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ORIGINAL ARTICLE

Energy balanced reliable and effective clustering for underwater wireless sensor networks

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Energy consumption;
Network lifetime

Abstract While sending data from a submerged wireless sensor network, more power is necessary due to the additional distance the signal must travel as well as the higher amount of energy lost along the route. Also, the acoustic medium generated by the shadow and the acoustic animals alters the transmission between the source and destination nodes. Multipath fading, significant path loss, and various interferences are some of the difficulties that come with communication at larger depths. The connection strength was variable, there was a low bandwidth, a high salt content, high pressure, high temperature, a sinkhole, and the route curved. These variables influence a variety of network aspects, including energy efficiency, link quality, and packet delivery ratio (PDR). The Energy Balanced Reliable and Effective Clustering (EBREC) method was created to ensure that data packets reach at their destination intact. This was done in order to avoid the complications caused by these considerations. PDR and transmission loss reduction are other targets of the presented effort. The anticipated EBREC's performance is assessed by comparing it to many already defined benchmarks. According to the evaluation report, the simulation results reveal that EBREC performs very well when compared to the other methods in terms of Residual Energy of 0.615 J, Consumed Energy of 2.3 mJ, Throughput of 10Mbps, PDR of 97.6 %, Network Lifetime of 1750 sec, Number of Alive Nodes of 91%. Hence, the simulation results reveal that the EBREC technique beats competing approaches.

Abbreviations: PDR, Packet Delivery Ratio; EBREC, Energy Balanced Reliable and Effective Clustering; UWSNs, Underwater Wireless Sensor Networks; TWSN, Terrestrial Wireless Sensor Networks; CH, Cluster Head; EECRP, Energy-Efficient Clustering Routing Protocol; RN, Relay Node; EAMC, Energy-Aware Multilevel Clustering; MCBOR, Multilayer Clustering-based Butterfly Optimization Routing; EGRCs, Energy-efficiency Grid Routing based on 3D Cubes; BEEC, Balanced Energy-Efficient Circular.

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1. Introduction

Underwater Wireless Sensor Networks (UWSNs) is a promising new means of monitoring the aquatic environment. UWSNs have a wide range of time-sensitive applications [1]. They are useful for monitoring aquatic animal habitats, obtaining data for oceanography, disaster prevention, and environmental monitoring [2]. UWSNs differ from their Terrestrial Wireless Sensor Networks (TWSN) counterparts in a variety of ways. Radio waves are used as the means of exchange in TWSN. Because of the distances involved, UWSN

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uses auditory communication rather than radio transmission. Water salinity, turbulence, signal attenuation, noise, and other environmental conditions can all have a deleterious impact on sensor nodes in a UWSN [3–6]. Notwithstanding these concerns, the most serious issue at UWSN is the network's long-term viability. Because they all run on batteries, the sensor nodes can be set up unattended. The battery is not removable for charging or replacement. We must optimise your network's energy consumption if we want it to endure as long as feasible [7]. There is a lot of research being done to improve energy efficiency in buildings.

The UWSN can be used for a variety of functions, including monitoring aquatic habitats, acquiring oceanographic data, and detecting marine pollution [8–10]. Sinkholes, excessive energy usage, and propagation delays are just a few of the problems that could occur as a result of UWSN routing. The speed of an underwater acoustic wave can be affected by a number of environmental factors, including salinity, depth, and temperature [11]. The propagation lag makes underwater data transmission more challenging than it would otherwise be. Also, a large quantity of power is lost as a result of the continuous flow of data via the network's nodes. If nodes in a network consume varied quantities of power, the network's lifespan can be reduced, and energy gaps can arise (sinkhole). As a result, the data cannot reach the washbasin, and the previously present connection between the source and the destination has been severed [12].

The preponderance of energy consumptionis caused by data transfer between nodes. The research proposes numerous methods for reducing energy consumption, such as radio optimisation, data minimization, sleep/wakeup schemes, energy-efficient routing, and battery depletion techniques, to mention a few [13–15]. When it comes to extending the life of a network, nothing is more advantageous than energy-efficient routing because radio transmission requires more energy. Various techniques, such as clustering designs, energy as a routing parameter, multi-path routing, strategies for situating relay nodes, and sink mobility mechanisms, are being studied as potential energy-efficient routing strategies [16].

Underwater acoustic broadcasts can travel up to ten kilometres. A more major issue is the insufficient bandwidth and the narrow transmission range of about 1500 m per second [17]. Because of the extraordinarily high quality of the underwater communication route, the error bit rate is quite high. Environmental variables that might produce Doppler distortion in communications include variations in sound speed, surface waves, and interior turbulence [18].

The sensor devices include internal batteries, however, they aren't particularly powerful. In UWSN, two of the most important benefits of clustering are increased network lifetime and decreased energy consumption by individual nodes. Before the clustering operation, the nodes are divided into a number of subgroups. Each network cluster is made up of a Cluster Head (CH) and additional nodes that are linked together to form the network. Following the completion of data fusion, the network's energy consumption should be reduced as a result of the information transmitted from the member nodes to the CH [19]. These nodes act as cluster hubs, gathering data from cluster members and relaying it to the surface station or sink nodes. Upon the completion of each round of voting for the CH, the network's power usage will be reduced. This prevents data from being sent by individual nodes, resulting in energy savings [20]. After a while, it becomes evident that every data packet was accurately transferred. This is the ideal option for data usage that could result in someone's life or death, such as military surveillance, rescue missions, and underwater monitoring. The general architecture of UWSN is as shown in Fig. 1.

Many different types of clustering techniques are used in WSNs, Unfortunately for UWSN, these clustering algorithms are unable to be utilised. The UWSN energy challenge study is just getting started right now [21]. Traditional systems struggle with reliable transmission and fail to choose the most productive cluster head. Furthermore, due to the harsh circumstances underwater, the procedure of replacing the batteries in the sensor nodes is time-consuming and costly [22]. Nevertheless, these underwater sensor nodes must remain operational for the duration of their service. The current focus of UWSN research is to determine the most efficient technique to extend network lifetime while minimising node energy usage.

In heterogeneous networks, resource allocation refers to the process of efficiently distributing network resources, such as frequency bands and transmission power, among different types of nodes or cells within the network. The goal is to maximize the overall network capacity and ensure fair and efficient resource utilization. Due to the presence of different types of nodes with varying capabilities and coverage areas, resource allocation in heterogeneous networks can be complex. It involves considering factors such as user demands, network conditions, interference management, and load balancing.

WSNs are typically composed of numerous low-power sensor nodes that collaborate to collect and transmit data from the monitoring environment. Resource and power allocation in WSNs focus on optimizing energy consumption and extending network lifetime. Since sensor nodes are usually battery-powered, efficient utilization of resources, including power, is crucial. Techniques such as data aggregation, adaptive power control, and scheduling algorithms are employed to reduce energy consumption and prolong the network's operational lifespan. To gain specific insights and details regarding resource and power allocation in heterogeneous networks and wireless sensor networks as discussed in the referenced paper, it is recommended to refer to the original source directly [23].

1.1. Problem formulation & motivation

The problem addressed in this context is the transmission of data from a underwater wireless sensor network. This problem arises due to several challenges associated with underwater communication. Firstly, the increased distance that the signal must travel underwater requires more power, as the signal experiences higher energy losses along the transmission path. Secondly, the acoustic medium generated by shadows and marine animals introduces additional complexities and alters the transmission between the source and destination nodes. Thirdly, communication at larger depths is hindered by multipath fading, significant path loss, and various interferences, which further degrade the signal quality.

Additionally, the network environment poses several variables that influence different aspects of the network. The connection strength is variable, implying that the signal strength can fluctuate, leading to unreliable communication. The low

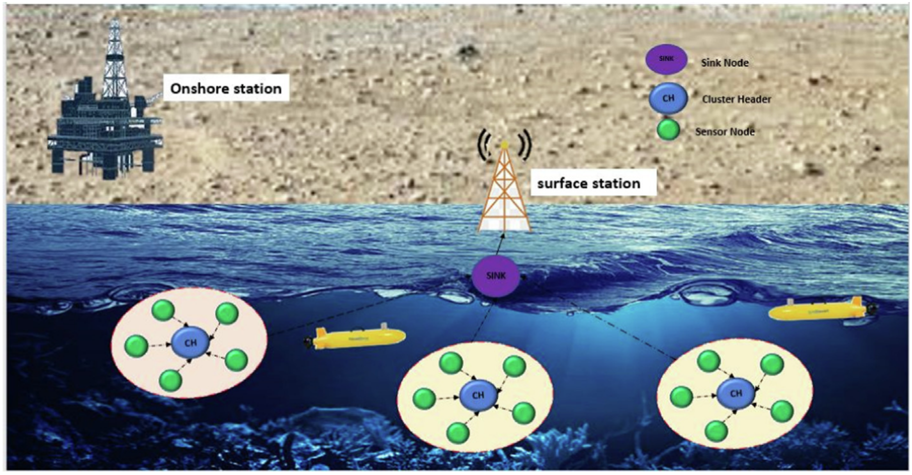

Fig. 1 General Architecture of UWSN.

bandwidth restricts the amount of data that can be transmitted at a given time, limiting the network's capacity. The presence of high salt content, high pressure, and high temperature in the underwater environment also affects the performance and longevity of the network. Furthermore, the presence of a sinkhole and a curved route introduces additional challenges in maintaining a reliable and efficient network connection.

Motivated by these challenges, the EBREC method was developed. The primary objective of EBREC is to ensure that data packets reach their destination intact, thereby addressing the complications caused by the underwater environment. In addition to reliable data delivery, the method aims to reduce packet loss and improve the PDR. This is crucial in maintaining the integrity of the transmitted data. To evaluate the anticipated performance of EBREC, it is compared against several established benchmarks. The simulation results presented in the evaluation report demonstrate that EBREC performs exceptionally well compared to other existing methods.

1.2. Contributions

As a solution to these issues, we developed an Energy Balanced Reliable and Effective Clustering (EBREC). The following is the most significant contributions:

- Development of the Energy Balanced Reliable and Effective Clustering (EBREC) method by addressing the challenges of sending data in an underwater wireless sensor network.
- Mitigating the impact of increased power requirements and energy losses due to signal distance by handling alterations in transmission caused by the acoustic medium generated by shadows and sound creatures;
- To improve the network's energy efficiency, link quality, and PDR in the network by designing a multilayer clustering routing algorithm for UWSN;
- Enlightening the network lifetime by considering CH is selected based on the residual energy of each node and the node's processing capability;
- Ensuring data packets reach their destination intact by reducing transmission loss and enhancing PDR.

In this brief summary, the remaining sections of the study are summarised as follows: Part 2 presents a review of the relevant literature. Part 3 presents the proposed network and energy model, while Part 4 describes the proposed EBREC algorithm. The performance metrics of UWSN are discussed in Part 5. In Part 6 simulation environment and results of the experiment are presented. The final section is Part 7, which provides the conclusion and examines the results.

2. Literature survey

In this section, a significant number of studies are analysed and assessed in order to acquire knowledge of the benefits and drawbacks of the various approaches used in the field of UWSN. The primary obstacles include but are not limited to, underwater noise, channel attenuation, bandwidth restrictions, the rapidity of acoustic waves, and a shortened network lifespan. All of these issues are being examined from various vantage points, and progress has been made. The low battery capacity of the nodes is the primary task that negatively impacts the UWSN's longevity. The majority of scholarly efforts are concentrated there due to its critical significance. Due to the fact that this data transmission utilises more energy, routing strategies for UWSN have been identified as an essential component for managing sensor node energy consumption. This is because these techniques require more power [24]. The two most prominent subcategories of UWSN routing protocols are localization-based and localization-independent protocols. Additionally, the route option can be used to ascertain its classification. This paper discusses energy efficiency in the context of UWSN, and its references are limited to protocols that achieve this objective within UWSN.

2.1. Related works

Xiao et al. [25] introduced an energy-efficient clustering routing protocol (EECRP) for UWSN. This protocol uses data fusion and genetic algorithms to reduce both the amount of unnecessary data transport and the amount of electricity consumed. When compared to other conventional routing algorithms, EECRP produces a higher quality of life.

Javaid et al. [26] were the first to propose the concept of distance and dependability-conscious cooperative routing. A metric depth threshold is used in the decision-making process to lower the total number of network hops required to execute a transaction between a sender and a receiver. They then choose a forward node with the fewest neighbour nodes possible. Furthermore, the cooperative technique makes two identical copies of a packet and sends them via two distinct channels. When both packets reach at their final destination, they are mixed using a diversity technique to provide the highest possible ratio. This design performs admirably; unfortunately, there is an issue with energy leakage.

Tavakoli et al. [27] proposed sensor power limits and network quality in UWSN, and a fuzzy-based Energy Efficient Clustering Routing protocol is implemented. The technique is divided into three separate steps using fuzzy logic. The first stage is to find the cluster; the second is to find potential paths; and the third is to choose the most difficult of those paths. By boosting the packet delivery ratio, the protocol promises to beat rival techniques.

Khan et al. [28] described a proactive routing strategy based on the selection of the least energy-consuming paths. Including the cluster construction technology into the mix also allows for efficient data transfer in terms of energy consumption. This protocol's communication flow can be changed to meet networks of varying densities (dense, somewhat dense, and sparse). In this scenario, they employ the adaptivity technique, which helps to prevent the transmission difficulty caused by vacant nodes. In its methodology, this inquiry used a multi-source, three-dimensional network. These holes are on the beach and drain into the ocean. It is possible to determine the number of hops between nodes as well as their proximity to one another by broadcasting a "beacon" message. This approach evaluates the node's residual energy (RE) to determine which CH should be used. As a result, the size of the node that contains nothing within it shrinks. On the other hand, it is unable to predict unexpected network outages, which is the fundamental reason for its short lifespan.

Subramani et al. [29] have proposed an optimization-based MCR routing method for UWSN. The first stage was the construction of clusters, and the second was the application of optimisation algorithms to identify numerous paths from the cluster heads to the sink.

Awais et al. [30] proposed a technique that modifies the data-gathering procedure during transmission so that the maximum number of adjacent neighbours is maintained. As stated previously, these two protocols are implemented in a three-dimensional network with multiple sinks. Nodes that serve as anchors, sources, and relays make up the network. Anchor nodes will be responsible for information sensing. Sink nodes allow for communication between the nodes in the water and the nodes on land. To protect the relay node (RN) networks, a designated area has been set aside. RN collects the data packets and sends them to CH, who is liable for their delivery. The BFS algorithm determines the shortest distance between two locations, whereas the SPB-WDFAD-DBR algorithm determines the shortest path. Despite the fact that these protocols help the system operate for longer, a significant number of packets are lost in the process.

Anuradha et al. [31] proposed to reduce the quantity of energy consumed in the event of a failed node. In this scenario, the node is deemed to have failed if the data was not conveyed to the intended location. It has been resolved prior to the expiration of the recognition timer. After that, the node will retransmit the data, resulting in a higher power consumption than the initial transmission. If the retransmission of the message also fails, it is assumed that the node is damaged, and an alternate route is sought. As a direct result of this, they devised a process flow in an effort to facilitate exploration in this study. During the inquiry process, the source node will send a message to the neighbour node in order to request information; however, this can be a complex procedure.

S. Cheema et al. [32] thought the ocean floor was a hemisphere when they proposed the BEAR protocol in 2016. Additionally, this area is divided into several sections. It is assumed that the nodes do not move and are evenly distributed over the two continents. Each node understands where it is, how far it is from the sink, and what data is available for its specific area. BEAR's functioning is divided into three stages: detection of neighbours, path discovery utilising the most efficient energy source, and transmission. Although BEAR is excellent at reducing power consumption, it suffers from considerable interference when positioned adjacent to the washbasin.

Kumari et al. [33] developed a fault-tolerant routing scheme for AUVs to deliver packets to the base station utilising the Moth Flame Optimization (MFO) algorithm (AUVs). Due to the possibility of overcrowding and subsequent re-clustering, AUVs are utilised rather than CH. A fitness function is then introduced to the MFO system to make it more resistant to connection interruptions. On all levels, AUVs are used in place of CH. Each grid is then examined for the presence or absence of sensor nodes. When grids are not constrained, the AUVs closest to the grids establish additional mobile nodes in the centres of the grids. We may be able to solve the node disjointness problem if we approach it in this fashion. This method uses less energy when implemented. Alternatively, for optimal utilisation, network coverage is essential.

S. Chinnaswamy et al. [34] proposed an Energy-Aware Multilevel Clustering (EAMC) algorithm to extend the longevity of an underwater wireless sensor network. The submerged portions of the network are represented as multi-tiered, concentric cylinders in three dimensions. Each tier is subdivided into numerous units, each of which represents a distinct cluster. The proposed algorithm employs a bottom-up approach, beginning at the ocean floor and communicating vertically upwards to the surface. Building the structure on multiple floors of differing heights facilitates communication despite the intense water pressure at the ocean floor. In simulations concentrated on measuring network lifetime and mean residual energy, it has been demonstrated that the proposed technique performs better. The simulation results demonstrate a significant increase in network longevity compared to current practices.

T.R. Chenthil et al. [35] developed the Multilayer Clustering-based Butterfly Optimization Routing (MCBOR) technique to ensure that data packets arrive at their destination intact and undamaged without being damaged in the route. PDR and transmission loss reduction are other targets of the presented effort. The new MCBOR's efficiency is measured against industry standards. According to the research findings, the proposed MCBOR has an E2E delay of 6.3 s, residual energy of 0.47 J, and a packet delivery ratio of

0.98%. As a result, MCBOR has been proven to be superior in terms of PDR efficiency and transmission loss reduction.

K.Wang et al. [36] developed and advocated a dependable data transfer method for observing Energy-efficiency Grid Routing based on 3D Cubes (EGRCs) in UWSN. A three-dimensional cube-based structure is used to model the network. Furthermore, each of them is cut into very small cubes (SCs). The precise location of the base station can be identified using positioning algorithms, and it has a reliable power source. This bundle includes both a radio modem and an acoustic modem. Upper and lower surface zones can be found wherever on the planet. The phrase "seabed" refers to the ocean's sediment-covered bottom, whereas "surface" refers to the topmost layer of water. The earth is the site of the monitoring station's base. Each teeny-tiny cube will choose one node to serve as the cluster's leader, and data will flow to that node from all other nodes in the cluster. The importance of residual energy is critical during the cluster selection process. We assume in this section that LEACH's model for calculating energy usage is correct. K-neighbourhood to awaken nodes and then put them back to sleep, a technique called Sleep Scheduling is used. Even though the protocol is effective at reducing end-to-end latency and power consumption, performance suffers as a result of the cluster head's energy supply running out too rapidly.

A.R. Hameed et al. [37] proposed that the UWSN implement the BEEC routing protocol, which stands for Balanced Energy-Efficient Circular. BEEC's primary objective is to reduce energy consumption whenever feasible. Within this model, the network field is depicted by ten concentric circles, each containing eight sectors. Each of the two portable basins is configured to service five distinct zones. We start by supplying the same amount of power to each node. Utilizing sound, transmission between the nodes is accomplished. Both acoustic and radio modems are installed in the basins for communication purposes. Mobile sources collect data from the nodes they encounter while traversing authorised areas. The node must transmit a "hi" message whenever there is a nearby mobile washbasin. The sources travel along a path that has been predetermined, but the locations of the nodes are not given special consideration. Regardless of the network's current state, the nodes are free to move about. This protocol is effective in densely populated areas with nodes located near together.

From Table 1, the existing routing protocols for underwater sensor networks, such as EECRP, distance and dependability-conscious cooperative routing, and fuzzy-based energy-efficient clustering routing, have shown limitations in terms of parameter sensitivity, energy trickle issues, and challenges related to sensor power limits and network quality. Additionally, proactive routing strategies and optimization-based routing methods face difficulties in predicting unexpected network outages and achieving optimal clustering. Techniques focusing on maintaining maximum adjacent neighbors during data transmission have encountered significant packet losses, while energy consumption reduction in the event of a failed node involves complex information request processes.

The BEAR protocol, fault-tolerant routing scheme, energy-aware multilevel clustering, and multilayer clustering-based routing techniques have also faced challenges such as interference, inefficiency for underwater sensor networks, energy depletion of cluster heads, and less energy efficiency. In this context, we propose the EBREC to address these limitations.

The EBREC algorithm aims to enhance energy efficiency and performance in underwater sensor networks. It incorporates innovative features, including data fusion, genetic algorithms, and improved data aggregation and communication. By reducing unnecessary data transport and electricity consumption, EBREC extends the network's lifetime and improves overall quality. However, the lack of standardization and established benchmarks in this field poses challenges for evaluating and comparing the effectiveness of EBREC against other protocols.

3. Proposed network and energy model

In this section, we will discuss the network model that would be used by the proposed EBREC for Underwater WSNs. The network model of a three-dimensional (3D) UWSN considers the number of sensor nodes, the selection of forwarder nodes, and the location of sinks. Sinks have been placed at the top and bottom of the network field, with sensor nodes distributed randomly. The communication protocol will determine which node will be the forwarder. The sink at the surface of the water is permanent and sends out a radio signal, whereas the sinks at the bottom of the water are mobile sensor nodes that can detect sound. Based on these characteristics, a radio signal is used to connect the data-gathering hub and sink nodes, and an acoustic signal is used to connect the underwater sensor nodes.

The network area under consideration here is defined by a cylinder. The effective range of transmission of the sensor is given by the value r in this expression. The cylindrical object has been sliced in half to make it easier to work with. The maximum depth in the network deployment region that can be reached is equal to the height of the cylinder. Each cylinder contains a number of distinct layers as shown in Fig. 2. Because the transmission loss caused by water pressure reduces with depth, each building's height varies in accordance with this principle. The technique proposed involves the establishment of clusters at each Block; thus, Block is used as the major divide as shown in Fig. 3.

Each Block will select a single node to serve as the Block's Cluster Head (CH). When selecting a channel, CH is the technology employed to transmit beacon messages is taken into account. A node with a RE greater than the energy threshold is eligible to vote in the CH election if it shares its RE and distance from the Block centre with all of its immediate neighbours. As a starting point, the energy limit is determined by the average quantity of energy contained within a block as shown in Fig. 4.

The cluster's header is the node with the most leftover energy and the closest geographical location to the cluster's centre as shown in Fig. 5. By selecting nodes that are physically close to the block's centre, the communication range between cluster members and CH can be reduced. When a winner is selected, the CH is responsible for broadcasting the winner's message to all of its neighbours. In addition to the current CH level, the selected message includes the amount of residual energy as well as the coordinates. A regular node will send a joining message to its CH in response to the chosen message. With this message, the node id will be sent. When a node

Table 1 Features and Challenges of existing UWSNs.

Author [citation]	Methodology	Features	Challenges
Xiao et al. [25]	Energy-efficient clustering routing protocol (EECRP)	Uses data fusion and genetic algorithms to reduce unnecessary data transport and electricity consumption	Sensitive to parameter settings
Javaid et al. [26]	Distance and dependability-conscious cooperative routing	Reduces the total number of network hops through a depth threshold metric.	Energy trickle issue.
Tavakoli et al. [27]	Fuzzy-based Energy Efficient Clustering Routing protocol	Utilizes fuzzy logic in three stages: cluster formation, path selection, and selection of difficult paths.	Sensor power limits and network quality.
Khan et al. [28]	Proactive routing strategy based on least energy-consuming paths	Selects least energy-consuming paths. Incorporates cluster construction technology for efficient data transfer.	Unable to predict unexpected network outages leading to a short lifespan.
Subramani et al., [29]	Optimization-based MCR routing method	Two-stage process involving cluster construction and optimization algorithms for path selection.	Clustering is not so much optimal
Awais et al., [30]	Technique to maintain maximum adjacent neighbors during data gathering	Maintains maximum number of adjacent neighbors during data transmission.	Significant number of packet losses.
Anuradha et al., [31]	Reduction of energy consumption in the event of a failed node	Implements a process flow to reduce energy consumption in the event of a failed node.	Complex process for requesting information from neighboring nodes.
S. Cheema et al.,[32]	BEAR protocol divided into several sections	Uses neighbor detection, path discovery, and transmission stages	Interference issues when adjacent sensor nodes.
Kumari et al., [33]	Fault-tolerant routing scheme for underwater vehicles (AUVs)	Utilizes AUVs instead of cluster heads for packet deliveryImplements the Moth Flame Optimization (MFO) algorithm.	Not efficient for UWSN
Chinnaswamy et al., [34]	Energy-Aware Multilevel Clustering (EAMC) algorithm	Represents the submerged network portions as multi-tiered, concentric cylinders in three dimensions.	Energy issues
T.R. Chenthil et al., [35]	Multilayer Clustering-based Butterfly Optimization Routing (MCBOR) technique	Ensures intact and undamaged packet delivery with reduced transmission loss	Less efficeincy
K.Wang et al., [36]	Dependable data transfer method using Energy-efficiency Grid Routing based on 3D Cubes (EGRCs)	Incorporates cluster selection based on residual energy.	Rapid energy depletion of cluster heads.
A.R. Hameed et al., [37]	Balanced Energy-Efficient Circular (BEEC) routing protocol	Aims to reduce energy consumption in UWSNs	Less energy efficiency.
Wang et.al.[38]	Edge prediction-based adaptive data transmission algorithm (EP-ADTA)	End–edge–cloud architecture	Developing a comprehensive data transmission algorithm considering application requirements
Shah, et al.[39]	Cluster-based Cooperative Energy Efficient Routing (CEER)	Maximized the lifetime and improved the overall performance	Less energy efficient
W.Tian et.al. [40]	Centralized control-based clustering scheme (CCCS)	node density-based adaptive clustering	Time slice allocation, network latency
Our work	EBREC	* Enhanced energy efficiency and performance* Improved data aggregation and communication	Standardization and established benchmarks

receives an elected message from more than one CH, it will select the CH with the highest Fitness score to be the recipient (F).

A separate evaluation is made to establish the worth of CH's fitness based on the level, the quantity of energy left, and the distance between each node. It is preferable to have a CH with a high residual energy value that is not too far away. Due of the fitness-based approach for selecting CH nodes, the nodes have been distributed uniformly among all clusters. While inside the cluster, each individual's broadcast range changes to account for the position of their various CHs. The amount of money required to communicate between nodes is greatly reduced.

According to UWSN experts, vertical acoustic data transmission was shown to be more dependable and controlled, resulting in lower transmission loss. Vertical communication has received special emphasis in the suggested clustering technique. As a result, information is transferred not just between clusters but also inside clusters in a vertical and bottom-up manner. Gateway nodes or sub sinks are deployed on the surface of each level to gather data from the CHs of the appropriate blocks located on the levels below. The radio and acoustic

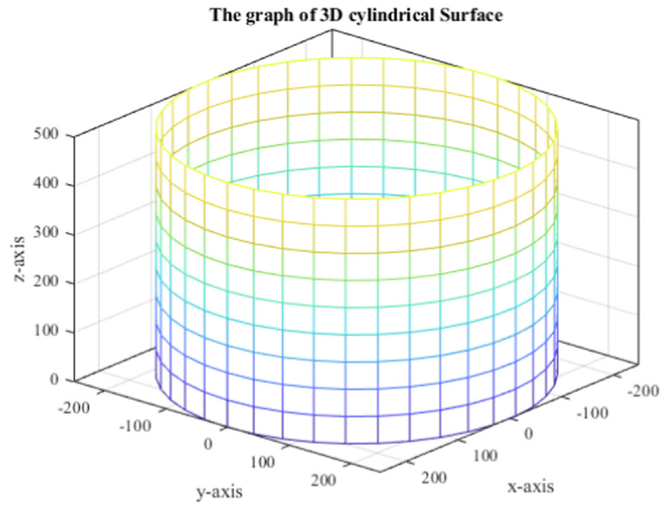

Fig. 2 3D cylindrical surface region.

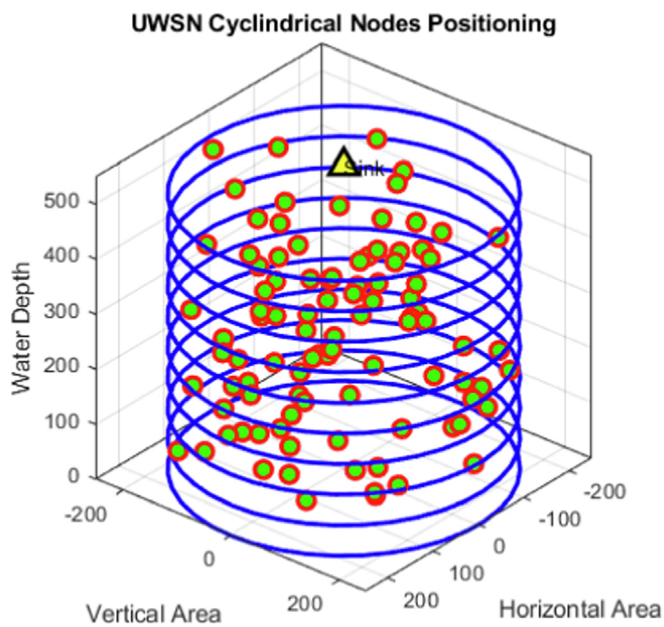

Fig. 3 Nodes positioning.

modems found on gateway nodes each have a large coverage area and a power supply that is either infinite or swappable. A surface level block's gateway node is the same as the block's cluster head as shown in Fig. 6.

Setting a consistent sleep and wake time is a simple but efficient approach to making the network use as little power as possible. Once the network's nodes have been organised into clusters, sleep and wake cycles will be automatically triggered at the appropriate periods. Each cluster must have exactly one active node that is fully charged in order to conserve resources. The remaining nodes will remain operational but in a low-power sleep mode.

This plan will begin with all nodes in the cluster online in order to assess the remaining energy. The purpose of this study is to determine the precise placement of the cluster's "active node" that saves the most residual energy. The sensing function will be handled by the cluster's active node. The cluster leader will choose which node will undertake the sensing duty. The cluster's leader will then send a message instructing the selected node on how to carry out its obligations as the active node. For the time being, one of these nodes has also been designated as the cluster leader. When it is time to sleep, the cluster master sends the SLEEP signal to the other nodes.

A little circle represents each of the sensor nodes in this area. The multilayer protocol is used by the system to calculate several potential paths. As a result of this calculation, a number of pathways with unique distances from the origin to the destination will be returned. When transmitting data from a source sensor to a sink sensor, it is best to first calculate multiple alternative routes, then choose the most efficient one, and finally use a wake-up scheduling algorithm to quickly activate the sensor nodes along the most efficient route while they are

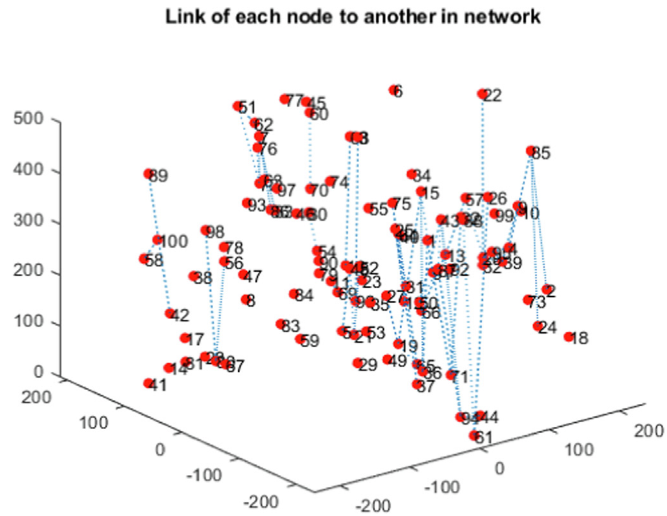

Fig. 4 Link of each node in the UWSN network.

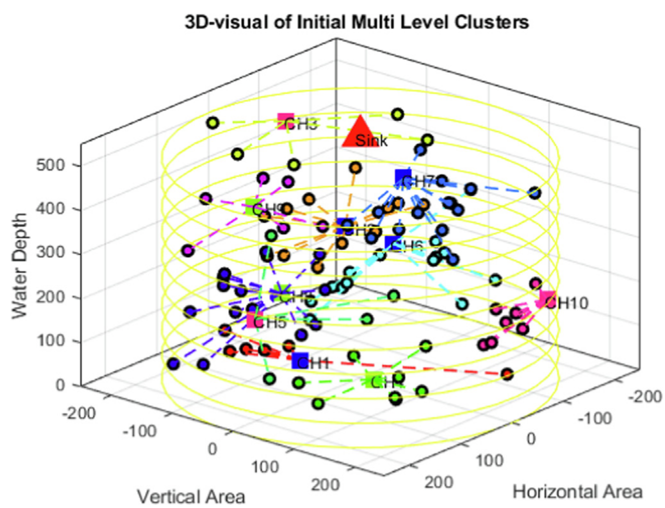

Fig. 5 Initial Multi-level clusters.

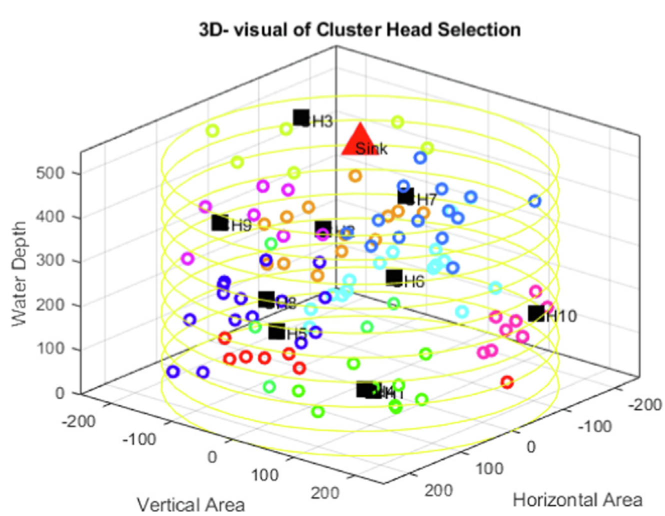

Fig. 6 Cluster Head Selection.

still in sleep mode. The TDMA Schedule will act as a reference for acquiring network information as shown in Fig. 7. Sub-sinks and gateways will collect data concurrently. The accumulated data from the other cluster nodes will be relayed to the washbasin by higher-level CHs within each individual.

4. Proposed EBREC algorithm

Following the energy calculation, we proposed Energy Balanced Reliable and Effective Clustering, to reduce the quantity of energy required for cluster construction in dynamically clustering UWSNs.After completing the energy estimation procedure, we developed an Energy Balanced Reliable and Effective Clustering mechanism to reduce the quantity of energy needed for cluster construction. Fig. 8 depicts a Flowchart of the proposed EBREC algorithm.

Algorithm 1. EBREC clustering algorithm.

1. Create the network Region Cylinder with r and h.
2. for each cylinder do.
3. Find, k = {max (R.E), min (Distance (k, C)}.
4. For each t belong to a neighborhood of k.
5. if t is not involved.
6. Set CH(t) = > k.
7. send a message to join.
8. set Number(k) = > Sleep until next round.
9. Wake-up k Sensor for some Period.
10. Find a better Path from Source to BS in Multi-Path.
11. Best path is found.
12. end.

In the Algorithm First, lines 1–2 define the network's commencement with a cylinder, and lines 3–4 are used to calculate the minimum and maximum distance between the sensor nodes with respect to the transmitter and receiver nodes. 5–9 denotes the time it takes to wake up the sensors for the Nth time iteration. Following that, the optimum path is determined based on the number of iterations.

5. Performance metrics of UWSN

5.1. Energy analysis

Energy analysis is a critical aspect of underwater wireless sensor networks (UWSNs) as the nodes in the network are typically battery-powered and have limited energy resources. Therefore, it is important to analyse the energy consumption of the network to ensure that the nodes have sufficient energy to carry out their functions for the required period [38]. There are several factors that contribute to the energy consumption of a UWSN, including node communication, data processing, sensing, and mobility. The energy consumption of the nodes can be estimated using the following equation (1):

$$E = T * P \tag{1}$$

Where E is the energy consumption, T is the time duration, and P is the power consumption rate. The power consumption rate of a node includes both the active power consumption rate when the node is transmitting or receiving data and the idle power consumption rate when the node is in sleep mode.

The energy consumption of the network can also be analyzed using the following equation (2):

$$E_{net} = E_{trans+}E_{recv} + E_{proc} + E_{sens} \tag{2}$$

where E_{net} is the network energy consumption,E_{trans} is the energy consumed during transmission, E_{recv} is the energy consumed during the reception, E_{proc} is the energy consumed during data processing, and E_{sens} is the energy consumed during sensing.

To optimize the energy consumption of a UWSN, it is important to consider several factors such as the network topology, routing protocol, and data aggregation method. For example, clustering algorithms can be used to reduce the energy consumption of the network by reducing the number

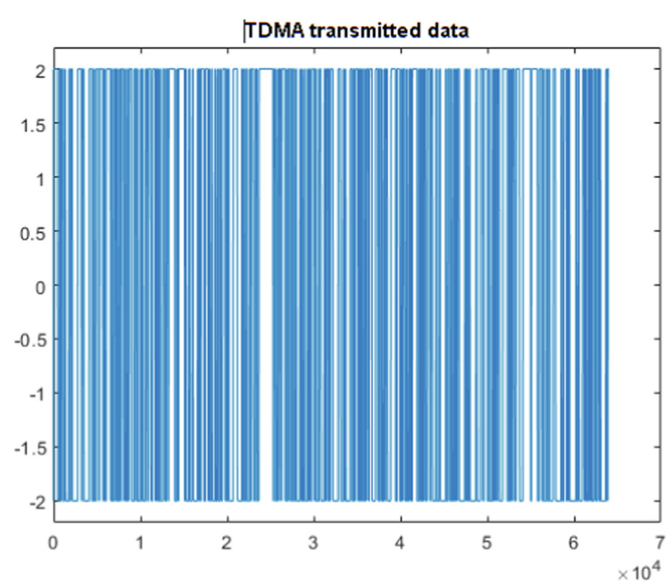

Fig. 7 TDMA data transmission.

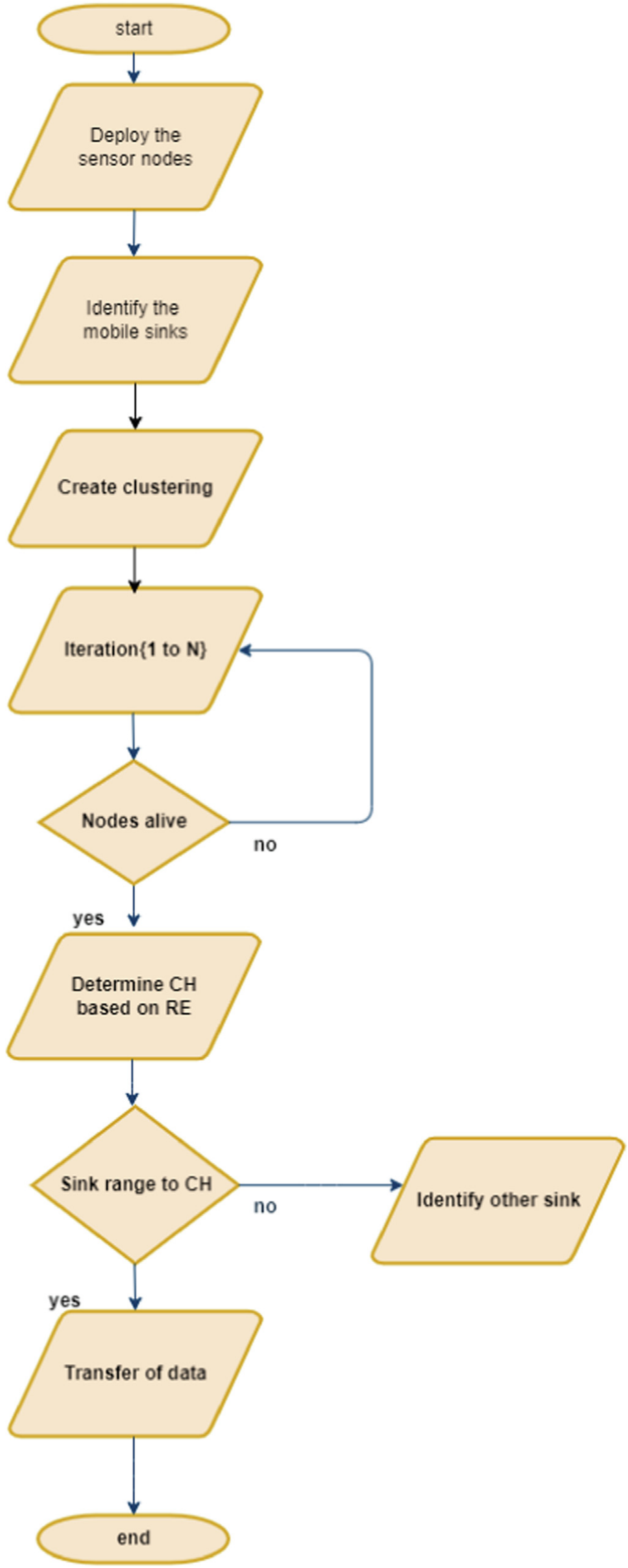

Fig. 8 Flowchart of proposed EBREC algorithm.

of nodes involved in data transmission and processing. Additionally, data aggregation methods such as data fusion can be used to reduce the number of transmissions and the amount of data processing required.

The energy equations for UWSNs depend on several factors, including the transmission distance, the data rate, and the type of modulation used for communication. The energy consumption for transmitting a single bit of data over a distance d can be calculated using the following equation (3):

$$E = E_{elec} + E_{amp} * \mathrm{d}^2 \tag{3}$$

where E_{elec} is the energy consumed by the electronics of the node, and E_{amp} is the energy consumed by the amplifier for transmitting the signal. The term d^2 represents the attenuation of the signal over distance due to absorption and scattering in the underwater environment.

The energy consumption for transmitting a packet of data can be calculated as follows (4):

$$E_{tx} = E + E_{header} + E_{data} \tag{4}$$

where E_{header} is the energy consumed for transmitting the packet header, and E_{data} is the energy consumed for transmitting the packet payload.

The energy consumption for receiving a packet of data can be calculated as follows (5):

$$E_{rx} = E_{elec} + E_{header} + E_{data} \tag{5}$$

Where E_{elec} is the energy consumed for processing the received signal, and E_{header} and E_{data} are the energy consumed for processing the packet header and payload, respectively.

5.2. Data transmission energy analysis

Data transmission energy analysis is a critical aspect of underwater wireless sensor network as it can have a significant impact on the network's performance and longevity. The energy required for data transmission in UWSNs depends on several factors such as distance, data rate, modulation technique, and signal attenuation due to the underwater environment.

The energy consumption for transmitting data can be calculated using the following equation (6):

$$E_{tx} = E_{elec} + E_{amp} * \mathrm{d}^2 * \mathrm{L} \tag{6}$$

Where E_{elec} represents the energy consumed by the node's electronics, E_{amp} is the energy consumed by the amplifier, d is the distance over which the signal is transmitted, and L is the number of bits in the transmitted data.

The term $E_{elec} + E_{amp} * \mathrm{d}^2$ represents the energy required for transmitting a single bit of data over a distance d as calculated previously in the energy analysis section. Multiplying this term with L gives the total energy consumed for transmitting L bits of data over the same distance.

The energy consumed during data reception can be calculated as follows (7):

$$E_{rx} = E_{elec} * L \tag{7}$$

Where E_{elec} represents the energy consumed by the electronics during signal reception and L is the number of bits received.

It is important to note that the transmission and reception energy calculations do not take into account other factors that can affect the energy consumption, such as signal attenuation, interference, and collisions. These factors can increase the energy consumption and reduce the overall network performance.

5.3. Residual energy analysis

Residual energy analysis is an important aspect of underwater wireless sensor networks as it helps to estimate the remaining energy of sensor nodes in the network. This analysis is important for predicting the network lifetime, scheduling maintenance activities, and optimizing network performance.

The residual energy of a node can be calculated using the following equation (8):

$$E_{res} = E_{init} - E_{tx} - E_{rx} \tag{8}$$

Where E_{init} the initial energy of the node is, E_{tx} is the energy consumed during transmission of data, and E_{rx} is the energy consumed during reception of data.

5.4. Consumed energy analysis

Consumed energy analysis is an important aspect of underwater wireless sensor networks as it helps to estimate the total energy consumed by the network over a period of time. This analysis is important for optimizing network performance, identifying energy-efficient protocols, and estimating the battery life of sensor nodes [39].

The total energy consumed by a node over a period of time can be calculated using the following equation (9):

$$E_{total} = E_{init} - E_{res} \tag{9}$$

Where E_{init} is the initial energy of the node and E_{res} is the residual energy at the end of the period. The residual energy can be estimated using the equation described in the previous section.

The total energy consumed by the network can be calculated by summing the energy consumed by all the nodes in the network over the period of time. This can be represented by the following equation (10):

$$E_{network} = \Sigma\, E_{total} \tag{10}$$

Where Σ represents the sum of the energy consumed by all the nodes in the network.

The energy consumed during data transmission and reception can be calculated using the equations described in the previous section. However, it is important to consider other factors that can affect the energy consumption, such as signal interference, collisions, and changes in the environment. These factors can be accounted for by using simulation or empirical testing.

5.5. Network lifetime analysis

Network lifetime analysis is an important aspect of underwater wireless sensor networks as it helps to estimate the duration for which the network can function without requiring maintenance or battery replacement. This analysis is important for designing energy-efficient protocols and algorithms, optimizing network performance, and scheduling maintenance activities [40].

The network lifetime can be estimated using the following equation (11):

$$T_{lifetime} = \min(\frac{E_{init}}{E_{avg}}), T_{avg} \tag{11}$$

Where E_{init} the initial energy of the node is, E_{avg} is the average energy consumption rate, and T_{avg} is the average time for which the network operates per node.

The average energy consumption rate can be calculated as follows (12):

$$E_{avg} = E_{tx} * P_{tx} + E_{rx} * P_{rx} \tag{12}$$

Where E_{tx} and E_{rx} are the energy consumed during data transmission and reception, respectively, and P_{tx} and P_{rx} are the probabilities of transmission and reception, respectively.

The average time for which the network operates per node can be calculated as follows (13):

$$T_{avg} = T_{cycle}/N \tag{13}$$

Where T_{cycle} is the duration of the cycle and N is the number of nodes in the network.

The cycle duration T_{cycle} can be calculated as follows (14):

$$T_{cycle} = T_{listen} + T_{sleep} \tag{14}$$

Where T_{listen} is the duration for which the node listens for incoming messages, and T_{sleep} is the duration for which the node is in sleep mode.

It is important to note that the network lifetime estimation assumes that the energy consumption and the network topology remain constant over time. However, in practice, the energy consumption and the network topology may change due to factors such as changes in the environment, signal interference, and node failures. Therefore, the network lifetime estimation should be considered as an approximation and should be validated through empirical testing.

5.6. Packet delivery ratio analysis

Packet delivery ratio (PDR) analysis is an important aspect of underwater wireless sensor networks as it helps to evaluate the reliability of data transmission in the network. This analysis is important for designing reliable protocols and algorithms, optimizing network performance, and diagnosing network problems [41].

The packet delivery ratio can be calculated using the following equation (15):

$$PDR = \left(\frac{N_{received}}{N_{sent}}\right). \tag{15}$$

Where $N_{received}$ the number of packets is received by the sink node and N_{sent} is the number of packets sent by the source node.

The PDR analysis can be used to evaluate the performance of different UWSN protocols and algorithms under various conditions. For example, the PDR can be evaluated for different routing protocols, modulation schemes, transmission power levels, and data rates.

To calculate the PDR, the number of packets received and sent must be accurately recorded. In practice, this can be challenging due to packet loss caused by factors such as signal attenuation, multi-path fading, and interference. Therefore, it is important to account for these factors by using appropriate models and simulation tools. The PDR analysis can be used to diagnose network problems such as node failure, congestion, and interference. For example, a low PDR may indicate a problem with a particular node or a congested path in the network.

5.7. Throughput analysis

Throughput analysis is an important aspect of underwater wireless sensor networks as it helps to evaluate the efficiency of data transmission in the network. This analysis is important for designing efficient protocols and algorithms, optimizing network performance, and diagnosing network problems [42].

The throughput can be calculated using the following equation (16):

$$Throughput = (N_{received} * L_{packet})/T. \tag{16}$$

Where $N_{received}$ is the number of packets received by the sink node, L_{packet} is the packet size, and T is the time taken to transmit the packets.

The throughput analysis can be used to evaluate the performance of different UWSN protocols and algorithms under various conditions. For example, the throughput can be evaluated for different routing protocols, modulation schemes, transmission power levels, and data rates. To calculate the throughput, the number of packets received, packet size, and time taken to transmit the packets must be accurately recorded. In practice, this can be challenging due to packet loss caused by factors such as signal attenuation, multi-path fading, and interference. Therefore, it is important to account for these factors by using appropriate models and simulation tools.

The throughput analysis can be used to diagnose network problems such as node failure, congestion, and interference. For example, a low throughput may indicate a problem with a particular node or a congested path in the network.

5.8. Number of cluster heads analysis

Number of cluster heads analysis is an important aspect of underwater wireless sensor networks as it helps to evaluate the effectiveness of clustering algorithms in the network. Clustering is a common technique used in UWSNs to improve network performance and reduce energy consumption by grouping nodes into clusters and selecting cluster heads to communicate with the sink node [43].

The number of cluster heads can be calculated using the following equation (17):

$$N_{CH} = sqrt(N) \tag{17}$$

Where N_{CH} is the number of cluster heads and N is the number of nodes in the network.

This equation assumes that the nodes are distributed uniformly in the network and that each cluster has an equal number of nodes. In practice, the clustering algorithm may assign different numbers of nodes to each cluster depending on various factors such as node proximity, node energy level, and network topology.

5.9. Packets to cluster heads analysis

Packets to cluster heads analysis is an important aspect of underwater wireless sensor networks as it helps to evaluate the efficiency of data transmission in the network using a clustering approach. In a clustered UWSN, the cluster heads are responsible for aggregating data from the nodes in their cluster and forwarding it to the sink node. Therefore, the number of packets sent to the cluster heads is an important factor to consider when evaluating the efficiency of data transmission in the network.

The number of packets sent to the cluster heads can be calculated using the following equation (18):

$$N_{packets} = N_{data}/N_{CH} \tag{18}$$

Where N_packets is the number of packets sent to the cluster heads, N_data is the total number of data packets generated by the nodes, and N_CH is the number of cluster heads in the network.

This equation assumes that each node generates an equal number of data packets and that the clustering algorithm assigns an equal number of nodes to each cluster. In practice, the number of data packets generated by each node may vary depending on various factors such as the sensing task, data rate, and energy level. Additionally, the clustering algorithm may assign different numbers of nodes to each cluster based on various factors such as node proximity, energy level, and network topology.

5.10. Packets-to-sink analysis

Packets-to-sink analysis is an important aspect of underwater wireless sensor networks as it helps to evaluate the efficiency of data transmission in the network from the cluster heads to the sink node. In a clustered UWSN, the cluster heads are responsible for aggregating data from the nodes in their cluster and forwarding it to the sink node. Therefore, the number of packets sent from the cluster heads to the sink node is an important factor to consider when evaluating the efficiency of data transmission in the network [44].

The number of packets sent from the cluster heads to the sink node can be calculated using the following equation (19):

$$N_{packets} = N_{data}/N_{CH} * (1 - p). \tag{19}$$

where $N_{packets}$ is the number of packets sent from the cluster heads to the sink node, N_{data} is the total number of data packets generated by the nodes, N_{CH} is the number of cluster heads in the network, and p is the probability of packet loss during transmission.

This equation assumes that each node generates an equal number of data packets and that the clustering algorithm assigns an equal number of nodes to each cluster. In practice, the number of data packets generated by each node may vary depending on various factors such as the sensing task, data rate, and energy level. Additionally, the clustering algorithm may assign different numbers of nodes to each cluster based on various factors such as node proximity, energy level, and network topology.

5.11. Number of alive node analysis

The number of alive node analysis is an important aspect of underwater wireless sensor networks as it helps to evaluate the network's lifetime and reliability. In UWSNs, the network's lifetime is determined by the number of nodes that are alive and operational [45]. The number of alive nodes can be calculated using the following equation (20):

$$N_{alive} = N_{total} * \exp(-lambda * t). \tag{20}$$

Where N_{alive} is the number of alive nodes, N_{total} is the total number of nodes in the network, *lambda* is the failure rate of the nodes, and t is the time.

This equation assumes that the failure rate of the nodes is constant over time and that the nodes fail independently. In practice, the failure rate of the nodes may vary depending on various factors such as the operating environment, the quality of the nodes, and the maintenance schedule.

6. Simulation environment and results of experiment

In terms of residual energy-based performance, the multilayer clustering-based Energy Balanced Reliable and Effective Clustering (EBREC) algorithm that was presented for prolonging the lifetime of UWSN while reducing energy consumption will be assessed in MATLAB and compared to the state-of-the-art methodologies. This will be done so that the method can be utilised to extend UWSN's lifespan.

6.1. Simulation environment

In this study, the efficacy of EBREC is compared to that of EAMC [34], MCBOR [35], EGRC [36], and BEEC [37]. The lifespan of the network, the remaining energy of the nodes, the throughput, and the PDR will all be compared. MATLAB software is used to execute a huge number of simulations. There are 100 nodes in the cylindrical underwater zone that is 500 m deep and 250 m in diameter. The parameters of the simulation are detailed in Table 2, which may be accessed here.

6.2. Comparative analysis

In order to evaluate the proposed EBREC in relation to existing protocols, such as EAMC [34], MCBOR [35], EGRC [36], and BEEC [37], and certain metrics, such as residual energy, consumed energy, PDR, network lifetime, number of alive nodes, throughput, packets to sink, packets to CH and number of CH are utilised. The EAMC, MCBOR, EGRC and BEEC algorithms are used as benchmarks to evaluate and establish the overall quality of the results. The simulation results show that the proposed strategy outperforms the alternatives by a wide margin.

6.2.1. Packets to sink

The packets-to-sink analysis can be used to evaluate the efficiency of different clustering algorithms under various condi-

Table 2 Simulation parameters and its values.

Simulation Parameters	Values
Number of Nodes	100
Radius of Cylinder	250 *m*
Number of Rounds	2000
Depth of Cylinder	500 *m*
Number of Packets	6400 bits

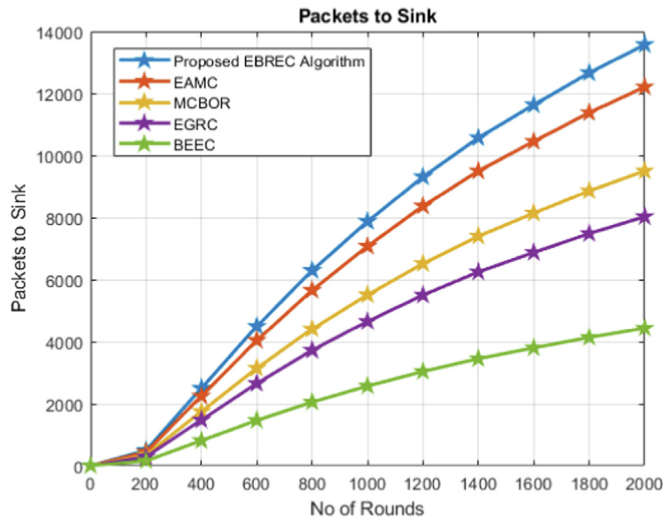

Fig. 9 Packets to sink.

tions. For example, the analysis can be used to evaluate the efficiency of clustering algorithms for different node densities, network sizes, and communication ranges. To optimize the efficiency of data transmission, it is important to consider factors such as network coverage, energy consumption, and communication overhead. A high number of packets to the sink node may increase communication overhead and energy consumption. A low number of packets to the sink node may reduce communication overhead and energy consumption, but may also reduce network coverage and reliability.

The efficient fitness function of EBREC is most likely responsible for the improvement in data packet success rates as shown in Fig. 9. These fitness functions enable node RE to be stored, resulting in an increase in the number of data packets that successfully reach their final destination. Furthermore, it aids in the prevention of transmission packet dropouts. When compared to the current EAMC, MCBOR, EGRC, and BEEC, the proposed EBREC results as represented in Table 3 in a higher number of packets sinking.

6.2.2. Number of cluster heads

The number of cluster heads can be used to evaluate the performance of different clustering algorithms under various conditions. For example, the number of cluster heads can be evaluated for different node densities, network sizes, and communication ranges. To optimize the number of cluster heads, it is important to consider factors such as network coverage, energy consumption, and communication overhead. A high number of cluster heads may increase network coverage but also increase communication overhead and energy consumption. A low number of cluster heads as shown in Fig. 10 may reduce communication overhead and energy consumption but may also decrease network coverage represented in Table 4.

6.2.3. Packets to CH

The packets to cluster heads analysis can be used to evaluate the efficiency of different clustering algorithms under various conditions. For example, the analysis can be used to evaluate the efficiency of clustering algorithms for different node densities, network sizes, and communication ranges. To optimize the efficiency of data transmission, it is important to consider factors such as network coverage, energy consumption, and communication overhead. A high number of packets to cluster heads may increase communication overhead and energy consumption as shown in Fig. 11 and represented in Table 5. A low number of packets to cluster heads may reduce communication overhead and energy consumption, but may also reduce network coverage and reliability.

6.2.4. Residual energy (Joules)

The residual energy can be used to estimate the network lifetime by calculating the minimum energy threshold required for the node to continue functioning. This threshold is typically set based on the minimum energy required to transmit a message to the sink node or the energy required for the node to function for a certain duration of time. The residual energy analysis can be used to identify nodes with low energy levels, which can be replaced or recharged to maintain the network

Table 3 Packets sent to sink.

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	816	1477	1749	2247	2500
800	2056	3721	4406	5658	6296
1200	3041	5504	6517	8368	9311
1600	3799	6875	8140	10,453	11,630
2000	4435	8026	9503	12,203	13,577

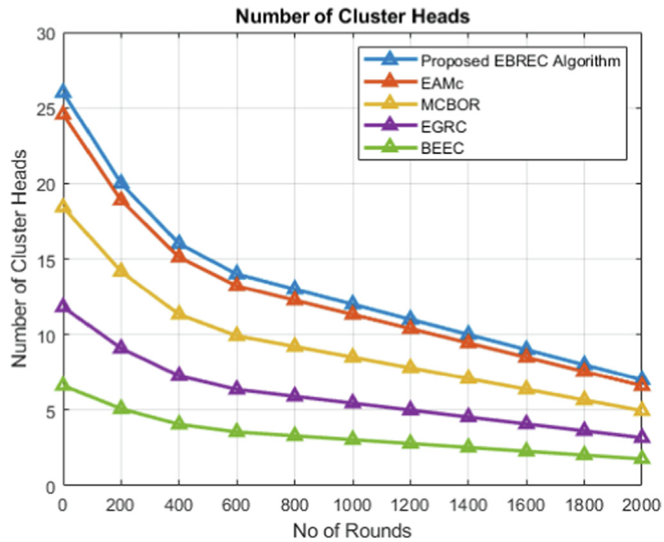

Fig. 10 Number of cluster heads.

Table 4 Number of CH.

No.of Rounds	Proposed EBREC	EGRC	MCBOR	EAMC	BEEC
400	8	9	11	15	16
800	6	5	9	11	13
1200	5	4	7	10	12
1600	3	4	6	7	9
2000	1	3	4	6	8

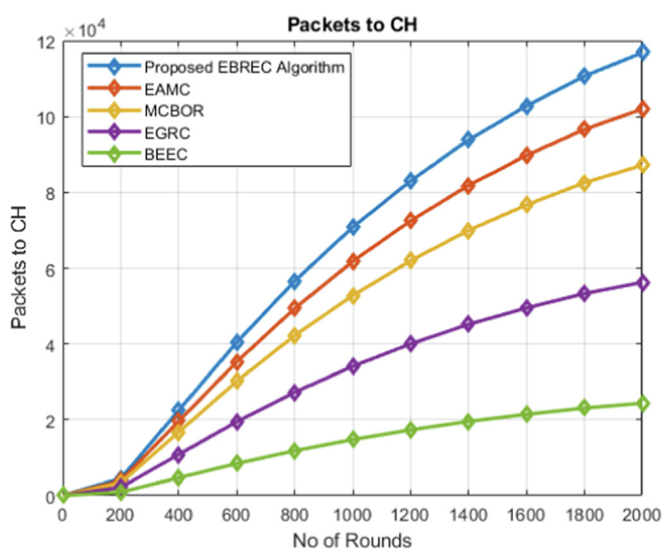

Fig. 11 Packets to CH.

performance. It is important to note that the residual energy analysis assumes that the energy consumption is constant and does not take into account variations in energy consumption due to factors such as signal interference, collisions, or changes in the environment. Therefore, the residual energy estimation should be considered as an approximation and should be validated through empirical testing.

The quantity of energy that remains in the node is referred to as "residual energy." Current methods select CH at random, but they do not take into account the distance between CHs.

Table 5 Packets to CH.

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	4693	10,834	16,781	19,634	22,500
800	11,805	27,253	42,210	49,387	56,596
1200	17,320	39,984	61,929	72,458	83,035
1600	21,444	49,503	76,673	89,709	102,804
2000	24,380	56,281	87,172	101,993	116,880

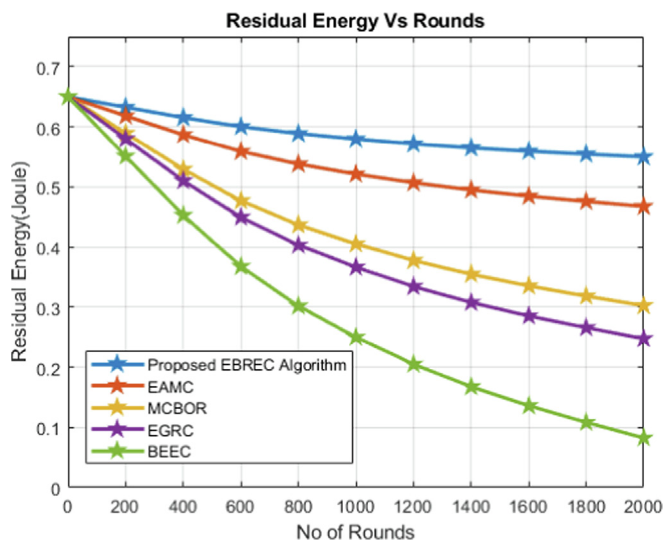

Fig. 12 Residual energy.

Table 6 Residual energy (Joules).

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	0.45284	0.510164	0.529272	0.586596	0.615258
800	0.301897	0.403107	0.436844	0.538055	0.58866
1200	0.204885	0.334302	0.377441	0.506857	0.571566
1600	0.136071	0.285495	0.335304	0.484728	0.55944
2000	0.0825	0.2475	0.3025	0.4675	0.55

This results in inefficient energy consumption. Choosing a node that is geographically close will reduce the amount of energy necessary to communicate with that node. As a result, our proposed EBREC uses significantly less power. The residual energy of our suggested EBREC methodology is 0.615 J for the 100 nodes, which is lower than the residual energies of the prior methods EAMC (0.58 J), MCBOR (0.52 J), EGRC (0.5 J), and BEEC (0.45 J). This is a significant improvement over the current methods. Fig. 12 compares the proposed nodes' entropy to that of the current EBREC, EAMC, MCBOR, EGRC, and BEEC and is also tabulated in Table 6.

6.2.5. Consumed energy (mJ)

The consumed energy analysis can be used to evaluate the energy efficiency of different UWSN protocols and algorithms. This analysis can be used to identify energy-intensive protocols and algorithms and optimize them to reduce energy consumption. Consumed energy analysis is an important aspect of UWSNs as it helps to estimate the total energy consumed by the network over a period of time. This analysis is important for optimizing network performance, identifying energy-efficient protocols, and estimating the battery life of sensor nodes.

As a result, our proposed EBREC uses significantly less power. The consumed energy of our suggested EBREC methodology is 2.3 mJ for the 100 nodes, which is lower than the residual energies of the prior methods EAMC (2.5 mJ), MCBOR (2.7 mJ), EGRC (3.5 mJ), and BEEC (3.8 mJ). Fig. 13 compares the proposed nodes' entropy to that of the current EBREC, EAMC, MCBOR, EGRC, and BEEC and is also tabulated in Table 7.

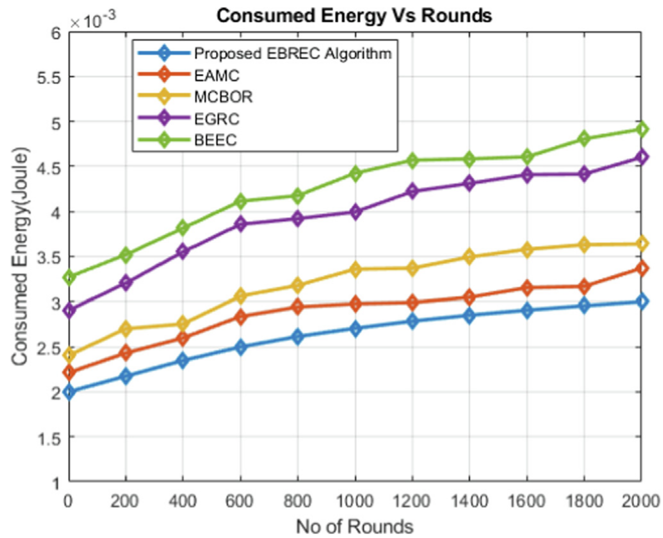

Fig. 13 Consumed energy.

Table 7 Consumed energy (mJ).

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	0.003815	0.00355208	0.00275223	0.00259752	0.00234712
800	0.00417634	0.00392099	0.00317868	0.00294119	0.0026134
1200	0.00456987	0.00422246	0.00337009	0.0029899	0.00278434
1600	0.00460673	0.00440919	0.00358012	0.00315403	0.0029056
2000	0.00491455	0.00460123	0.00363921	0.0033702	0.003

6.2.6. Packet delivery ratio (PDR)

The packet delivery ratio is a network performance indicator that compares the number of successfully delivered packets to the total number of packets transmitted between the source and destination nodes. The goal is to successfully deliver as many data packets as possible to their appropriate place. The network's speed improves proportionally to the PDR. The PDR results obtained using the proposed technique outperform those obtained utilising existing options.

By adding up the amount of energy consumed during each situation, you can determine how much energy the sensor node still has. BEEC nodes quickly ran out of power if route estimate was performed frequently, which increased transmission overheads. Furthermore, because more energy is wasted during intra-cluster transmission, EGRC loses nodes in a correspondingly fewer number of cycles. Although EBREC outperforms EAMC, MCBOR, BEEC and EGRC as shown in Fig. 14. CH nodes continue to suffer due to erratic energy utilisation and unbalanced load. The fact that the proposed solution passed the more difficult test shows that it is more capable of spreading the load across the network as a whole. On the basis of the percentage of packets successfully conveyed to each of the 100 nodes, our proposed technique 97.6% outperforms the state-of-the-art algorithms EAMC (96%), MCBOR (94%), EGRC (92%) and BEEC (89%) shown in Table 8.

6.2.7. Network lifetime (sec)

The amount of time it takes for all of a network's nodes to become fully functional and fully alive is the measure of how long a network has a lifespan. Because of the mobility of the nodes, the MCBOR, EAMC, and BEEC algorithms have a limited lifetime, causing them to suffer route estimation and transmission overheads on a regular basis. These overheads are costly. EGRC does not consider the node's position while selecting the CH, resulting in a larger intra-cluster transmission distance. As a result, long-distance data transmissions place a tremendous burden on the nodes' power supplies. Sinkholes and early depletion of energy sources are two problems caused by CHs. While EBREC focuses on reducing the time it takes for data to be transferred from start to finish, it pays less attention to how the load is distributed among CHs. The consumption of CH power increased as a result of the increased demand as well as the increased network density. They distribute the node across CHs by combining the proposed technique with the fitness value of CH nodes. The proposed technique leads in increased network stability. Each of the other four algorithms has a smaller total number of rounds than this one.

The network lifetime of our suggested EBREC methodology is 1750 sec for the 100 nodes, which is lower than the residual energies of the prior methods EAMC (1605 sec), MCBOR (1540 sec), EGRC (1157 sec), and BEEC (905 sec). Fig. 15

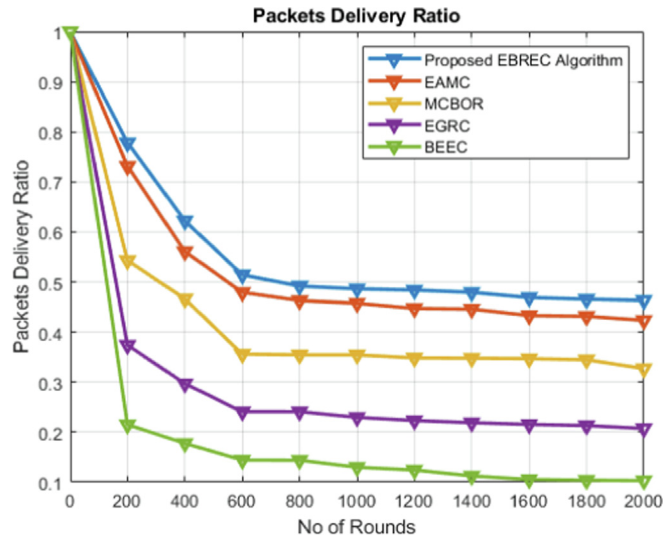

Fig. 14 Packet delivery ratio (PDR).

Table 8 Packet delivery ratio (PDR).

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	0.177552	0.296904	0.466383	0.560606	0.622132
800	0.143806	0.240971	0.354756	0.462981	0.491833
1200	0.124162	0.223123	0.348672	0.447357	0.483904
1600	0.105395	0.215413	0.34712	0.43309	0.468943
2000	0.102954	0.207228	0.326958	0.423498	0.463364

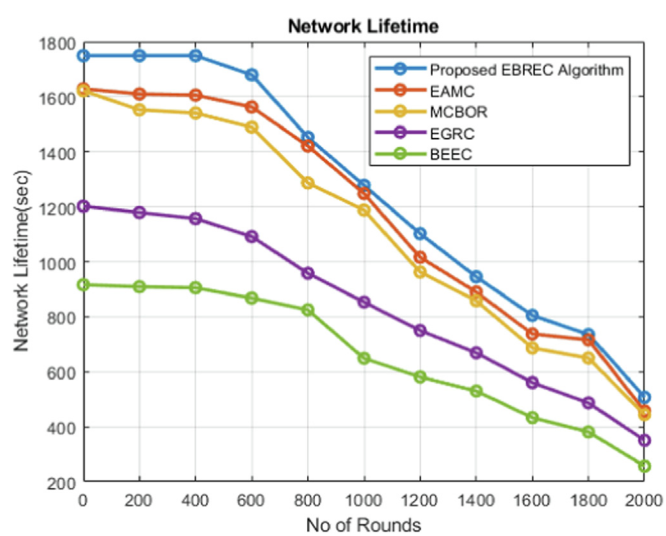

Fig. 15 Network Lifetime (sec).

compares the proposed nodes' entropy to that of the current EBREC, EAMC, MCBOR, EGRC, and BEEC and is also tabulated in Table 9.

6.2.8. Throughput (bps)

Fig. 16 depicts the link between average network throughput and node density in the network for both the proposed and benchmarking protocols. The average throughput of EBREC's network exceeds that of EAMC, MCBOR, EGRC, and BEEC combined. Because the transmission range for source nodes varies according to cluster width, nodes can easily transfer data packets at their respective CHs. When the proposed procedures are used, this results in a high data rate at the surface sinks. On the basis of the percentage of packets successfully

Table 9 Network lifetime (sec).

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	905	1157	1540	1605	1750
800	825	957	1286	1401	1452
1200	581	749	962	1016	1120
1600	433	560	686	732	805
2000	256	350	444	457	520

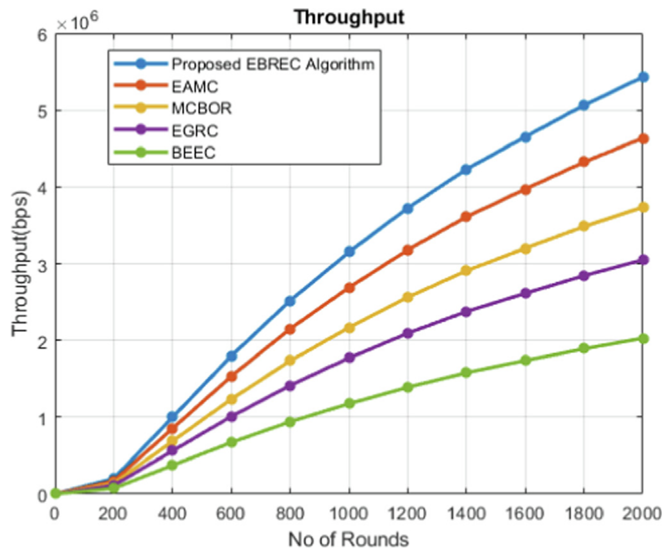

Fig. 16 Throughput (bps).

conveyed to each of the 100 nodes, our proposed EBREC technique 10Mbps outperforms the state-of-the-art algorithms EAMC (8 Mbps), MCBOR (6 Mbps), EGRC (5 Mbps) and BEEC (3 Mbps) shown in Table 10.

6.2.9. Number of alive nodes

The number of alive node analysis can be used to evaluate the network's lifetime and reliability under various conditions. For example, the analysis can be used to evaluate the network's lifetime for different node densities, network sizes, and communication ranges. To optimize the network's lifetime and reliability, it is important to consider factors such as node deployment, energy consumption, and network topology. For example, deploying nodes in a grid pattern may improve network coverage and reduce energy consumption, but may also increase communication overhead. On the other hand, deploying nodes randomly may increase network coverage and reduce communication overhead, but may also increase energy consumption. The number of alive nodes of our suggested EBREC methodology is 91% for the 100 nodes, which is lower than the residual energies of the prior methods EAMC (88%), MCBOR (86%), EGRC (81%), and BEEC (79%). Fig. 17 compares the proposed nodes' entropy to that of the current EBREC, EAMC, MCBOR, EGRC, and BEEC and is also tabulated in Table 11.

The comparison of the given protocols based on the analyzed results reveals several insights as shown in Table 12. In terms of the number of packets successfully delivered to the sink, Proposed EBREC outperforms the other protocols with 2500 packets. When considering the number of cluster heads, MCBOR has the highest number with 11, while Proposed EBREC has the lowest with 8 cluster heads. In terms of pack-

Table 10 Throughput (bps).

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	373,342	561,761	687,872	853,541	1,000,000
800	940,225	1,414,740	1,732,340	2,149,560	2,518,400
1200	139,048	2,092,220	2,519,104	3,178,930	3,724,400
1600	173,679	2,613,310	3,199,980	3,970,670	4,652,000
2000	2,027,550	3,050,810	3,735,690	4,635,410	5,430,800

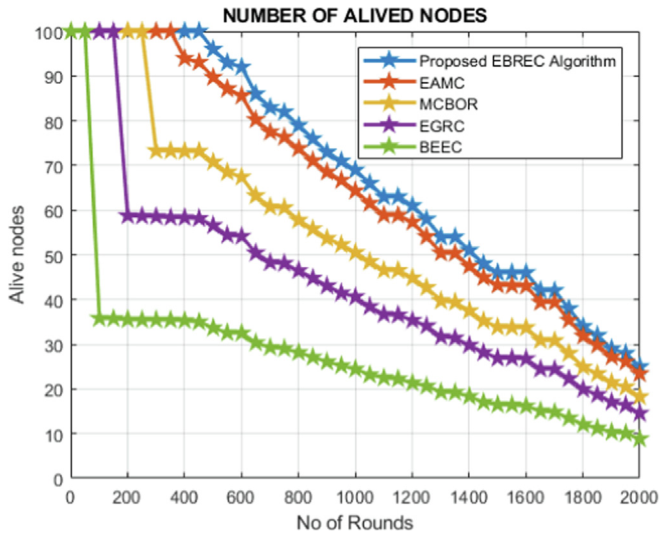

Fig. 17 Number of alive nodes.

Table 11 Number of alive nodes.

No.of Rounds	BEEC	EGRC	MCBOR	EAMC	Proposed EBREC
400	35	58	73	93	100
800	28	46	57	73	79
1200	21	35	44	57	61
1600	16	26	33	43	46
2000	8	14	18	23	25

Table 12 Comparison analysis of EBREC with existing approaches.

Features	BEEC[37]	EGRC[36]	MCBOR[35]	EAMC[34]	Proposed EBREC
Packets to sink	816	1477	1749	2247	2500
Number of CH	16	9	11	15	8
Packets to CH	4693	10,834	16,781	19,634	22,500
Residual Energy (J)	0.45284	0.510164	0.529272	0.586596	0.615258
Consumed Energy (mJ)	0.003815	0.00355208	0.00275223	0.00259752	0.00234712
PDR (%)	0.177552	0.296904	0.466383	0.560606	0.622132
Network Lifetime (Sec)	905	1157	1540	1605	1750
Throughput (Mbps)	373,342	561,761	687,872	853,541	1,000,000
Number of Alive Nodes	35	58	73	93	100

ets transmitted to the cluster heads, MCBOR again leads the comparison with 16,781 packets, followed by EGRC with 10,834 packets. However, Proposed EBREC surpasses them all with 22,500 packets. When examining the residual energy, Proposed EBREC demonstrates the highest value of 0.615258 J, indicating better energy conservation. The consumed energy is lowest for Proposed EBREC with 0.00234712 mJ, highlighting its energy efficiency. Proposed EBREC also achieves the highest packet delivery ratio (PDR) of 0.622132, signifying superior reliability in packet delivery. Moreover, Proposed EBREC exhibits the longest network lifetime of 1750 s, ensuring extended network operation. Additionally, it attains the highest throughput of 1 Mbps, indicating efficient data transfer. Finally, Proposed EBREC maintains the highest number of alive nodes with 100, emphasizing its superior network connectivity and stability. Overall, the analysis suggests that Proposed EBREC outperforms the other protocols in terms of packet delivery, energy efficiency, network lifetime, throughput, and the number of alive nodes.

7. Conclusion

One of the challenges affecting the UWSN's success in this regard is that its energy sources run out too rapidly. One probable explanation is that various nodes demand different amounts of energy. The issue of early energy depletion has an impact on the performance of the UWSN in terms of network lifespan. The EBREC was created with the goal of prolonging the useful life of the network. The goal of EBREC is to increase the amount of time the network can remain active. Because vertical communication is completed faster, communication in UWSN is handled via a bottom-up routing technique. When the residual energy of the CH hits a certain threshold, it is switched to provide local relief until the threshold is reached again. The cylinder's height has been changed such that it is higher near the surface and lower towards the sea floor. This modification was done to keep the water pressure from interfering with the transmissions. The network's lifespan should be greatly extended as a result of changes made to its underlying architecture. The simulation results reveal that EBREC performs very well when compared to the other methods in terms of Residual Energy of 0.615 J, Consumed Energy of 2.3 mJ, Throughput of 10Mbps, Packet Delivery Ratio of 97.6 %, Network Lifetime of 1750 sec, Number of Alive Nodes of 91%, the simulation results reveal that the EBREC technique beats competing approaches. During this inquiry, many key avenues and potential future prospects are discovered. As a result, more work is required to develop routing algorithms based on features that increase service quality. This work could be expanded in future to investigate the extremely variable underwater media and the necessity to construct proper security procedures in order to create new secure clustered routing protocols for use underwater.

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Declaration of Competing Interest

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