

\[ 10 \log A(l, f) = k \cdot 10 \log l + l \cdot 10 \log a(f) \quad (2) \]

In the equation, there are two terms in the summation. The former represents the spreading loss, and the latter represents the absorption loss. The spreading factor k denotes the geometric propagation. The commonly used values for k are as follows:

K=2, if the spreading is spherical
K=1, if the spreading is cylindrical

Equation (3) gives the absorption coefficient a(f) derived using the thorp's equation [6]. The absorption coefficient is usually expressed in dB/km for a frequency f in kHz.

\[ 10 \log a(f) = 0.11 \cdot \frac{f^2}{1+f^2} + 44 \cdot \frac{f^2}{4100+f} + 2.75 \cdot 10^{-4} f^2 + 0.003 \quad (3) \]

The above equation is used for higher frequencies. For lower frequencies, the following

\[ 10 \log a(f) = 0.002 + 0.11 \cdot \frac{f^2}{1+f^2} + 0.011 f^2 \quad (4) \]

The other parameter that majorly affects acoustic communication is the noise that comes from the ocean. Noise can be caused due to the following factors, namely turbulence, shipping, waves and thermal noise. The noise sources can be described by power spatial density (p.s.d.). The following formulae can calculate the p.s.d

\[ 10 \log N_r(f) = 17 - 30 \log f \quad (5) \]

\[ 10 \log N_s(f) = 40 + 20(s - 0.5) + 26 \log f - 60 \log(f + 0.03) \quad (6) \]

\[ 10 \log N_w(f) = 50 + 17w^{1/2} + 20 \log f - 40 \log(f + 0.4) \quad (7) \]

\[ 10 \log N_h(f) = -15 + 20 \log f \quad (8) \]

where s denotes the shipping activity factor, which can take the value 0 or 1 for low and high activity, respectively. w is the wind speed in m/s.

Sozer et al. [16] proposed an energy consumption model for underwater acoustic communication. The same model is used in this proposed method to calculate energy consumption. Let \( P_{\text{Rec}} \) denote the power required to receive the data at a node, \( T_s \) be the time delay in sending n bits of data, then the energy required to send n bits of data can be calculated as

\[ E_{\text{Trans}}(n, d) = T_s \cdot P_{\text{Rec}} \cdot a(f) \quad (9) \]

Where \( a(f) \) is the absorption coefficient which can be calculated using the equation (3)

Energy consumption of a sensor by receiving n bits of data can be written as

\[ E_{\text{Rec}}(n) = n \cdot E_{\text{Pro}} \quad (10) \]

where \( E_{\text{Pro}} \) is the energy consumption of one acoustic sensor node in processing one bit of data

The energy consumption of an acoustic sensor in aggregating n bits of data can be written as

\[ E_{\text{Agg}}(n) = n \cdot E_{\text{El}} \quad (11) \]

where E\text{El} is the energy consumed to integrate one bit of data.

III. PROPOSED MODEL
A. NETWORK MODEL

The following section describes the network model considered in the proposed Energy-Aware Multi-Level Clustering Scheme (EAMC) for Underwater Wireless Sensor Networks. The following assumptions hold in the construction of the network.

1. The underwater network region is considered as a logical concentric cylinder with six sectors and multiple levels of different heights numbered from $L_1$ to $L_n$.

2. All the nodes are deployed through long flexible rope anchored at the sea bed. The node's mobility is restricted, but its position can be adjusted with the help of the rope.

3. Gateway nodes are placed at the surface level of each Block and are equipped with both radio and acoustic modem.

The network region is divided into concentric cylinders. The distance between the cylinder is fixed as $r$, where $r$ is the transmission range of the sensor. The distance between the two cylinders is referred to as a track. The cylindrical structure is further divided into sectors, each having 60° at the centre point. The height of the cylinder is equal to the maximum depth of the network deployment region. Each cylinder is divided into several plates/levels. The height of each plate depends on transmission loss due to water pressure which is reduced when depth increases. Tracks at each sector are subdivided into blocks which ensure inter-cluster communication. Block is a primary partition in the proposed approach since clusters are constructed at each Block. The number of blocks in a track is dependent on the position of the track i.e, track number.

Let $T_i$ be the $i^{th}$ track in the network, then Numer of Block $N$ is

$$N = \frac{2\pi \times T_i}{r} \quad (12)$$

The blocks are numbered using four attributes such as level($L$), Sector ($S$), Track ($T$) and Block ($B$), where sectors are numbered between 1 to 6. Tracks are numbered as $l$ to $k$, depending on the radius of the deployment region. Let $R$ be the radius of the deployment region (since the deployment region is considered cylindrical), then $k$ is the $R/r$.

Block in a track is numbered in sequence, starting from 1 to the number of blocks in the corresponding track. For example, the first Block of track 2 at sector 1 in level 0 is denoted as 0121 (i.e. 0th level, 1st sector, 2nd Track and 1st Block). Fig. 1 shows the proposed cylindrical structure, and Fig. 2 depicts the top plate with sectors and blocks.

B. CLUSTERING PHASE

Initially, the 3-Dimensional network region is divided into levels, sectors, tracks and blocks. Later, each Block in the network is assigned a valid block number. Subsequently, Cluster Head (CH) nodes are selected from each Block. CH selection is based on the beacon message broadcasting method. A node with more residual energy (RE) than the energy threshold can participate in the CH election by sharing its RE and distance from the Block centre to all its neighbour nodes. The average block energy is considered as the energy threshold. A node is selected as a cluster head with maximum residual energy and minimum distance from the Block centre in each Block. The node selection with minimum distance to the block centre ensures a minimum communication range between cluster members and CH. Once the CH is selected, it broadcasts the elected message to its neighbours irrespective of their Block. The elected message contains the level of the CH, residual energy, position coordinates. When a normal node receives the elected message, it responds to its CH through a joining message which contains the node id. If a node receives an elected message from more than one CH, the node will choose the CH with the maximum Fitness value (F). The fitness value of CH is estimated independently at each node.
based on its distance, residual energy and level. A CH with minimum distance and maximum residual energy has a higher fitness value. Let \( v \) be the node that belongs to the \( i \)th cluster, then the fitness value of \( CH_i \) respect to \( v \) is coined as

\[
F(v, CH_i) = \frac{\alpha}{d(v, CH_i)} + (1 - \alpha)RE(CH_i) \quad (13)
\]

The fitness-based CH selection method leads to an even distribution of nodes among the clusters. Nodes can choose their CH only from their level or lower-level Block CHs. After joining with the cluster, each cluster member adjusts its transmission range based on the distance of its CH. It considerably reduces the transmission cost of nodes. Since the research community of UWSN identified the vertical acoustic data transmission as more manageable and more reliable, it experiences less transmission loss as well. The proposed clustering method focuses on vertical communication. Hence, inter and intra-cluster communication are carried out vertically in a bottom-up fashion. Each CH only communicates with the corresponding block CH in the lower level in inter-cluster communication. Level 0 CHs directly communicate with gateway nodes. For example, let \( u \) be the CH node of block 3211 (Level 3 sector2, track 1 block 1), then \( u \) will communicate to CH of block 2211. Similarly, the CH of Block 2211 will communicate to the CH of block ID 1211 and so on. Gateway nodes or sub sinks are deployed at each surface level block to collect data from CHs of respective blocks in all lower levels. Gateway nodes are equipped with radio and acoustic modems with a high transmission range and an unlimited or replaceable power source. Gateway node in a surface level block also acts as a cluster head of its Block.

Algorithm – EAMC Clustering Algorithm

1. Divide the network region \((l x b x h)\) into several levels, sectors, tracks and blocks
2. For each Block \( B \) do
3. Assign block number \((BN)\)
4. End for
5. For each block \( B \) do
6. Find \( u \in B \) \( u \)= \{max(RE), min(d(u, B))
   //d(u, B) is the distance from \( u \) to the centre of \( B \)
7. For each \( v \in N(u) \) // N(u) is the neighbour set of \( u \)
8. If \( v \) is uncovered or \( F(v,u) > F(v,w) \&\& BN(u) \leq BN(v) \)
   //w is current head of \( v \).
9. Set head(v) \( \leftarrow u \)
10. Send joining message to \( u \)
11. Else ‘do nothing’
12. end if
13. end for
14. end for

C. ROUTING PHASE

Data from the network will be collected according to the TDMA Schedule. Since CHs communicate with the same block number of adjacent levels, the data collection will be done parallel by the sub sinks or gateways. Data from the cluster members are aggregated by the respective CH and forwarded to the sink through its higher level CHs as shown in Fig.3.

Fig.3 represents the routing phase of the proposed algorithm. The legends used in Fig.3 are as follows: Small circle represents the deployed sensor nodes. The small triangle represents the CH. The small cylinder represents the gateway node or sink node deployed over the surface level blocks. Arrows represent data transmission flow between the cluster members and cluster heads. The arrow between the cluster heads represents the vertical communication that happens in the bottom-up fashion. The routing process avoids horizontal transmission as it is costly compared to vertical transmission. CH aggregates cluster data and is forwarded to the CH of the same Block in the upper level. The entire transmission happens in a vertical bottom-up fashion, as shown in (3).

CH position is rotated among the nodes periodically. Once the energy threshold value of a CH is reduced to a certain level, it is replaced by another node with maximum energy and minimum distance to its block centre. This local remedy or reselection process is independent of every Block. For the selection of new CH, the current CH sends a retire message to all the nodes in the Block. Then all other nodes send their position and energy value to the current CH. Further, the current CH selects the appropriate node as a new CH and intimates to all its members. Cluster members update their CH information and adjust their transmission range according to the distance of selected CH. The substituted CH acts as a regular node until its next turn.

D. CONTRIBUTION OF EAMC

1. The proposed algorithm reduces the transmission distance of the nodes by allowing them to join with the nearest CH. It significantly reduces the energy consumption of nodes for data transmission.
2. EAMC provides a local remedy for energy suffering CHs by allowing on-demand CH rotation. In this approach, each Block can initiate the CH selection independently whenever the current CH residual energy is reduced to the minimum threshold level. It reduces the re-clustering overheads and also addresses the void-hole problem.
3. EAMC ensure reliable and cost-effective data transmission by providing vertical data transmission in all aspect of data collection (gathering and forwarding).
IV. RESULTS AND DISCUSSION

The performance of EAMC is evaluated against EGRC and BEEC. The parameters identified for comparison are the network's lifetime, residual energy of nodes, and the percentage of alive nodes. Extensive simulations are carried out in NS2 with the Aquasim package.

A total of 200 – 1000 nodes are deployed on the cylindrical underwater area of 250m radius and 500m depth. The simulation parameters are listed in Table 1. The simulations are conducted by varying the network size from 200 to 1000 nodes. Three types of analysis are carried out throughout the simulation.

Case 1: Lifetime of the network with varying network size
Case 2: Percentage of alive nodes against the network lifetime
Case 3: Average residual energy versus varying network size

A. NETWORK LIFETIME WITH VARYING NETWORK SIZE

Case 1: Here, the lifetime in terms of rounds is calculated for different network sizes, starting from 200 nodes to 1000 nodes. The results are compared against MCBOR, BEEC and EGRC algorithms. By the simulation results, it is evident that the proposed algorithm outperforms the other two compared algorithms. Fig. 4 portrays the comparison made for the network lifetime with a varying number of nodes.

BEEC algorithm is highly suffered by frequent path estimation and transmission overheads due to sink's mobility, which drastically reduces the nodes lifetime. EGRC fails to consider the node's position in the CH selection, which leads to the node's intra-cluster transmission distance. As a result, the nodes suffer from high energy depletion to transfer the longer distances—additionally, CHs cause early energy depletion problems and sinkhole problems. MCBOR mainly addresses the end-to-end delay of data transmission, but it does not consider the load distribution among CHs. Hence the higher load CH energy depleted earlier, which is extreme in the dense network. They using fitness value of CH nodes and also proposed algorithm distribute the node among CHs. Even though the lifetime decreases when the number of nodes in the network increases, the proposed algorithm prolongs the network lifetime. It lasts for a more significant number of rounds when compared to the other two algorithms.

**FIGURE 3. Sector Based Vertical Data Collection.**

**TABLE I**

| SIMULATION PARAMETERS | VALUES |
|------------------------|--------|
| Number of nodes        | 200-1000 |
| Deployment area in 3-D | 1,000m × 1,000m × 800m |
| Distance between the layer of nodes | 200m |
| Data packet size       | 1,500 Bits |
| Transmission range     | 125m |
| Antenna type           | Omni |
| Channel types          | Wireless |
| Initial Node Energy (in joule) | 5J |

**FIGURE 4. Network lifetime with Varying Number of Nodes.**
B. PERCENTAGE OF ALIVE NODES AGAINST THE NETWORK LIFETIME

Case 2: Fig. 5 represents the analysis made on the percentage of alive nodes with the network lifetime. The network lifetime is represented in terms of rounds. The percentage of alive nodes at the end of each round for the proposed algorithm, EGRC, MCBOR and BEEC are given. Due to frequent path estimation and higher transmission overheads nodes in BEEC suffered by high energy depletion. It is inferred that BEEC has only 20% percentage of alive nodes at the end of 1590 rounds which is 960 rounds less than the Proposed Algorithm. EGRC also lose more energy during intra-cluster transmission and it lose 80% percentage of nodes within 1750 rounds. MCBOR shows higher performance compared to BEEC and EGRC but due to poor load distribution CH nodes are suffered by uneven energy consumption issues. So, within 2200 rounds it loses 80% percentage of nodes. The proposed algorithm reaches the level of 20% percentage of alive nodes only at 2580 rounds which implies the superiority of proposed algorithm in terms of load distribution and network lifetime. The proposed algorithm attain the lifetime of 75% more than BEEC, 45% more than EGRC and 21% more than MCBOR when 20% nodes alive.

![Network lifetime with Percentage of Alive Nodes](image)

FIGURE 5. Network lifetime with Percentage of Alive Nodes.

C. AVERAGE RESIDUAL ENERGY VERSUS VARYING NETWORK SIZE

Case 3: The average residual energy for different network sizes varying from 200 to 1000 nodes is calculated and compared with the other algorithms. The proposed EAMC algorithm shows the gradual consumption of energy which is evident in Fig. 6. It is because the CH is changed whenever it reaches a threshold value, and another node with higher residual energy takes its turn as a CH. Additionally, the proposed algorithm excellently reduces the inter and intra cluster transmission cost. Therefore, energy consumption of nodes equally distributed among nodes in the network. Concerning the increase in the number of nodes, the average residual energy of the network in all the algorithms is decreased.

![Average Residual Energy Vs Network Size](image)

FIGURE 6. Average Residual Energy Vs Network Size.

V. ENERGY CONSUMPTION ANALYSIS

A. ENERGY CONSUMPTION ANALYSIS OF PROPOSED ALGORITHM PER ROUND

Each sensor node generates l bits of data and sends it to the corresponding CH at each round. Assume CH_i is the cluster of i_th cluster, and it is associated with n nodes. Hence from Equation (9), the energy consumption for sending data from all the cluster members to CH_i is expressed as

\[ E_{cm}(CH_i) = \sum_{k=0}^{n} (E_{Trans}(l, d_k) + l(E_{elec})) \]  \hspace{1cm} (13)

Where \( d_k \) is the distance from the node \( k \) to its cluster head (i.e., \( CH_i \)). \( E_{elec} \) is the energy consumption of sensor electric circuitry. Also, from Equation (10), the energy consumption of \( CH_i \) for receiving data from its cluster members is expressed as

\[ E_{rec}(CH_i) = n \times l \times E_{pro} \]  \hspace{1cm} (14)

Once data is collected from entire cluster members, \( CH_i \) performs data aggregation. Let \( E_{DA} \) be the energy consumption to aggregate one bit of data. Then the energy consumption for data aggregation is given as

\[ E_{agg}(CH_i) = (n + 1) \times l \times E_{DA} \]  \hspace{1cm} (15)

Further, \( CH_i \) sends aggregated data to the base station through lower-level Cluster head. Hence the Energy consumption of i_th cluster, including data forwarding, is calculated as

\[ E_{total} (CH_i) = E_{rec}(CH_i) + E_{agg}(CH_i) + E_{cm} + E_{Trans}(l, d_{CH_i}) \]  \hspace{1cm} (16)

The total energy consumption of the proposed algorithm per round is calculated from equation 16

\[ E_{perround} = \sum_{k=0}^{m} (E_{total} (CH_k)) \]  \hspace{1cm} (17)
where \( m \) is the total number of blocks in the network, derived from equation (12). Let \( L \) be the number of levels in the network and \( n_t \) is number of tracks in each level then \( m \) is

\[
m = L \sum_{i=0}^{nt} (2\pi \times T_i) \quad (18)
\]

![Graph showing energy consumption (Joule) vs. network size.](Image)

**FIGURE 7.** Energy Consumption of Nodes per Round

All the compared algorithms abortive in reducing intra-cluster transmission range and even load distribution. Thus increase the energy consumption of nodes per round significantly which is evidenced from Fig.7. The proposed algorithm performs multiple data aggregation, so the cluster head sends a maximum of one data transmission per round. It reduces energy consumption significantly due to data forwarding. Moreover, the proposed algorithm constructs the clusters with a higher possibility of vertical data transmission. Because of vertical transmission, the energy consumption of nodes is reduced further. All other compared algorithms follow the multi-hop data forwarding and fail to concentrate the vertical transmission. It is also observed from Fig.7; the proposed algorithm drastically reduces the energy consumption of nodes per round.

**VI. CONCLUSION**

Early energy depletion is one of the issues that degrade the performance of UWSN with respect to network lifetime. It may be due to the uneven energy consumption of nodes in the network. EAMC focuses on prolonging the lifetime of the network. Since vertical communication is faster in UWSN, it follows a bottom-up routing strategy for communication. It also provides a local remedy by alternating the CH once its residual energy reaches the threshold value. The level of the cylinder is fixed in such a way that at surface level, the height of the level is more, and towards the seabed, the height is less so that the water pressure will not affect the communication. The improvements in the network structure considerably enhance the network lifetime. Simulation results show that EAMS performs well in terms of prolonging the lifetime of the network when compared with the other two algorithms.

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Dr. G. Sambasivam (Member, IEEE) received the Ph.D. degree in computer science and engineering from Pondicherry University, Puducherry, India. He is currently working as the Dean and an Associate Professor with the Faculty of Information and Communication Technology, ISBAT University Kampala, Uganda. His research interests include artificial intelligence, machine learning, deep learning, and Web service computing.

Dr. Naveen J is presently working as an Assistant Professor in the Department of Computer Science & Engineering, CHRIST (Deemed to be University), Bengaluru. He earned his PhD from National Institute of Technology (NITT), Tiruchirappalli -15, India. His research interests are Wireless Sensor Networks and Internet of Things.

Dr. P.J.A. Alphonse is presently working as Professor and Head in the Department of Computer Applications, National Institute of Technology, Tiruchirappalli. He did his MTech (computer science) in IIT Delhi, India and earned his PhD from NIT-Tiruchirappalli under Bharathidasan University. His specializations are Graph Theory and its Algorithms, Wireless and Ad-hoc Networks, Fault Tolerant Networks, Cryptography and Network Security.

Dr. D. Chandramohan is currently Assistant Professor, Computer Science and Engineering Department, Thapar Institute of Engineering & Technology, Patiala, Punjab, India. His area of interest includes Distributed Web Service, Web Service (Evaluation) Testbed, Software Metrics, Grid, Cloud Computing, Opportunistic Computing, Evolutionary Computing, Service Computing, Software Engineering, Multi-Agent, Pervasive & Ubiquitous Computing, Fog & Edge Computing, Underwater Communication, Privacy and Security. Currently he is working on E-Waste Management, Disaster Management, Bio-Inspired Algorithms and Privacy Preserving Generic Framework for Cloud Data Storage, Optimization approach for minimizing Agro-crops. He is having 9-Years of academic and research expertise and 3-years of industrial experience. He is serving as the Guest Editorial Member of International Journal of Handheld Computing and Research, IGI Global (IJHCR). Acting as an editorial Board Member of International Journal of Information Technology, Modeling and Computing (IJITMC), Review member of International Journal JOHN WILEY-Concurrency and Computation: Practice and Experience, Security and Communication Networks, IEEE- ACCESS and ACM Computing Survey-International journal.

Dr. Sivaraj Chinnasamy is currently working as an Assistant Professor in the Department of Computer Applications, Madanapalle Institute of Technology and Science, Madanapalle. He earned his PhD from National Institute of Technology (NITT), Tiruchirappalli -15, India. He received MCA degree from Anna University, Tamil Nadu, India. His research interests include the areas of wireless ad-hoc and wireless sensor networks.
