

Implementation and Iterative Analysis of LEACH and Its Variants in UWSN Protocols

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ABSTRACT

The LEACH protocol is widely used for analysing and simulating underwater wireless sensor networks (UWSNs). This paper examines the impact of varying parameter values in the LEACH protocol and presents simulation results. The findings indicate that commonly used parameters are applicable only to specific network environments. Underwater wireless sensor networks (UWSNs) have gained significant research attention due to their diverse applications. These networks consist of numerous small sensor nodes powered by self-charged batteries. While some nodes allow battery replacement, others operate in environments where changing the power source is impractical. As a result, network degradation over time poses a major challenge, making prolonging the lifespan of UWSNs a critical research focus. Several UWSN protocols have been developed to enhance network longevity. This study explores LEACH and its modified versions, including V-LEACH, TL-LEACH, S-LEACH, and Multi-hop LEACH, to evaluate their effectiveness in wireless sensor networks. LEACH and Multi-hop LEACH are simulated using NS2, and their performance is assessed through detailed charts and comparative analysis to validate the efficiency of these protocols.

Keywords: LEACH, V LEACH, TL LEACH, S LEACH, Multi-hop LEACH, Network Simulator

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INTRODUCTION

The rapid advancement in wireless communication has enabled the development of small, durable, cost-effective, and easy-to-handle sensors capable of monitoring the environment, processing data, and transmitting signals to users from remote locations. Underwater Wireless Sensor Networks (UWSN) are widely used in applications such as environmental pollution and weather forecasting, remote healthcare, air traffic monitoring, military surveillance, force protection, early warning systems, and post-disaster search and rescue operations. Wireless sensor network (WSN) nodes require energy to communicate and transmit data to other nodes and the base station[1]. However, since these sensor nodes are battery-operated and often deployed in remote or hostile environments, battery replacement or recharging is challenging. Data in these networks is routed through multiple nodes using a routing protocol that ensures efficient communication[2]. The key challenge in WSN technology is designing an energy-efficient routing protocol to minimize power consumption, enhance sensor node performance, and extend network lifespan.

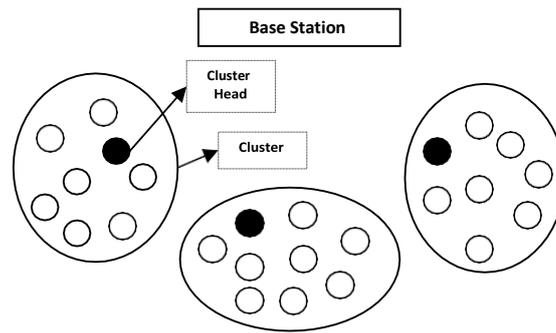


Fig. 1 UWSN arrangement of BS & CH

This protocol estimates energy consumption using a radio model during data transmission[3]. The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol comprises numerous associate nodes along with a cluster head. The cluster head is responsible for gathering data from member nodes, compressing it, and transmitting it to the base station. To prevent data collision, each node is assigned a specific time slot for communication.

OBJECTIVES

LEACH Model: An Energy-Efficient Hierarchical Routing Protocol

LEACH (Low-Energy Adaptive Clustering Hierarchy) is an energy-efficient hierarchical routing protocol that utilizes a clustering approach to minimize energy consumption during data transmission. In this method, sensor nodes are grouped into clusters, with one node designated as the cluster head. The cluster head aggregates and compresses the collected data before transmitting it to the base station. Non-cluster head nodes communicate exclusively with their cluster head using a TDMA-based schedule, ensuring efficient data transfer and reduced energy usage[4].

Comparison of LEACH and Modified LEACH Protocols

Every routing protocol has its strengths and limitations. To enhance their performance, it is essential to analyze and compare different LEACH variants[5]. Through such comparisons, modifications can be made to optimize the protocol for better energy efficiency and network performance.

V-LEACH (Vice Cluster-LEACH)

The cluster head (CH) in traditional LEACH depletes energy quickly, leading to early failure[6]. V-LEACH introduces a vice cluster head (VCH), selected based on the residual energy of sensor nodes. When the CH fails, the VCH takes over, ensuring uninterrupted operation[7]. Simulation results indicate that V-LEACH extends network lifetime by approximately 12.5%. It also consumes less energy than LEACH over a specific number of rounds.

TL-LEACH (Two-Level LEACH)

Routing sensor data from Sensor Nodes (SN) to the Base Station (BS) in Underwater Wireless Sensor Networks (UWSN) is challenging due to constraints like limited energy, low memory, and processing power. TL-LEACH introduces a two-level hierarchical structure to improve energy efficiency[8]. The protocol minimizes communication overhead and enhances the robustness of communication between end-nodes, cluster heads, and the BS. However, two key drawbacks are: Limited scalability for large-scale UWSN applications[9]. Challenges in ensuring robust communication among nodes.

Multi-Hop LEACH

We evaluate the efficiency of the Low-Energy Adaptive Clustering Hierarchy (LEACH) and its variants in prolonging the lifespan of energy-constrained Underwater Wireless Sensor Networks (UWSNs) [15]. To enhance energy efficiency and ensure balanced consumption, an improved LEACH-based clustering protocol, known as Enhanced Multi-Hop LEACH, is introduced[10]. This approach aims to optimize energy usage, increase packet delivery rates, and extend the overall network lifetime in UWSNs [16].

S-LEACH (Solar-Aware Low Energy Adaptive Clustering Hierarchy)

S-LEACH is designed to extend the lifespan of sensor nodes and improve network stability. This protocol leverages solar-powered sensor nodes for energy-intensive tasks, assigning them as cluster heads[11]. By utilizing solar energy, S-LEACH enhances the power availability of isolated sensor nodes, thereby improving overall network performance [17].

METHODS

Wireless Sensor Networks (WSNs) play a crucial role in various mission-critical applications, including battlefield search and rescue operations in remote and inaccessible areas. These sensor nodes are deployed in locations where manual intervention for battery replacement is not feasible. Due to this limitation, ensuring an extended network lifetime becomes a significant challenge in WSNs[12]. To address this issue, various energy-efficient routing protocols have been developed, among which S-LEACH (Solar Low Energy Adaptive Clustering Hierarchy) stands out as an effective solution[13].

S-LEACH is an enhancement of the traditional LEACH protocol, incorporating solar-powered sensor nodes that serve as cluster heads (CHs). The selection of CHs in S-LEACH is based on a combination of the available solar energy and the residual energy within the sensor nodes[14]. This hybrid approach ensures that nodes with a higher energy supply take on leadership roles, reducing the burden on battery-powered nodes and thereby extending the overall network lifespan.

Simulation Parameters and Performance Analysis

To evaluate the effectiveness of the LEACH and its modified versions, we conducted a series of simulations using specific parameter values[15]. These simulations provided insights into various network metrics, including energy consumption, average distance between nodes, and network lifetime. The key findings from our simulations are as follows:

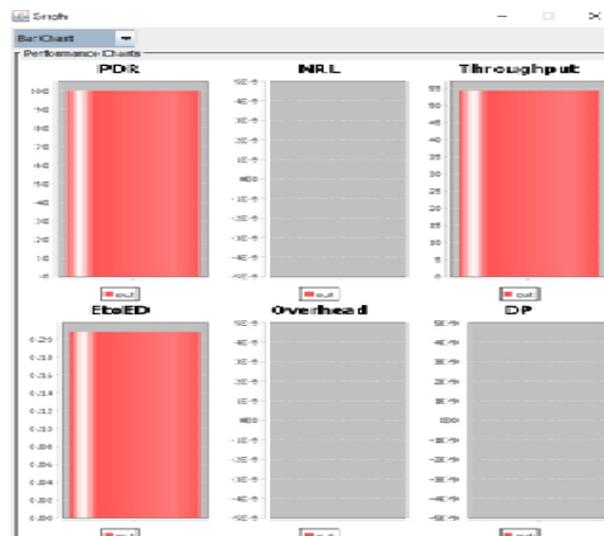


Fig. 2 Graphical Structure of Different Parameter

Average Energy Consumption: The mean energy consumed by the sensor nodes was recorded at 9.61349 units, while the total energy consumed across the network amounted to 96.1349 units. **Node Distribution and Distance Metrics:** The average distance between two sensor nodes in the simulation environment was maintained at **X: 150, Y: 150**. This parameter is crucial for assessing communication overhead and energy efficiency in data transmission[16].

Significance of Routing Protocols in WSNs

Routing is a critical aspect of WSNs, as it determines the optimal paths for data transmission between nodes. Over the years, extensive research has been conducted to develop efficient routing protocols that enhance network lifetime, reliability, and data delivery rates. In this study, we have analyzed and discussed the LEACH routing protocol in detail. LEACH is a well-known hierarchical clustering algorithm designed to minimize energy consumption and extend network lifespan by rotating CHs periodically[17]. Despite its advantages, LEACH also has certain limitations, such as unbalanced energy distribution among nodes, leading to premature network failures[18].

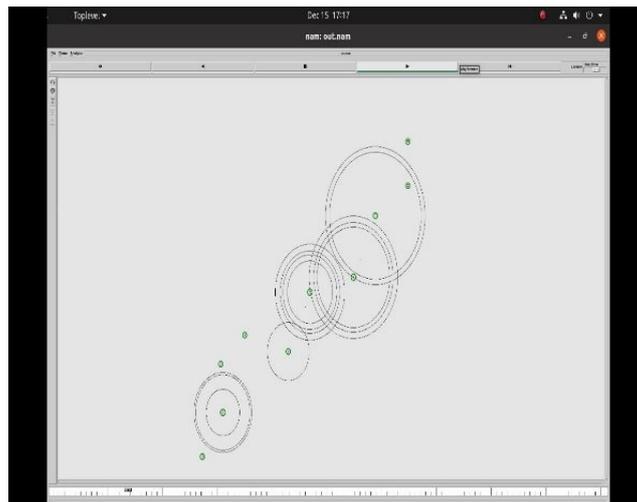


Fig. 3 Snapshot of NS2 Implementation of UWSN

Comparative Analysis of LEACH and Its Variants

Our study compares the performance of LEACH with its successors, including S-LEACH and other hierarchical protocols. The results from our simulations and previous research indicate that several key network performance parameters are affected by these routing modifications[19].

Sr. No.	Parameter Name	Value
1	Sent Packet	39
2	Received Packet	39
3	Dropped Packet & Overhead	00
4	Dropped Bytes	00
5	EtoE Delay	0.21
6	Packet Delivery Ratio	100%
7	Throughput	54.34
8	Normalized Routing Load	00%

Table 1 Test Parameter Value

Alive and Dead Nodes: The number of active (alive) and inactive (dead) nodes over time provides a clear indication of the energy efficiency of different routing protocols. Our analysis showed variations in node survival rates when LEACH was compared to its modifications, such as S-LEACH and other hierarchical techniques.

Packet Transmission to Base Station (BS): The total number of packets successfully delivered to the BS was evaluated. Efficient routing protocols should maximize packet transmission while minimizing energy expenditure.

Cluster Head Selection and Network Energy: Different criteria for CH selection affect the overall network energy consumption and lifetime. S-LEACH's solar-assisted CH selection resulted in a more balanced energy utilization compared to the traditional LEACH protocol.

Outcomes of Simulation

Clustering routing protocol	Randomizedrotation	Distributed	Centralized
LEACH	Yes	Yes	No
V LEACH	Yes	Yes	Yes
TL LEACH	Yes	Yes	Yes
MUTIHOP LEACH	Yes	Yes	No
S LEACH	Yes	Yes	Yes

Clustering routing protocol	Classification	Mobility	Scalability	Self-organization
LEACH	Hierarchical	Fixed BS	Limited	Yes
V LEACH	Hierarchical	Fixed BS	Very good	Yes
TL LEACH	Hierarchical	Fixed BS	Very good	Yes
MUTIHOP LEACH	Hierarchical	Mobile BS and nodes	Very good	Yes
S LEACH	Hierarchical	Fixed BS	Good	Yes

Clustering routing protocol	Hop count	Energy efficiency	Resource awareness
LEACH	Single Hop	High	Good
V LEACH	Single Hop	Very High	Very good
TL LEACH	Multi Hop	Very High	Very good
MUTIHOP LEACH	Single Hop	Very High	Very good
S LEACH	Single Hop	Very High	Very good

Throughput and Packet Delivery Ratio: The network throughput and packet delivery ratio were observed to vary across different protocols. Hierarchical routing modifications influenced these metrics based on the parameters used in our simulations.

Impact on Network Lifetime

One of the primary objectives of this study was to analyze how different routing protocols impact the overall network lifetime. Hierarchical protocols, such as S-LEACH, introduce additional parameters that contribute to extended network operation.

Clustering routing protocol	Randomizedrotation	Distributed	Centralized
LEACH	Yes	Yes	No
V LEACH	Yes	Yes	Yes
TL LEACH	Yes	Yes	Yes
MUTIHOP LEACH	Yes	Yes	No
S LEACH	Yes	Yes	Yes

Our comparisons indicated that: Networks implementing energy-efficient CH selection strategies, such as those based on solar power availability, exhibited prolonged operational durations. The use of multiple routing criteria, including energy levels and solar charging capabilities, improved network stability and data transmission reliability. Protocols that adaptively select CHs based on dynamic parameters demonstrated better resilience against energy depletion[20].

CONCLUSION

This paper explores modified versions of the LEACH protocol, analyzing how each variant addresses specific aspects of clustering-based routing. It highlights that further improvements in energy efficiency can be achieved by refining cluster head (CH) selection techniques. Enhancing these parameters will improve network performance, impacting various applications of Underwater Wireless Sensor Networks (UWSNs) across industries such as manufacturing, robotics, and agriculture. The study emphasizes the significance of energy-efficient routing protocols in optimizing Wireless Sensor Networks (WSNs). By utilizing solar-powered CHs, S-LEACH offers a practical solution to the energy limitations of traditional LEACH-based networks. Simulation results confirm the effectiveness of this approach, showing notable improvements in network lifespan, energy consumption, and data transmission reliability. Future research should focus on optimizing CH selection mechanisms, integrating machine learning for adaptive routing, and exploring hybrid energy-harvesting techniques to support sustainable and efficient WSN deployments in real-world applications.

REFERENCES

- [1] Y. Yuan, M. Liu, X. Zhuo, Y. Wei, X. Tu, and F. Qu, "A Q-Learning-Based Hierarchical Routing Protocol With Unequal Clustering for Underwater Acoustic Sensor Networks," *IEEE Sens J*, vol. 23, no. 6, pp. 6312–6325, 2023, doi: 10.1109/JSEN.2022.3232614.
- [2] X. Geng and B. Zhang, "Deep Q-Network-Based Intelligent Routing Protocol for Underwater Acoustic Sensor Network," *IEEE Sens J*, vol. 23, no. 4, pp. 3936–3943, 2023, doi: 10.1109/JSEN.2023.3234112.
- [3] A. Datta and M. Dasgupta, "Energy efficient topology control in Underwater Wireless Sensor Networks," *Computers and Electrical Engineering*, vol. 105, p. 108485, 2023, doi: <https://doi.org/10.1016/j.compeleceng.2022.108485>.
- [4] P. Bedi, S. B. Goyal, J. Kumar, and S. Kumar, "Chapter 8 - Analysis of energy-efficient cluster-based routing protocols for heterogeneous WSNs," in *Comprehensive Guide to Heterogeneous Networks*, K. Ahuja, A. Nayyar, and K. Sharma, Eds., Academic Press, 2023, pp. 217–247. doi: <https://doi.org/10.1016/B978-0-323-90527-5.00003-4>.
- [5] P. Gou, B. Guo, M. Guo, and S. Mao, "VKECE-3D: Energy-Efficient Coverage Enhancement in Three-Dimensional Heterogeneous Wireless Sensor Networks Based on 3D-Voronoi and K-Means Algorithm," *Sensors*, vol. 23, no. 2, Jan. 2023, doi: 10.3390/s23020573.
- [6] M. Ayaz, M. Ammad-Uddin, Z. Sharif, M. Hijji, and A. Mansour, "A hybrid data collection scheme to achieve load balancing for underwater sensor networks," *Journal of King Saud University - Computer and Information Sciences*, vol. 35, no. 3, pp. 74–86, Mar. 2023, doi: 10.1016/j.jksuci.2023.02.006.
- [7] M. Dehghani, Z. Montazeri, E. Trojovská, and P. Trojovský, "Coati Optimization Algorithm: A new bio-inspired metaheuristic algorithm for solving optimization problems," *Knowl Based Syst*, vol. 259, Jan. 2023, doi: 10.1016/j.knosys.2022.110011.
- [8] Z. Zhang, S. Tian, and Y. Yang, "Node Depth Adjustment Based Target Tracking in Sparse Underwater Sensor Networks," *J Mar Sci Eng*, vol. 11, no. 2, Feb. 2023, doi: 10.3390/jmse11020372.
- [9] X. Xue, R. Shanmugam, S. K. Palanisamy, O. I. Khalaf, D. Selvaraj, and G. M. Abdulsahib, "A Hybrid Cross Layer with Harris-Hawk-Optimization-Based Efficient Routing for Wireless Sensor Networks," *Symmetry (Basel)*, vol. 15, no. 2, Feb. 2023, doi: 10.3390/sym15020438.
- [10] S. Joshi, T. P. Anithaashri, R. Rastogi, G. Choudhary, and N. Dragoni, "IEDA-HGEO: Improved Energy Efficient with Clustering-Based Data Aggregation and Transmission Protocol for Underwater Wireless Sensor Networks," *Energies (Basel)*, vol. 16, no. 1, Jan. 2023, doi: 10.3390/en16010353.
- [11] Mr. Bhaumik Machhi and Dr. Paresh P Kotak, "UWSN for Real-time Underwater Observation Technique for Freshwater (River/Lake) Section A-Research paper Eur," 2023. Accessed: Sep. 05, 2024. [Online]. Available: <https://www.eurchembull.com/archives/volume-12/issue-7/6650>
- [12] Mr. Bhaumik Machhi and Dr. Paresh P kotak, "An Implementation & Iterative study on LEACH and Its Different Versions of Protocol of UWSN," 2023. Accessed: Sep. 05, 2024. [Online]. Available: <https://www.eurchembull.com/archives/volume-12/issue-5/6169>

- [13] Q. Zhang and Y. Liu, "An energy cooperation method of wireless sensor networks based on partially observable Markov decision processes," *Sustainable Energy Technologies and Assessments*, vol. 55, p. 102997, 2023, doi: <https://doi.org/10.1016/j.seta.2022.102997>.
- [14] A. Vyas and S. Puntambekar, "Cluster Based Leach Routing Protocol and Its Successor: A Review," *JOURNAL OF SCIENTIFIC RESEARCH*, vol. 66, no. 01, pp. 326–341, 2022, doi: [10.37398/jsr.2022.660135](https://doi.org/10.37398/jsr.2022.660135).
- [15] M. Nagarajan, N. Janakiraman, and C. Balasubramanian, "A new routing protocol for WSN using limit-based Jaya sail fish optimization-based multi-objective LEACH protocol: an energy-efficient clustering strategy," *Wireless Networks*, vol. 28, Jul. 2022, doi: [10.1007/s11276-022-02963-5](https://doi.org/10.1007/s11276-022-02963-5).
- [16] H. H. Rizvi, S. A. Khan, and R. N. Enam, "Clustering Base Energy Efficient Mechanism for an Underwater Wireless Sensor Network," *Wirel Pers Commun*, vol. 124, no. 4, pp. 3725–3741, 2022, doi: [10.1007/s11277-022-09536-x](https://doi.org/10.1007/s11277-022-09536-x).
- [17] M. Al-Bazoor, A. Musa, K. Alzoubi, and T. Gharaibeh, "A Directional Selective Power Routing Protocol for the Internet of Underwater Things," *Wire Commun Mob Compute*, vol. 2022, 2022, doi: [10.1155/2022/3846621](https://doi.org/10.1155/2022/3846621).
- [18] H. H. Rizvi, S. A. Khan, R. N. Enam, K. Nisar, and M. R. Haque, "Analytical Model for Underwater Wireless Sensor Network Energy Consumption Reduction," *Computers, Materials and Continua*, vol. 72, no. 1, pp. 1611–1626, 2022, doi: [10.32604/cmc.2022.023081](https://doi.org/10.32604/cmc.2022.023081).
- [19] L. Li, Y. Qiu, and J. Xu, "A K-Means Clustered Routing Algorithm with Location and Energy Awareness for Underwater Wireless Sensor Networks," *Photonics*, vol. 9, no. 5, May 2022, doi: [10.3390/photonics9050282](https://doi.org/10.3390/photonics9050282).
- [20] I. Ahmad, T. Rahman, A. Zeb, I. Khan, M. T. Ben Othman, and H. Hamam, "Cooperative Energy-Efficient Routing Protocol for Underwater Wireless Sensor Networks," *Sensors*, vol. 22, no. 18, Sep. 2022, doi: [10.3390/s22186945](https://doi.org/10.3390/s22186945).