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Optimized Energy Conservation for Underwater Wireless Sensor Networks using Clustering-Based Data Aggregation and Transmission Protocol

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Abstract: Since manual battery maintenance and recharging is not possible with the new technology in underwater wireless sensor networks (UWSN), many researchers are studying this area. Because they are quickly recharged by an unconventional resource like solar energy, network duration should be considered. Clustering is a useful technique for building vibrant, efficient UWSNs when it comes to the data collection process. Due to the dynamic nature of the channel and the sparse deployment of nodes, UWSNs have different clustering behaviors than terrestrial wireless sensor networks (TWSNs). In order to facilitate efficient data transmission with an ideal clustering procedure, this study suggests the improved efficient data aggregation in a Hexagonal grid with energy optimization (IEDA-HGEO) protocol. It is further contrasted with EGRC (Energy-efficient Grid Routing based on 3D Cubes) and ERP2R, an energy-efficient routing system. The suitability of the three aforementioned techniques for underwater communication is specifically investigated, and a comparison of their performance is made with respect to energy consumption, efficiency, throughput, packet delivery ratio, and delay. The following metrics were attained by the suggested method: 41% delay, 48% energy usage, 95% efficiency, 95% throughput, and 92% PDR.

Keywords: energy usage, multi-hop, clustering, and UWSN

1. Introduction

Over the past ten years, UWSNs have emerged as a crucial tool for underwater monitoring and exploration, including applications in science, business, and the military [1,2]. When compared to other remote sensing competitors, UWSNs offer a number of advantages that allow for more accurate and localized data collection. Additionally, they have access to a broader variety of sensors, including motion, chemical, temperature, and light sensors. Unmanned undersea vehicle (UWSN) technology is replacing traditional underwater instrumentation equipment. Large sensor nodes that could store data were previously physically positioned in the target area beneath the water. Each node operates independently for the duration of the operation in order to gather readings in compliance with a preset program [3]. After the operation is over, SNs are collected, and the data collected is retrieved and analyzed. Underwater sensor nodes can network thanks to UWSN technology, which allows them to send real-time data for instant analysis to an offshore or even on-shore control center. Sending control signals over a communication channel from the control station to underwater sensor networks allows for interactive control of the underwater sensor network deployment. Unmanned Wireless Sensor Networks (UWSNs) offer notable advantages over traditional instrumentation techniques [4]. Energy saving is a significant concern because UWSN-SN are powered by batteries, which are difficult to replace or recharge in aquatic environments [5]. The development of dependable, scalable, and energy-efficient routing protocols in these networks is a fundamental research challenge. Ground-based sensor networks cannot directly employ most of the data forwarding protocols now in use because they were designed for stationary networks [6]. The UWSN network's fundamental clustering formation is shown in Figure 1, and the information is sent to the satellite via two different types of sinks: onshore and surface sinks. In order to gather data, the surface node, cluster head, and undersea sink node are also connected to one another [7]. Here, an autonomous underwater vehicle is employed to move between clusters and to maintain contact with the surface node in the event of an emergency arising during packet transmission [8].

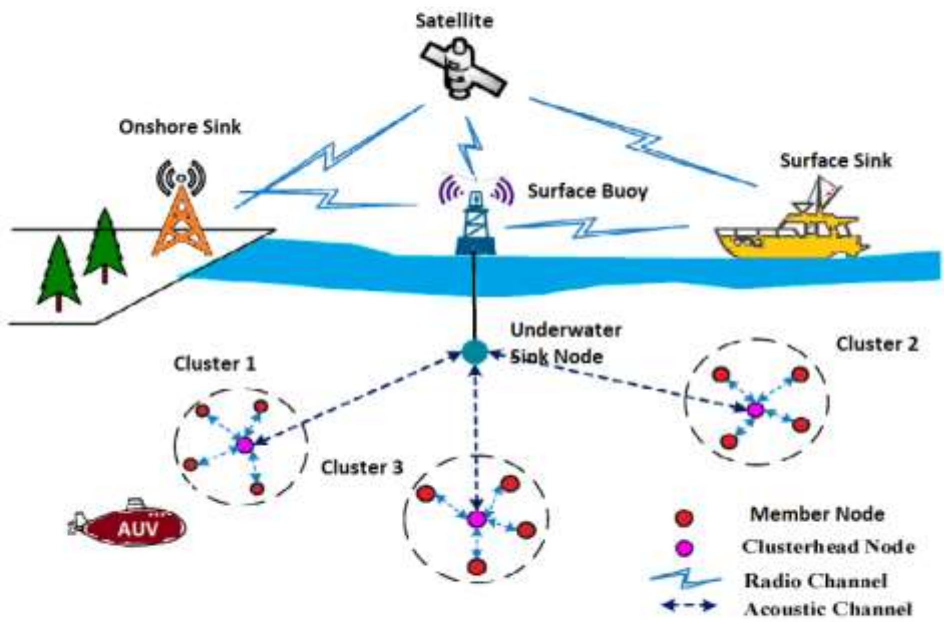


Figure 1: Underwater wireless sensor networks: a basic clustering technique

The following is the research's contribution:

1. We provide a data-gathering protocol based on AUV route planning that accounts for the energy usage and journey time of underwater vehicles.

2. To suggest more effective data aggregation in the IEDA-HGEO protocol for efficient data transfer and the best possible clustering procedure.

3. EGRC and ERP2R, an energy-efficient routing technology, are further compared.

The structure of the paper is as follows: A brief overview of UWSN and its uses, transmission challenges, energy-efficient protocols currently in use, and network clustering is provided in Section 1. The surveys of the current techniques used in the UWSN clustering process were discussed in Section 2. The suggested approach for an effective clustering and data transmission procedure is described in Section 3. In Section 4, the results are presented in detail and are compared with current methods. Section 5 concludes with some thoughts for further research.

2. Review of the Literature

DUCS is a new protocol for distributed energy-aware routing [9]. Its purpose is to provide UWSNs with random node mobility and no GPS support for long-term, non-time-critical aquatic monitoring applications. Ordinary nodes just listen to the signals from beacon nodes in a proposed Underwater Positioning Scheme (UPS) in [10]. The time difference is then translated into a range distance when four beacon messages are received. The coordinates of sensor nodes are found by the authors of [11] using a mobile beacon node and Cayley-Menger. The separation between nodes is determined using the combined radio and acoustic signals, which are not affected by multipath fading. To mitigate the effects of uneven energy consumption, researchers published a number of mobile node-based tactics in [12], including AUVs.

network on a tour path and gathering data from stationary nodes in a neighborhood by pausing at a predetermined spot called a tour point. Selvi et al. introduced the UCAPN technique for WSNs, which increases network lifespan [13]. In order to increase network lifetime and balance node energy consumption, UCAPN divides SNs into different-sized clusters. Prior to being transmitted to the sink node, information from non-cluster-head nodes is sent straight to the nearest cluster-head.

Gulnaz Ahmed et al. [14] presented a MOCHs selection for WSNs using a control approach wherein BS governs the number of CHs and CHs regulate cluster members. This method tackles the problem of backward transmission while offering strong clustering. Enhancing this procedure can be achieved by adding energy-collecting mechanisms [15]. Khan et al. developed a system in [16] that can adjust to three distinct kinds of networks based on the node density. In [17], underwater sensors are assigned cubic regions and positioned locally within this kind of structure. Another work is introduced in [18] to prevent void nodes. In this work, the packet's every second hop is checked to determine whether the node's state is void or not. In this family of greedy routings, the void problem is addressed by a void-aware pressure routing (VAPR), which is proposed in [19]. A routing technique called Clustered Vector-Based Forwarding (CVBF) is proposed in [20]. CVBF is designed for both sparse and dense areas of seawater. The authors claim that CVBF reduces end-to-end delay and improves the data delivery ratio. However, until the AUVs' missions to balance the energy consumption among sensor nodes are completed, cluster rebuilding for CH switching by AUVs is repeated in these protocols. Because of the high energy consumption of the aforementioned constraints, AUVs may run out of energy before finishing their missions. Additionally, the information transmission mechanism is improved in and the CHN determination conspires in In light of 3D solid shapes (EGRCs) for UWSNs, Wang et al. adopted an energy-efficient lattice guiding scheme wherein the organization is divided into piles of small blocks and each 3D square is perceived as a group [23]. Furthermore, the EGRC convention refines the CHN selection process and advances the quest cycle for the next bounce hub. That being said, the EGRC does not provide the information combination instrument's detail because overt information repetition may occur and should be reduced. To improve the display of UWSNs, a submerged bunching convention based on the fuzzy c means and the marshmallow advancement (FCMMFO) was presented in [24]. However, the multi-jump steering method has not been improved.

3. Proposed Method

The idea is to propose more effective data aggregation in UWSNs using hexagonal grids with energy optimization (IEDA-HGEO). The following are the characteristics of our recommended protocol: First, you want to cover as much ground as you can. We partitioned our WSN into hexagonal sections to cover the majority of nodes. Hexagonal cells are ideal for clustering in networks. Each cell has a single node that acts as the cluster head (CH), and to handle both data aggregation and transmission, the cluster head is chosen using a special technique that entails choosing the node in smaller cells with the highest residual energy and the closest location to the base station (BS).

3.1. Gateway Nodes are Deployed

The undersea network is composed of the Cluster Head and Surface Gateways (SG) (CH). Static nodes attached to buoys at the surface are called SGs. Their interfaces are acoustic and electromagnetic, respectively. SGs connect the undersea network to the Internet via an electromagnetic interface. To send and receive packets to the underwater network, SG uses an acoustic interface. Every SG may have one or more CHs connected to it. Figure 2 illustrates how CHs are positioned underwater at different depths in order to transfer packets from SGs to the active AUVs at the ocean floor and vice versa.

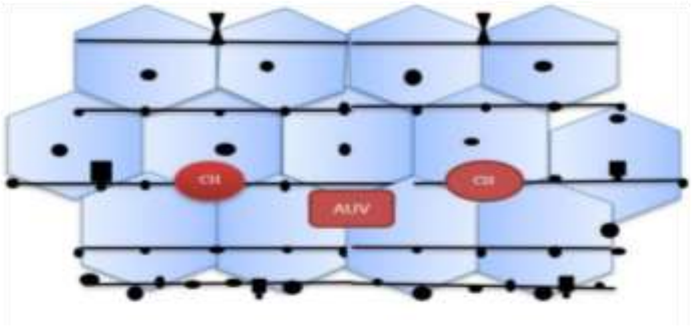
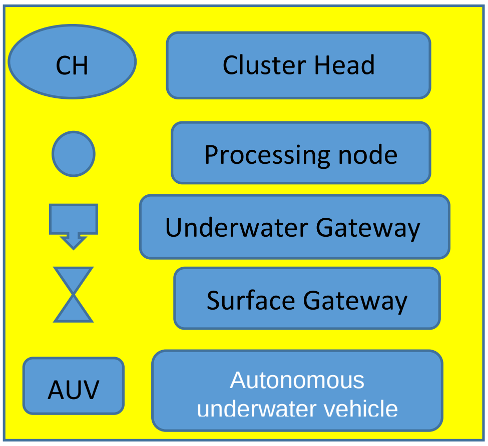


Figure 2. Node deployment in the network



The energy consumption plan of UWSNs differs from the energy-consuming strategy of WSNs because of the peculiarities of an underwater communication network. Equation (1) provides an example of the numerical answer.

$$E(\text{distance}, fc) = \text{EnergyTh}(\text{distance}, fa) \qquad (1)$$

I here stands for a node's frequency. It is equivalent to Equations (2) and (3)

$$fa = 10^{fa(fc)/10} \qquad (2)$$

$$fa(fc) = [\,0.11\,((fc)^2 *(\frac{1}{(1+fc)})^2) + 0.22\,((fc)^2 *(\frac{1}{(1+fc)})^2)\ldots\ldots + n\,((fc)^2 *(\frac{1}{(1+fc)})^n) \qquad (3)$$

Equation (4) can be used to characterize the private network's radial distance NR, node density ND, sector width RingW, hop limit MaxH, and total number of participants Np because each sensing device's exposure zone is boundary-based.

$$\mathbf{Np} = \sum_{i=0}^{n} NR * ND * MaxH * Ring * W \qquad (4)$$

From inside to outside, the UWSN's connectivity is segregated into several tiny ring portions or Ar1 to Arn. The maximum number of ring regions can be found using RingW/OT, where OT is the ideal connection path length threshold for sensing devices and RingW is the network radius. The maximum delay on the route is represented by Dlmax. When there is a connection between nodes I and J, the frequency of Yij equals 5. Yij's total value is 0 otherwise. We see multi-hop route search as a multi-objective optimization problem where the only goal is to find the optimal path at the lowest cost. The process of obtaining an objective formula (Fobj) is illustrated by Equations (5)–(7).

The proposed system architecture is shown in Figure 3.

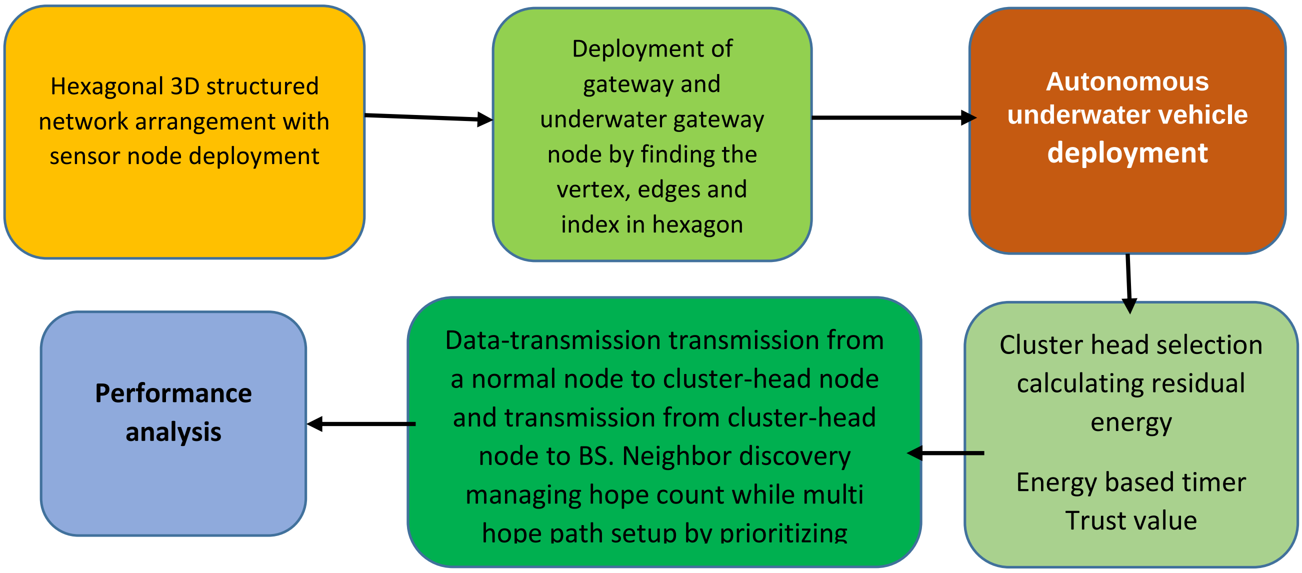


Figure 3. Proposed system architecture

$$\textbf{Min Fobj} = \sum_{i=1}^{n} \sum_{j=1}^{n} Yij * Dij \quad (5)$$

$$\textbf{Dij} = \textbf{Dtij MinPower Kij} + \textbf{Drj} \quad (6)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} Yij * Dij < \textbf{Dlmax} \quad (7)$$

3.2. Cluster Head Selection

Cluster heads are chosen in this study using two procedures: TCH and FCH selection. The cluster head is selected using a tentative CH selection procedure based on EBT and Trust Value. A timer is sent to the node, and trust values are computed using the node's total Trust value in order to select TCH. The node with the highest energy and trust value determines the TCH. The final cluster head is also displayed in Figure 4 and is determined by the anticipated head count, node degree, and competition range.

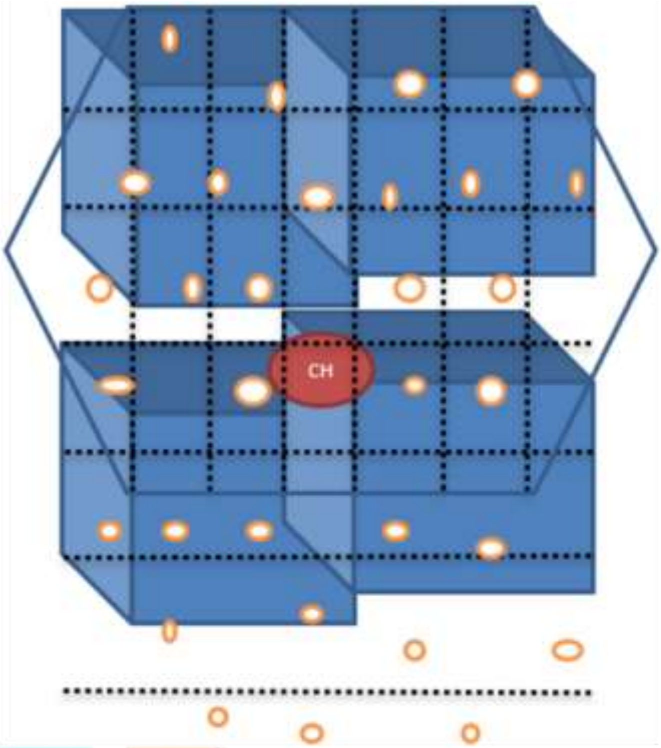


Figure 4. Clustering process at one coverage area

3.2.1. TCH Selection Based on Energy-Based Timer (EBT)

A timer is assigned to each sensor node based on its energy consumption. Energy determines the waiting times provided to the nodes. During this stage, high energy nodes are encouraged to become the possible new cluster leader. If not, the node with the highest transmission energy is CH. Here is the model description for this timer using an energy foundation. Let's assume that node I has k neighbors if every node is able to ascertain the average energy value of its neighbors. i1, i2, i3,... in... ik,, where in is the nth neighbor node, make up Si. Equation (8) provides the average energy of node I.

$$\textbf{Average Energy (i)} = {}_{0}\sum_{n=1}^{k} Energy(i_n) \qquad \mathbf{k > 0, k = 0} \qquad \mathbf{(8)}$$

TCH is chosen using an energy-based timer from the SNs. The following equation is utilized to evaluate the energy-based waiting time value for any sensor node ID S_i by Equation (9).

$$Wait\ time\ (S_i) = \frac{Avg\ Energy\ of\ si\ Neighbor\ node}{Energy\ of\ S_i} \qquad (9)$$

The above equation indicates that when node energy increases, waiting times are shorter. Higher energy nodes will have shorter waiting times. This node is selected to be the future Cluster Head. When this communication is received prior to the beginning of their waiting period, other SNs choose not to use CH selection. Within its broadcast range, a tentative CH message is broadcast by a selected tentative CH.

Fn collects information in a hierarchical manner. In its role as a parent node, Fn collects data from its progeny. With rdt representing the communication range and dth representing the Fnby Equation (10), the distance (d) between parent and child nodes is equal to 2rdt < d < 2Rf.

$$\mathbf{S = \{C \in S/\ 2r_{dt} < d_{F\_C} < 2R_f} \qquad \mathbf{(10)}$$

The total amount of data gathered at Fnis if each C transmits a packet of l bits by Equation (11).

$$\text{Fdata} = \sum_{i}^{|S|} \ell i$$

Following data gathering, we compute Fn's energy consumption using Equation (12) as follows:

$$\mathbf{E_{Fn}} = \mathbf{es} + (\mathbf{et} * \mathbf{R}(\textstyle\sum_{i}^{|S|} \ell i + \ell)\, \phi) + \mathbf{EDA} + \mathbf{SNR} \quad \mathbf{(12)}$$

where R is the radius, ' is the data aggregation factor, es is sensing energy, et is electronic energy per bit during transmission, and EDA is data aggregation energy.

The volume of S1 is evaluated as follows by Equation (13),

$$\mathbf{V_{s1}} = \int_0^r \int_0^{\pi/2} \int_0^{2\pi} \boldsymbol{\ell}^2 \cos\phi \, d\, \theta \, d\ell$$

$$= \pi \int_0^r (R^2 - Z^2)\, dz \quad \mathbf{(13)}$$

$$= \frac{2}{3}\pi R^3$$

Similarly, the volume of S2 is evaluated as follows by Equations (14) and (15),

$$\mathbf{V_{s2}} = \frac{2}{3}\pi R^3 \quad (14)$$

$$\mathbf{V_{s2}} = \mathbf{V_{s2}} - \mathbf{V_{s1}}$$

$$= \frac{2}{3}\pi (R^3 - r^3) \quad (15)$$

If the node density of the network is y, then Equations (16) and (17) yield the number of nodes in the limited spherical section.

$$\mathbf{N_{ss}} = \frac{2}{3}\pi\, \psi(R^3 - r^3) \times \ell \quad (16)$$

$$\sum_{Fn-all}^{rcv} = \boldsymbol{\ell}_{\mathbf{r}} + \frac{2}{3}\pi\, \psi(R^3 - r^3) \times \ell \quad (17)$$

3.2.2. Trust Value-Based TCH Selection

Trust Value (TV) is used to determine node behavior, node quality, and node services. It is also used for data collection, reconfiguration, and routing of sensor nodes. It provides a way to determine SNs' trustworthiness. The trust value is used in this study to collect data and monitor different node behaviors. Trust value and an Energy-based Timer (EBT) are used to identify possible CH. Tentative CH selection makes use of the EBT and TV methodologies in order to optimize the efficacy of optimal CH selection. The equation (18) below is used to calculate the trust value of nodes.

$$\textbf{Trust Value (TV)}_{\textbf{nodes}} = \frac{\mathbf{N_{FD}}}{\mathbf{N_{REC}}} \quad \mathbf{(18)}$$

where NREC denotes the number of packets received and NFD denotes the number of packets forwarded. Once the trust values of each individual node have been established, the node with the highest trust value is selected as the temporary cluster leader. After then, the last CH procedure is completed. The outcome of the TCH selection is finally returned by the EBT and the TV.

3.3. Transfer of Data

To begin network operation and route discovery, every node exchanges a handshake with every other node and shares its properties with the node that came before it in the route. The neighbor node is chosen by utilizing the position property that was collected during handshaking to calculate the distance between the two nodes. Every node must be handshaking with other nodes in order to determine the path. Node N1 is chosen as the source node when a route is found, and the other nodes are considered while choosing the best neighbor node. At the moment, N1 is communicating with every other node by sending "HELLO" messages and getting "REPLY" responses in return. The suggested data transmission flowchart is shown in Figure 5.

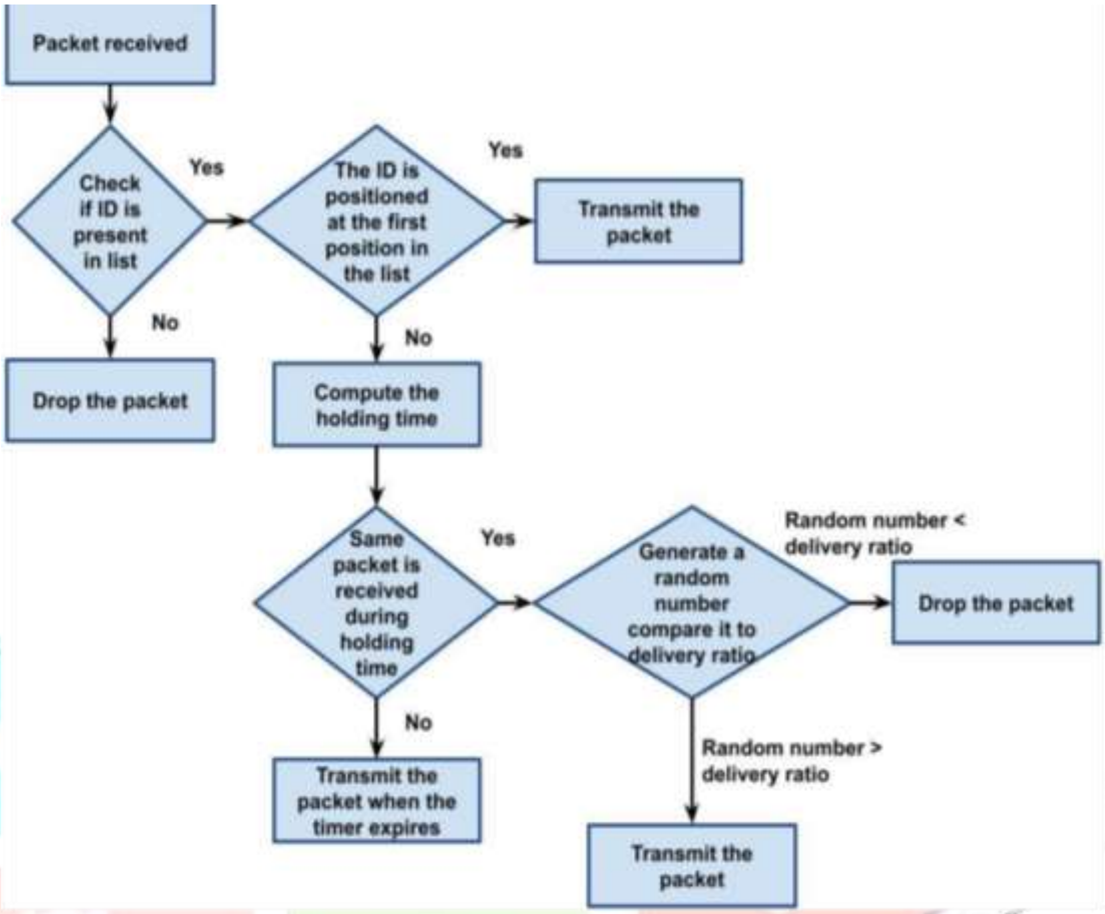


Figure 5. Proposed data transmission flowchart.

Node N2 now receives a message from node N1, and it starts sending "HELLO" packets to every other node and getting "REPLY" messages in return. Similar methods can be used to obtain multipath between the source and destination nodes.

For every transmission, the forwarder measures the candidate node's distance from the sink and the forwarder. As the value decreases, the priority increases. Each forwarder set's highest priority node is the first to be expanded, then those whose distances are less than the node transmission radius (Cr), and lastly, those in the Ci whose distances are less than the communication radius for every node currently in the cluster. After making the computation, the forwarder selects the set with the highest priority as the next-hop forwarder set. The remaining forwarder set will only send the packets in order if the highest priority set is unable to transmit.

To balance energy consumption, we divide the node's initial energy into m equal halves and insert an EL. A node's EL is i (1 i m) if its current energy is more than i 1 parts and less than or equal to I parts. During the constant data transmission phase, each uw-sensor has two transmission options: either send the packets via MT or send them directly to the uw-sink (DT). The suggested IEDA_HEGO system is represented by Algorithm 1.

Algorithm 1: Algorithm of IEDA-HGEO.

Require:

- Set_rn(SN, SN_x) _ + USet _ rn(SN)

Initially : HC(rn_x) = 0

hop _ set (rn_y) = 0

Ensure:

- SN_{Ry} : elected as RN

1: if USet rn(SN) =null then

2 : Elect RN

(USet _rn(SN) is a set of SN responding to SPK packets to NN)

3 : USet_rn (SN) = USet_ rn(SN) + Set rn (SN_y, SN_x)

where SN_y ϵ SN_{Ry}, with a value of Set_ rn (SN_y, SN_x) in RPKpacket

4 : HC(rn_x) = HC(rn_x) + 1

5 : Repeat Steps 1 to 5 to elect the next neighbour node for SN_y Dest_Node

6 : hop_set (rn_y) = hop set (my) + 1

Return

5 : end if

8: if no SPK control packets are returned, then

10: End if

11 : for every SPK is generated from SN_z do

15: compute Confidence_level using Equation (4)

16 : USet rn(SN) = USet rn(SN)+ Set rn(SN_z, SN_x)

17 : if Confidence_level(y) < Confidence_level(z)) then

18 : Remove SN_{Ry} from USet rn(SN)

19 : Add the SN_{Rz} as the next node for SN_x

20: end if

21 : drop this SPK control packet

22: end for

23: HC(SN_x) = HC(SN_x) + 1

4. Experimental Analysis

Table 1 displays settings for a number of different parameters. In contrast to previous research, the network is implemented in three dimensions. The area measures three thousand two thousand and fifty meters. There are 1055 sensor nodes at the surface of the water where BS is situated. Nodes are dispersed randomly over a distance of 1000–250 meters. Three to four hops are required for packet delivery within the 260-meter transmission radius of SN. Four packet sizes are available: 1500, 2000, 3000, and 4000 bytes. Network connectivity is achieved with the help of RNs, CHs, and CCOs. The sizes of the control packets for SPK and RPK are set to 9B and 13B, respectively. For link quality in IEDA-HGEO, a leveling parameter of 0.85 has been chosen. The transmission power is set at 1.5 W for control packets and 2.8 W for data packets. Random packets may be generated by the SNs; these packets should be forwarded to the BS via the chain consisting of the RNs, CHs, and CCOs. 4300 packets with varying payload counts are produced in the simulations, and energy consumption is recorded. The trials were conducted using the MATLAB simulator (R2021a). It was created by MathWorks and is a condensed form of "matrix and laboratory." Matplotlib provides a comprehensive solution for research inquiries, structural engineering, and a wide spectrum of scientific difficulties requiring accurate numerical estimations.

This section assesses and contrasts the performance of the two widely-used routing protocols, ERP2R and EGRC, with that of the suggested enhanced efficient data aggregation in IEDA-HGEO. These two algorithms were selected since the approach under discussion shares the same objectives with them and is well-known in the literature. The EE-DHS's performance is evaluated using the following metrics: Table 2 shows the factors that include energy consumption, energy efficiency, throughput, network longevity, and latency.

Table 1. Simulation parameters.

Parameters	Value
Network area	1000 2000 250 m^3
Transmission radius	260 m
Number of nodes	1055
Size of data packets	1500, 2000, 3000, and 4000 bytes
Transmission power for data packet	2.8 (W)
RPK and SPK control packets size	13 bytes and 9 bytes
Transmission power for a control packet	1.5 (W)

Table 2. Comparison of various parameters for the proposed protocol.

Parameters	**ERP^2R**	**EGRC**	**IEDA-HGEO [Proposed]**
Energy consumption	55	51	48
Efficiency	88	92	95
Throughput	91	93	95
Packet delivery ratio	85	87	92
Delay	45	43	41

The amount of energy required by each individual node to process information is referred to as its energy consumption. Energy expenditure during data transmission from the packet to linked element "j" is described by Equation Eelec* k (1). Equation (19) shows how the K bit of the data packet uses energy to represent sensing element I while receiving it.

$$Tx(x,y) = Eene*M + Eamp * d2(x,y) *M \quad (19)$$

Weight between connected nodes I and j are denoted by dij. When one bit of energy is transmitted, Equation (20) is

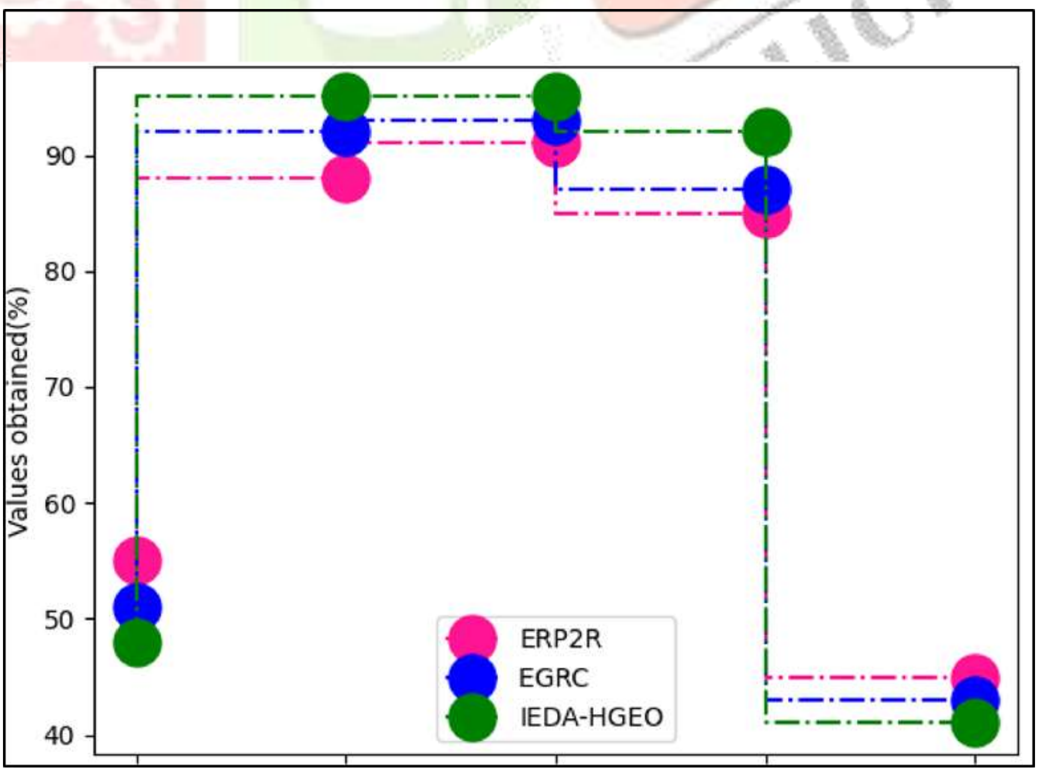
$$etx(d)= pd1 + ptd*dn \quad (20)$$

where ptd is the energy needed to move the nodes across a large distance, and pd1 is the power lost when transferring one piece of data.

The energy usage of our proposed EE-DHS, which leads to 30% higher resource conservation, is depicted in Figure 6. Presently, 50% and 65% of the resources are used by ERP2R and EGRC, respectively. By dividing the total quantity of data packets generated by the source by the number of data packets that were successfully delivered, data PDR is computed, as illustrated in Figure 6. When the system is in operation, it is typical for certain nodes to have low energy levels and other nodes to have high energy levels. Nodes with very little energy left have to reduce their energy use because they will soon reach the end of their operational lives. Packet delivery ratio trace files are post-processed in order to ascertain the data packet delivery ratio. more especially, the connection between sent and received packets. Throughput is the average rate of messages that are successfully delivered over a communication channel. This data may pass through a particular network node or a logical or physical link. Although it can also be stated in data packets per second, the throughput is commonly expressed in bits per second.

Figure 6. Parametric comparison between proposed and existing techniques

Talk: Rather of focusing on actual implementation, this study focuses on reproduction analysis. A boat on the ocean's surface and a large number of submerged sensor hubs are needed for the actual execution. The hubs are furnished with sensors to detect and procure data, a battery to give energy, a memory gadget to store information, a processor to accomplish controlling and handling capabilities, an acoustic modem to accomplish submerged remote acoustic correspondences, a power enhancer, the waterproof gadget, etc. In terms of performance, the hubs should be quick, steady, and energy-efficient. They must ensure that no data is lost with the passing of hubs and have an enormous stockpiling limit in memory. We're trying to achieve low dormancy, low mistake rate, and large distance interchanges using the submerged distant correspondence innovation.



5. Conclusions

The two main issues in the field of underwater acoustic sensor networks networking in the future will be network coverage and energy usage. An enhanced energy-efficient data collection technique for hexagonal grid layouts in wireless sensor networks was presented in this paper: the IEDA-HGEO algorithm. In this case, the data transmission mechanism is a grid structure with multi-hop routing, and the parameters that determine the next hop are energy, distance, and end-to-end delay. We thoroughly evaluated our proposed technique with two other well-known routing methods, the ERP2R and EGRC, with respect to energy usage, throughput, PDR, and latency. Simulation results showed that our method successfully prolonged network lifetime and outperformed existing approaches. Proposed method achieved the following metrics: delay 41%, energy consumption 48%, efficiency 95%, throughput 95%, and PDR 92%.

References

1. Lilhore, U.K.; Khalaf, O.I.; Simaiya, S.; Tavera Romero, C.A.; Abdulsahib, G.M.; Kumar, D. A depth-controlled and energy-efficient routing protocol for underwater wireless sensor networks. Int. J. Distrib. Sens. Netw. **2022**, 18, 15501329221117118. [CrossRef]

2. Khan, Z.A.; Karim, O.A.; Abbas, S.; Javaid, N.; Zikria, Y.B.; Tariq, U. Q-learning based energy-efficient and void avoidance routing protocol for underwater acoustic sensor networks. Comput. Netw. **2021**, 197, 108309. [CrossRef]

3. Yang, Y.; Wu, Y.; Yuan, H.; Khishe, M.; Mohammadi, M. Nodes clustering and multi-hop routing protocol optimization using hybrid chimp optimization and hunger games search algorithms for sustainable energy efficient underwater wireless sensor networks. Sustain. Comput. Inform. Syst. **2022**, 35, 100731. [CrossRef]

4. Iqbal, S.; Hussain, I.; Sharif, Z.; Qureshi, K.H.; Jabeen, J. Reliable and energy-efficient routing scheme for underwater wireless sensor networks (UWSNs). Int. J. Cloud Appl. Comput. (IJCAC) **2021**, 11, 42–58. [CrossRef]

5. Subramani, N.; Mohan, P.; Alotaibi, Y.; Alghamdi, S.; Khalaf, O.I. An efficient metaheuristic-based clustering with routing protocol for underwater wireless sensor networks. Sensors **2022**, 22, 415. [CrossRef]

6. Liu, Z.; Jin, X.; Yang, Y.; Ma, K.; Guan, X. Energy-efficient guiding-network-based routing for underwater wireless sensor networks. IEEE Internet Things J. **2022**, 9, 21702–21711. [CrossRef]

7. Nain, M.; Goyal, N. Energy efficient localization through node mobility and propagation delay prediction in underwater wireless sensor network. Wirel. Pers. Commun. **2022**, 122, 2667–2685. [CrossRef]

8. Gola, K.K.; Gupta, B. Underwater acoustic sensor networks: An energy efficient and void avoidance routing based on grey wolf optimization algorithm. Arab. J. Sci. Eng. **2021**, 46, 3939–3954. [CrossRef]

9. Chaaf, A.; Saleh Ali Muthanna, M.; Muthanna, A.; Alhelaly, S.; Elgendy, I.A.; Iliyasu, A.M.; El-Latif, A.; Ahmed, A. Energy-efficient relay-based void hole prevention and repair in clustered multi-AUV underwater wireless sensor network. Secur. Commun. Netw. **2021**, 2021, 9969605. [CrossRef]

10. Menaka, D.; Gauni, S. An energy efficient dead reckoning localization for mobile Underwater Acoustic Sensor Networks. Sustain. Comput. Inform. Syst. **2022**, 36, 100808. [CrossRef]

11. Mohan, P.; Subramani, N.; Alotaibi, Y.; Alghamdi, S.; Khalaf, O.I.; Ulaganathan, S. Improved metaheuristics-based clustering with multihop routing protocol for underwater wireless sensor networks. Sensors **2022**, 22, 1618. [CrossRef]

12. Khan, Z.U.; Gang, Q.; Muhammad, A.; Muzzammil, M.; Khan, S.U.; Affendi, M.E.; Ali, G.; Ullah, I.; Khan, J. A Comprehensive Survey of Energy-Efficient MAC and Routing Protocols for Underwater Wireless Sensor Networks. Electronics **2022**, 11, 3015. [CrossRef]

13. Wang, C.; Shen, X.; Wang, H.; Mei, H. Energy-efficient collection scheme based on compressive sensing in underwater wireless sensor networks for environment monitoring over fading channels. Digit. Signal Process. **2022**, 127, 103530. [CrossRef]

14. Chenthil, T.R.; Jesu Jayarin, P. An energy-efficient distributed node clustering routing protocol with mobility pattern support for underwater wireless sensor networks. Wirel. Netw. **2022**, 28, 3367–3390. [CrossRef]

15. Moussaoui, D.; Hadjila, M.; Irid, S.M.H.; Souiki, S. Clustered chain founded on ant colony optimization energy efficient routing scheme for under-water wireless sensor networks. Int. J. Electr. Comput. Eng. **2021**, 11, 5197. [CrossRef]

16. Noorbakhsh, H.; Soltanaghaei, M. EEGBRP: An energy-efficient grid-based routing protocol for underwater wireless sensor networks. Wirel. Netw. **2022**, 28, 3477–3491. [CrossRef]

17. Sivakumar, V.; Kanagachidambaresan, G.R.; Arif, M.; Jackson, C.; Arulkumaran, G. Energy-Efficient Markov-Based Lifetime Enhancement Approach for Underwater Acoustic Sensor Network. J. Sens. **2022**, 2022, 3578002. [CrossRef]

18. Anuradha, D.; Subramani, N.; Khalaf, O.I.; Alotaibi, Y.; Alghamdi, S.; Rajagopal, M. Chaotic search-and-rescue-optimization-based multi-hop data transmission protocol for underwater wireless sensor networks. Sensors **2022**, 22, 2867. [CrossRef]

19. Goutham, V.; Harigovindan, V.P. Full-duplex cooperative relaying with NOMA for the performance enhancement of underwater acoustic sensor networks. Eng. Sci. Technol. Int. J. **2021**, 24, 1396–1407. [CrossRef]

20. Su, Y.; Li, L.; Fan, R.; Liu, Y.; Jin, Z. A Secure Transmission Scheme with Energy-Efficient Cooperative Jamming for Underwater Acoustic Sensor Networks. IEEE Sens. J. **2022**, 22, 21287–21298. [CrossRef]

21. Sampathkumar, A.; Mulerikkal, J.; Sivaram, M. Glowworm swarm optimization for effectual load balancing and routing strategies in wireless sensor networks. Wirel. Netw. **2020**, 26, 4227–4238. [CrossRef]

22. Murugan, S.; Sampathkumar, A.; Kanaga Suba Raja, S.; Ramesh, S.; Manikandan, R.; Gupta, D. Autonomous Vehicle Assisted by Heads up Display (HUD) with Augmented Reality Based on Machine Learning Techniques. In Virtual and Augmented Reality for Automobile Industry: Innovation Vision and Applications; Hassanien, A.E., Gupta, D., Khanna, A., Slowik, A., Eds.; Studies in Systems, Decision and Control; Springer: Cham, Switzerland, 2022; Volume 412. [CrossRef]

23. Reshma, G.; Al-Atroshi, C.; Nassa, V.K.; Geetha, B.; Sunitha, G.; Galety, M.G.; Neelakandan, S. Deep Learning-Based Skin Lesion Diagnosis Model Using Dermoscopic Images. Intell. Autom. Soft Comput. **2022**, 31, 621–634.

24. Arun, A.; Bhukya, R.R.; Hardas, B.M.; Kumar, T.C.A.; Ashok, M. An Automated Word Embedding with Parameter Tuned Model for Web Crawling. Intell. Autom. Soft Comput. **2022**, 32, 1617–1632.

25. Li, G.; Liu, F.; Sharma, A.; Khalaf, O.I.; Alotaibi, Y.; Alsufyani, A.; Alghamdi, S. Research on the natural language recognition method based on cluster analysis using neural network. Math. Probl. Eng. **2021**, 2021, 9982305. [CrossRef]

26. Alsufyani, A.; Alotaibi, Y.; Almagrabi, A.O.; Alghamdi, S.A.; Alsufyani, N. Optimized intelligent data management framework for a cyber-physical system for computational applications. Complex Intell. Syst. **2021**, 1–13. [CrossRef]