

Systematic Literature Study: Energy Efficient Heterogeneous and Hybrid LEACH Variants of Routing Protocol

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ABSTRACT : In the realm of wireless sensor networks (WSNs), energy efficiency stands as a paramount concern due to the resource-constrained nature of sensor nodes. The Low Energy Adaptive Clustering Hierarchy (LEACH) routing protocol has emerged as a prominent solution to mitigate energy consumption in WSNs. However, the proliferation of heterogeneous and hybrid network environments necessitates the adaptation and enhancement of routing protocols to accommodate diverse node capabilities and network conditions. This systematic literature review investigates the landscape of energy-efficient variants of the LEACH protocol tailored for heterogeneous and hybrid networks. By synthesizing findings from a comprehensive selection of scholarly articles, conference papers, and technical reports, this review elucidates the design principles, performance metrics, and optimization techniques employed in these variants. Furthermore, it identifies emerging trends, challenges, and opportunities for future research in the domain of energy-efficient routing protocols for WSNs, paving the way for the development of robust and adaptive solutions to sustainably manage energy resources in diverse sensor network deployments.

KEYWORDS: Energy efficiency, wireless sensor network, routing protocol, sensor nodes, Low energy adaptive clustering hierarchy

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I. INTRODUCTION

As a cutting-edge technology of the twenty-first century, wireless sensor networks (WSNs) are transforming a number of industries, including home automation, healthcare, military operations, and surveillance. Not only has their widespread deployment produced a wealth of data, but it has also brought to light a basic problem: the finite energy resources of sensor nodes. Because WSNs depend on these battery-powered nodes for continuous operation, research and development efforts are focused on developing energy-efficient routing protocols. The Low Energy Adaptive Clustering Hierarchy (LEACH) is a cutting-edge and adaptable approach to energy conservation and network performance optimization among the wide range of routing protocols. However, as WSNs have changed, so too has the requirement to modify and enhance LEACH, which has resulted in the creation of hybrid and heterogeneous versions. The goal of this Systematic Literature Study is to thoroughly investigate and assess these variations in order to determine whether or not they have the capacity to improve network stability, energy efficiency, and durability in the context of WSNs.

In response to the increasing number of WSNs and the growing need for novel solutions, scholars have developed a wide range of LEACH-based routing protocols, each with special modifications and improvements. This research undertakes a thorough examination of these protocols, classifying them into two distinct groups: those intended for situations that are homogeneous and those that are made to flourish

in contexts that are heterogeneous. We aim to identify these variants' subtle advantages and disadvantages by painstaking research and rigorous comparison, illuminating the opportunities they present for advancing the state of energy-efficient routing in WSNs. The details of the Exclusion and Inclusion Criteria and the keywords are explained in Fig 1.

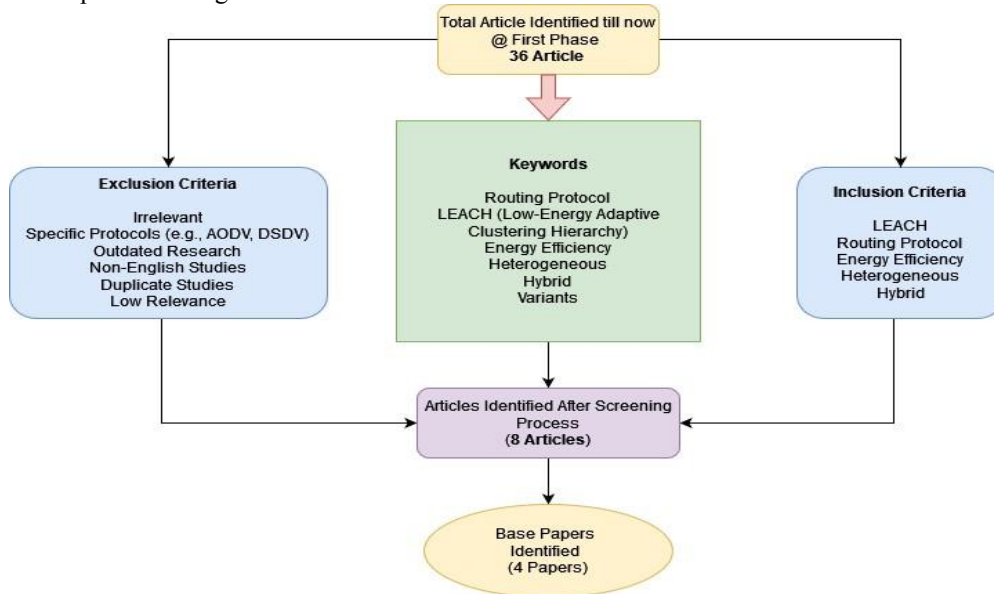


Fig.1: Inclusion and Exclusion criteria

II. LITERATURE STUDY

1.	Title & Published at	“Variants of LEACH Routing Protocol in WSN: A Comparative Analysis,” 2018 8th International Conference on Cloud Computing, Data Science & Engineering (Confluence)
	Objective	This paper examines the relevance of wireless sensor networks (WSNs) in the twenty-first century, emphasizing how they are used in military, residential, medical, and surveillance systems. Numerous sensor nodes are placed throughout WSNs to provide dependable surveillance and environmental monitoring. The study highlights the necessity of energy-efficient methods because sensor nodes have a limited battery life. It explores protocols based on clusters and specifically looks at the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, going over its problems and limitations. The research performs a thorough search for LEACH protocol variations, provides a taxonomy of these offspring, and evaluates their performances according to a number of criteria, such as mobility, data aggregation, and scalability.
	Contribution	The study made a contribution by offering a thorough examination of the LEACH procedure and its modifications, addressing its problems and shortcomings. It provides a taxonomy of offspring of LEACH and evaluates them based on key performance indicators, offering insightful information about energy-efficient WSN protocols.

Findings	The study addresses several LEACH protocol variations and emphasizes the value of cluster-based protocols like LEACH in WSNs. By contrasting these variations, researchers and practitioners can make well-informed decisions on which protocols to use for certain applications by comparing the variations' scalability, data aggregation, and mobility performance.
Conclusion	In conclusion, this research underscores the significance of energy-efficient protocols in WSNs and specifically examines the LEACH protocol and its descendants. By presenting a taxonomy and performance comparison, the study aids in the understanding and selection of appropriate protocols for various WSN applications, enhancing the reliability and effectiveness of surveillance and environmental monitoring systems.
Citation	S. Varshney and R. Kuma, "Variants of LEACH Routing Protocol in WSN: A Comparative Analysis," 2018, 8th International Conference on Cloud Computing, Data Science & Engineering (Confluence), Noida, India, 2018, pp.199-204,
2.	Title & Published at "A Comparative Analysis on Variants of LEACH based routing protocols for prolonging network lifetime: Survey," 2022 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS)
Objective	In the context of Wireless Sensor Networks (WSNs), this paper analyzes the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol and its different variants. The main goal is to decrease energy usage and increase network longevity. Based on transmission from clusters to the base station, the survey divides LEACH-based routing methods into two categories: single hop communication and multi-hop communication. It examines LEACH-integrated hierarchical routing protocols and offers a study of their various attributes, including communication style, network lifetime, clustering processes, and more. The survey finishes with suggestions for possible future research directions in WSNs and lists the benefits and drawbacks of each version of LEACH.
Contribution	The study made a contribution by offering an extensive overview of LEACH and its different WSN modifications. It facilitates comprehension of the distinctions and uses of these variations for academics and practitioners by classifying the protocols into single hop and multi-hop communication. Protocol selection is aided by a review of each version's features, advantages and disadvantages.
Findings	The survey shows that LEACH and its modifications have been widely used in WSN research. It emphasizes the significance of using energy-efficient protocols to increase network longevity. LEACH-based routing protocol landscape can be better understood by analyzing the features of single-hop and multi-hop protocols and classifying them accordingly.

	Conclusion	This study offers a thorough analysis of LEACH and its modifications, presenting a distinct classification of protocols according on the kind of communication. A deeper understanding of their applicability in WSNs is made possible by the examination of various characteristics and the advantages and disadvantages of various LEACH versions. The paper also suggests potential directions for future research in the field.
	Citation	A. Jukuntla and V. Dondeti, "A Comparative Analysis on Variants of LEACH based routing protocols for prolonging network lifetime: Survey," 2022 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS), Greater Noida, India, 2022, pp.351-355, doi:10.1109/ICCCIS56430.2022.10037707.
3.	Title & Published at	"Comparative Analysis of Classical Routing Protocol LEACH and Its Updated Variants that Improved Network Life Time by Addressing Shortcomings in Wireless Sensor Network," 2011 Seventh International Conference on Mobile Ad-hoc and Sensor Networks
	Objective	The Low Energy Adaptive Clustering Hierarchy (LEACH), widely acknowledged as the first dynamic routing protocol for Wireless Sensor Networks (WSNs), is the main topic of this research. In comparison to other protocols such as static clustering, minimum-transmission-energy protocols, and direct communication, LEACH is renowned for its capacity to increase network lifetime. The goal of the study is to uncover the flaws in the original protocol and then offer a comparative analysis of several modified versions of LEACH.
	Contribution	By conducting a comparative analysis of updated LEACH versions, the research addresses the shortcomings of the original methodology and makes a valuable contribution. Researchers and practitioners can use this analysis to better understand the advantages and disadvantages of various LEACH adaptations, which will help them choose the right protocol for a given WSN application.
	Findings	The study emphasizes how important LEACH is to WSNs as a leading dynamic routing technology and how well it performs in comparison to other protocols. It emphasizes how LEACH has changed throughout time and how their upgraded versions may be advantageous in resolving the issues with the original protocol.
	Conclusion	This study's conclusion highlights the significance of LEACH in WSNs and the continuous creation of improved versions to overcome its shortcomings. In order to maximize energy- efficient routing in wireless sensor networks (WSNs), academics and practitioners can benefit greatly from the comparative examination of these variants.

	Citation	M. Haneef and Z. Deng, "Comparative Analysis of Classical Routing Protocol LEACH and Its Updated Variants that Improved Network Life Time by Addressing Shortcomings in Wireless Sensor Network," 2011 Seventh International Conference on Mobile Ad-hoc and Sensor Networks, Beijing, China, 2011, pp. 361-363, doi:10.1109/MSN.2011.27.
4.	Title & Published at	"Low energy adaptive clustering hierarchy (LEACH) protocol: A retrospective analysis," 2017. International Conference on Inventive Systems and Control (ICISC)
	Objective	The objective of this research is to assess and contrast several versions of Low Energy Adaptive Clustering Hierarchy (LEACH) in Wireless Sensor Networks (WSNs) in order to determine their advantages and disadvantages. The goal is to give researchers and practitioners a better understanding of how various LEACH adaptations have evolved and whether they are still appropriate for a given set of WSN applications.
	Contribution	By addressing the crucial issue of battery life in WSNs and putting out a strategy to improve energy efficiency in cluster-based routing protocols such as LEACH, the research makes a valuable contribution. It highlights how crucial the energy model is to maintaining network energy balance.
	Findings	The study emphasizes how crucial energy efficiency is for wireless sensor networks (WSNs) and how cluster-based routing techniques can control energy consumption. It emphasizes that in order to attain even higher energy efficiency, a thorough analysis and reform of these processes are required.
	Conclusion	This paper highlights the need of energy-efficient protocols in wireless sensor networks (WSNs) and uses the LEACH protocol as a case study. The study tackles the crucial problem of battery life in WSNs by putting out an energy model approach that tries to balance energy in the network and increase overall energy efficiency.
	Citation	N.G. Palan, B.V. Barbadekar and S. Patil, "Low energy adaptive clustering hierarchy (LEACH) protocol: A retrospective analysis," 2017 International Conference on Inventive Systems and Control (ICISC), Coimbatore, India, 2017, pp. 1-12, doi: 10.1109/I- CISC.2017.8068715.
5.	Title & Published at	"Performance Investigation of Advanced Multi-Hop and Single-Hop Energy Efficient LEACH Protocol with Heterogeneous Nodes in Wireless Sensor Networks," 2015 Second International Conference on Advances in Computing and Communication Engineering.
	Objective	In order to help researchers and practitioners choose protocols, this study will examine and contrast various implementations of the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol in Wireless Sensor Networks (WSNs). This will provide a thorough understanding of each variant's advantages and disadvantages.

Contribution	This study made a contribution by analyzing and contrasting the LEACH variants, providing information on how well they work and how applicable they are for particular WSN applications, and illuminating the development of these adaptations.
Findings	The study emphasizes the value of LEACH and its numerous adaptations in improving network performance and energy efficiency, underscoring the necessity of energy-efficient routing in WSNs.
Conclusion	This study concludes by highlighting the critical role that LEACH and its variations play in resolving the energy restriction in WSNs and provides recommendations for choosing suitable protocols in accordance with application needs.
Citation	V. Sharma and D. S. Saini, "Performance Investigation of Advanced Multi-Hop and Single-Hop Energy Efficient LEACH Protocol with Heterogeneous Nodes in Wireless Sensor Networks," 2015 Second International Conference on Advances in Computing and Communication Engineering, Dehradun, India, 2015, pp. 192-197, doi: 10.1109/ICACCE.2015.32.
6. Title & Published at	"Behavior of LEACH protocol in heterogeneous and homogeneous environment," 2015 International Conference on Computer Communication and Informatics (ICCCI)
Authors	Sujee R. and Kannammal K.E.
Objective	In order to address the issue of sensor nodes having limited battery life, this paper provides an overview of the Low Energy Adaptive Clustering Hierarchy (LEACH) routing protocol in Wireless Sensor Networks (WSNs). In order to improve energy efficiency and extend the lifespan of sensor nodes, it compares LEACH's performance in both homogeneous and heterogeneous environments.
Contribution	By examining LEACH in both homogeneous and heterogeneous environments, the study makes a valuable contribution by shedding light on how well it works to save energy and extend the lifespan of WSNs.
Findings	The study reveals that LEACH in a heterogeneous environment significantly reduces energy consumption and extends the total lifetime of WSNs compared to a homogeneous environment.
Conclusion	This article provides important insights for WSN design and deployment by highlighting the significance of LEACH in improving energy efficiency and extending the lifespan of WSNs, especially in heterogeneous environments.

	Citation	Sujee R. and Kannammal K.E., "Behavior of LEACH protocol in heterogeneous and homogeneous environment," 2015 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 2015, pp. 1-8, doi:10.1109/ICCCI.2015.7218126.
7.	Title & Published at	"LEACH-HPR: An energy efficient routing algorithm for Heterogeneous WSN," 2010 IEEE International Conference on Intelligent Computing and Intelligent Systems
	Objective	This research develops an energy-efficient routing system to handle quality of service (QoS) issues in wireless sensor networks (WSNs). It presents a heterogeneous WSN scenario in which sensor nodes have different energy resources and suggests an energy-efficient cluster head election protocol (LEACH-HPR) for inter-cluster routing in conjunction with the least spanning tree technique.
	Contribution	The study made a contribution by presenting the LEACH-HPR protocol, which aims to balance energy consumption and increase network lifetime in heterogeneous WSNs through energy-efficient cluster head election
	Findings	The effectiveness of the suggested strategy in lowering and balancing energy consumption and extending the lifetime of the WSN is demonstrated by the simulation results.
	Conclusion	This study concludes by highlighting the need of energy-efficient routing in WSNs, especially in diverse environments, and provides insightful information about how to enhance QoS for sensor networks.
	Citation	H. Li, "LEACH-HPR: An energy efficient routing algorithm for Heterogeneous WSN," 2010, IEEE International Conference on Intelligent Computing and Intelligent Systems, Xiamen, China, 2010, pp.507-511, doi:10.1109/ICICISYS.2010.5658274.
	8.	Title & Published at
Objective		In both homogeneous and heterogeneous contexts, the problem of prolonging the lifespan of battery-powered sensor nodes in wireless sensor networks is the focus of this research. It presents a new resilient relay node-based hybrid protocol for LEACH with the goal of resolving problems with cluster heads' energy depletion and network performance when relay nodes are not present.

Contribution	Within the relay node-based method, the research suggested a novel hybrid LEACH protocol that combines relay nodes with energy comparison LEACH. With its distributed cluster size control and assurance of network operation even in the event of relay node failure, this architecture optimizes energy consumption.
Findings	The suggested method outperforms relay node-based schemes in terms of packet loss during communications, as seen by the simulation findings, which show a 6%–30% longer network lifetime.
Conclusion	Conclusively, this study presents a novel approach to improve the longevity and efficacy of sensor nodes in wireless sensor networks by the implementation of a resilient relay node-based hybrid LEACH protocol. It tackles important problems with network durability and energy efficiency in both homogeneous and heterogeneous environments.
Citation	A. Azim and M. M. Islam, “Hybrid LEACH: A relay node based low energy adaptive clustering hierarchy for wireless sensor networks,” 2009 IEEE 9th Malaysia International Conference on Communications (MICC), Kuala Lumpur, Malaysia, 2009, pp. 911-916, doi:10.1109/MICC.2009.5431462.

III. ANALYSIS AND DISCUSSION

In the quest for energy-efficient routing in WSNs, the pioneering Low Energy Adaptive Clustering Hierarchy (LEACH) protocol and its subsequent variants have taken center stage. These routing protocols have garnered extensive attention due to their potential to extend the network’s lifetime and stabilize its performance. As we delve into the analysis and discussion of these variants, we will explore their characteristics, functionalities, and comparative performance in both homogeneous and heterogeneous WSN environments.

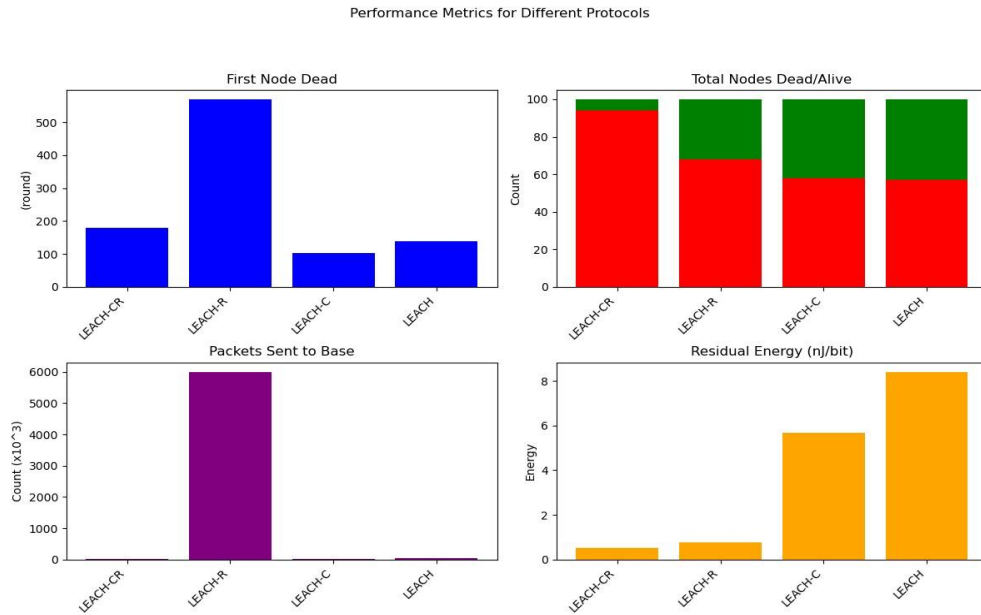


Fig. 2: Comparative Analysis of LEACH Variant

Clustering-based routing is exemplified by the LEACH protocol, which is based on homogeneous environments. It provides a unique method for choosing cluster heads and planning data transmission that reduces energy use and increases network lifetime. But when we move into heterogeneous WSNs, it becomes clear that LEACH needs to be modified. Improved cluster head election methods are introduced by variants such as LEACH-HPR, which frequently use minimum spanning tree techniques for inter-cluster routing. These modifications seek to alleviate the difficulties brought about by the varied nature of sensor nodes, balance energy consumption, and lengthen network lifespan.

The analysis and discussion encompass the investigation of various metrics such as network lifetime, communication type, clustering mechanisms, and more, providing a comprehensive evaluation of the performance of LEACH and its variants. Additionally, we explore the robustness of relay node-based schemes, a critical component in extending the network's operational life. Simulation results attest to the effectiveness of these innovations, demonstrating significant improvements in energy efficiency, stability, and overall network lifetime.

This study revealed how the LEACH protocol has changed from its beginning as a dynamic and energy-efficient routing solution in the diverse WSN landscape. The ability to adapt to various settings and the emergence of hybrid variations indicate that the future of WSNs' energy-efficient operation is bright. By delving into the minute details, this study and discussion helps to understand the advantages and disadvantages of these novel protocols as well as how well they might work to solve the crucial problem of energy efficiency in contemporary WSNs.

This research work compared the performance of various LEACH methods. The comparative analysis is shown in Figure 2. The results showed significant variations among the four protocols: LEACH-CR, LEACH-R, LEACH-C, and LEACH. LEACH-C and LEACH-R demonstrate lower residual energy per bit, suggesting their potential for better energy efficiency. LEACH-R sends a considerably higher number of packets to the base station compared to the other protocols. LEACH-C maintains a larger number of nodes alive, although it has higher residual energy. LEACH-CR experiences the earliest death of the first node in the network. These differences highlight the trade-offs between energy efficiency, network longevity, and communication load, emphasizing the importance of selecting the most suitable protocol based on specific application requirements and priorities.

IV. CONCLUSION

The pursuit of energy-efficient routing in the dynamic field of Wireless Sensor Networks (WSNs) has given rise to a wide range of LEACH-based versions. Encouragingly, this Systematic Literature Study

has started a thorough investigation and assessment of these variations in both homogeneous and heterogeneous contexts in order to tackle the urgent problem of prolonging the operational lifetime of the network without sacrificing stability.

The results of this study show that one of the key components of energy-efficient WSNs is still the LEACH protocol, which was a pioneer in clustering-based routing. LEACH is adaptable to heterogeneous contexts; variants like LEACH-HPR and Advanced-Multi-hop LEACH show this by utilizing cutting-edge methods and algorithms to improve network stability, durability, and energy efficiency. Relay node integration and cluster size control have shown to be useful solutions for lowering energy usage and distributing energy throughout the network.

The examined versions demonstrate significant increases in energy efficiency, network stability, and total network longevity, as demonstrated by the simulation findings. A significant step forward in the development of WSN technology, the suggested hybrid LEACH systems show promise in tackling the pressing problem of energy efficiency and prolonging the operational life of sensor nodes.

In conclusion, the methodical investigation and evaluation of various LEACH variations provide priceless information about how energy-efficient routing is developing in WSNs. This study opens the door for new developments and highlights the critical role that LEACH and its hybrid adaptations will play in determining the direction that energy-efficient WSNs take in the future.

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