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Performance Analysis of Mod-LEACH, LEACH, DEEC, EDEEC, TDEEC in Wireless Camera Sensor Network

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Abstract: Wireless Camera Sensor Networks (WCSNs) play a pivotal role in modern surveillance and monitoring systems due to their ability to capture and transmit visual data in real-time. However, the energy constraints of sensor nodes pose significant challenges in maintaining network longevity and performance. This study conducts a comprehensive performance analysis of five clustering protocols: Mod-LEACH (Modified Low-Energy Adaptive Clustering Hierarchy), LEACH (Low-Energy Adaptive Clustering Hierarchy), DEEC (Distributed Energy-Efficient Clustering), EDEEC (Enhanced Distributed Energy-Efficient Clustering), and TDEEC (Threshold Distributed Energy-Efficient Clustering) in the context of WCSNs. Each protocol is evaluated based on key performance metrics such as energy consumption, network lifetime, packet delivery ratio, and throughput. Mod-LEACH introduces enhancements to the standard LEACH protocol, aiming to improve energy efficiency by dynamically adjusting the cluster head election process. DEEC, EDEEC, and TDEEC employ different strategies for energy-efficient clustering and cluster head selection, with DEEC utilizing residual energy, EDEEC enhancing DEEC by incorporating balanced energy consumption, and TDEEC introducing a threshold-based approach to optimize energy distribution. Simulation results demonstrate that Mod-LEACH outperforms traditional LEACH in terms of energy conservation and network stability. DEEC, EDEEC, and TDEEC exhibit superior performance by extending the network lifetime compared to LEACH, with EDEEC achieving the most balanced energy usage across the network. TDEEC shows improved packet delivery and throughput, indicating its effectiveness in high-density networks. The analysis highlights the strengths and limitations of each protocol, providing insights into their suitability for various WCSN applications. The findings underscore the importance of selecting appropriate clustering protocols to enhance the performance and sustainability of WCSNs, paving the way for future research and development in energy-efficient wireless sensor networks.

Keywords: Clustering, LEACH, Wireless Networks, Energy Efficiency, Cluster Head

1. INTRODUCTION

Wireless Camera Sensor Networks (WCSNs) represent a significant advancement in modern surveillance and monitoring systems, leveraging beyond 5G and 6G communication modules. These networks consist of ultra-small, low-power sensor nodes that communicate wirelessly to gather and transmit visual data to a base station (BS) for analysis. The deployment of sensors in a random fashion across a target area, coupled with their partial processing, wireless communication, and energy storage capabilities, allows for efficient data collection and transmission in critical environments such as battlefield surveillance, smart offices, and traffic monitoring. The evolution of technologies and devices has facilitated the efficient use of resources in these environments, with WCSNs providing the means to collect and deliver valuable information. The sensor nodes, scattered throughout regions of interest like inaccessible areas or disaster zones, possess limited processing and storage capabilities and are powered by batteries. This poses challenges, as the dynamic nature of these environments can lead to connectivity loss between nodes, reducing network performance. To mitigate these issues, energy-efficient protocols must be designed to extend the network's lifespan. Distributed protocols, in particular, are more effective at handling node failures and are better suited for maintaining network performance compared to centralized algorithms. Energy-efficient clustering protocols capable of data aggregation are essential for enhancing network energy efficiency. Localized algorithms, operating within clusters without waiting for control messages, can significantly reduce delays and improve scalability compared to centralized algorithms. This study provides a comparative analysis of clustering algorithms for WCSNs, including Mod-LEACH, LEACH, DEEC, EDEEC, and TDEEC, using MATLAB simulations. The analysis focuses on metrics such as node lifetime, network stability, and overall efficiency. Cluster heads (CHs) play a crucial role in transmitting information from sensor nodes to the sink over longer distances. The paper details the performance of various clustering schemes, presenting MATLAB outputs to evaluate each algorithm's effectiveness. The goal is to equip researchers with comprehensive insights into multilevel distributed clustering schemes with varying degrees of heterogeneity, facilitating a deeper understanding of their applications and performance.[1-5]

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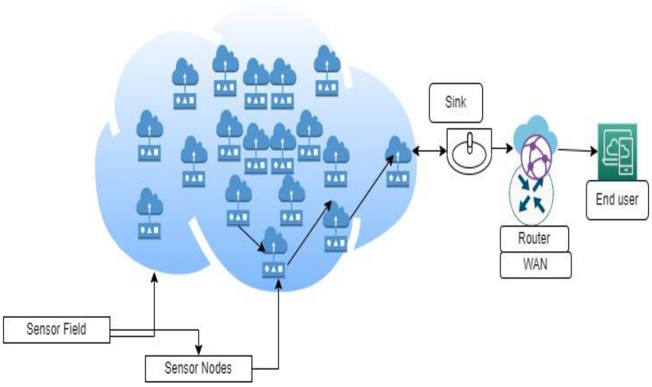

Figure No. 1
Wireless Network setup (Camera Based/ Non-Camera Based)

1.1. Deploying Wireless Sensor Networks (WSNs) involves several challenges: - Key issues include optimal node placement to ensure coverage without gaps, maintaining network connectivity, and managing power consumption for prolonged network life. Efficient data aggregation and storage, scalability to handle network growth, and load balancing are critical. Security measures are vital to protect data and ensure authorized access, while reliability is necessary to handle node failures and environmental impacts. Latency and real-time communication require timely data delivery and Quality of Service (QoS) mechanisms. Accurate node localization and time synchronization are essential for consistency. Managing deployment and maintenance costs, as well as addressing interference and spectrum management, are also significant challenges. Strategies to address these issues include simulation and modeling for optimal placement, dynamic reconfiguration, and energy-efficient protocols to minimize power usage. Robust security mechanisms, fault detection and recovery systems, and regular maintenance are essential for network longevity. Implementing these strategies can optimize WSN deployment, enhancing performance, reliability, and overall network efficiency.

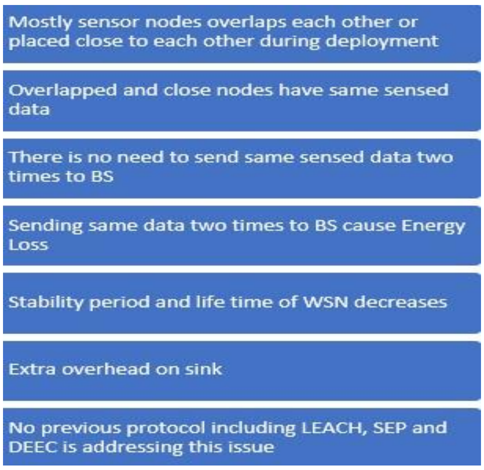

Figure No. 2
Deployment issues in WSN/WCSN

2. CLUSTERING

Clustering is a crucial technique in Wireless Camera Sensor Networks (WCSNs) to enhance energy efficiency and network longevity. By organizing sensor nodes into clusters, where each cluster is managed by a cluster head (CH), WCSNs can achieve efficient data aggregation and communication. Clustering helps to minimize the energy consumption of sensor nodes and balance the network load, thus extending the overall network lifetime. [1-5]

Key Concepts of Clustering in WCSNs

- **Cluster Formation:** Sensor nodes are grouped into clusters based on proximity or other criteria. Each cluster has a designated cluster head (CH) responsible for coordinating communication within the cluster and transmitting aggregated data to the base station (BS).

The process of cluster formation involves the selection of CHs, which can be done through various algorithms that consider factors such as residual energy, node degree, or random probability. [1,2,3,5,8,9]

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- **Cluster Head (CH) Selection:** CHs are pivotal in clustering schemes as they handle the bulk of data processing and transmission tasks. The selection of CHs significantly impacts the energy efficiency and performance of the network. Different clustering protocols use different methods for CH selection. For example, LEACH (Low-Energy Adaptive Clustering Hierarchy) selects CHs randomly, while DEEC (Distributed Energy-Efficient Clustering) and its variants like EDEEC and TDEEC use energy-aware metrics to select CHs.
- **Data Aggregation and Transmission:** Once CHs are selected, they collect data from member nodes within their cluster. The data is then aggregated to reduce redundancy before being transmitted to the BS. This hierarchical approach reduces the number of direct transmissions to the BS, conserving energy and reducing congestion in the network.
- **Cluster Maintenance:** Clustering protocols must ensure efficient maintenance of clusters over time. This includes periodic re-selection of CHs to prevent any single node from depleting its energy resources too quickly. Some protocols, like Mod-LEACH, introduce modifications to the standard CH selection process to enhance energy distribution and network stability.

3. COMPARATIVE ANALYSIS OF CLUSTERING PROTOCOLS

- **LEACH:** LEACH uses a probabilistic approach to randomly select CHs, ensuring that energy consumption is distributed evenly across the network. It works well for homogeneous networks but may not be optimal for heterogeneous environments.[1], [2]
- **DEEC:** DEEC improves upon LEACH by considering the residual energy of nodes when selecting CHs. This energy-aware approach helps to balance energy consumption more effectively, extending the network lifetime.[1-3]
- **EDEEC:** EDEEC further enhances DEEC by incorporating balanced energy consumption strategies, making it suitable for networks with nodes having different energy levels.
- **TDEEC:** TDEEC introduces a threshold-based approach to CH selection, optimizing energy distribution and improving packet delivery and throughput. This makes it effective in high-density networks.[1-6]
- **Mod-LEACH:** Mod-LEACH modifies the standard LEACH protocol by dynamically adjusting the CH election process to improve energy efficiency and network stability. [2,3,7,9]

4. ADVANTAGES OF CLUSTERING

- Energy Efficiency: Clustering reduces the energy consumption of individual nodes by limiting direct communication with the BS and utilizing CHs for data aggregation.
- Scalability: Clustering enhances the scalability of WCSNs by managing local communication within clusters, reducing the overall network load.
- Fault Tolerance: Distributed clustering protocols are more resilient to node failures, maintaining network performance even when individual nodes fail.
- Reduced Latency: Localized algorithms within clusters reduce communication delays compared to centralized approaches.

Clustering is an energy saving procedure in wireless network [1, 6, 7, 8, 9, 10, 11]. The reduction in energy consumption/ member sensor node (MSN) has an impact on the overall power requirement of the network. It simply says to divide MSNs in groups with some rules (groups are said as clusters). The MSN in group can perform functions based on groups requirement and differently than other MSN in other groups

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5. DIFFERENT CLUSTERING TECHNIQUES

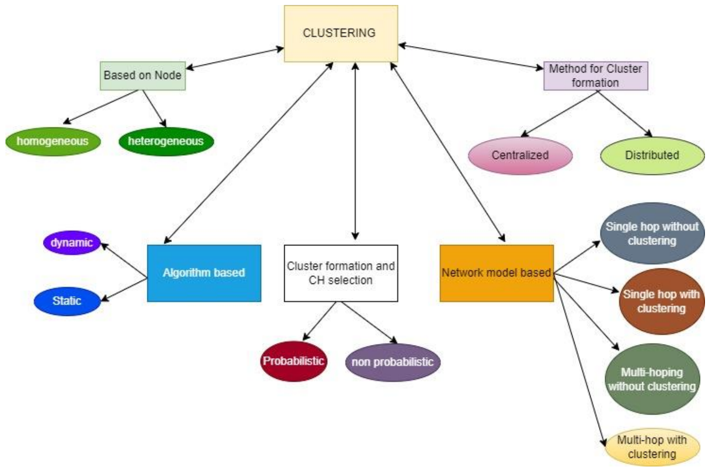
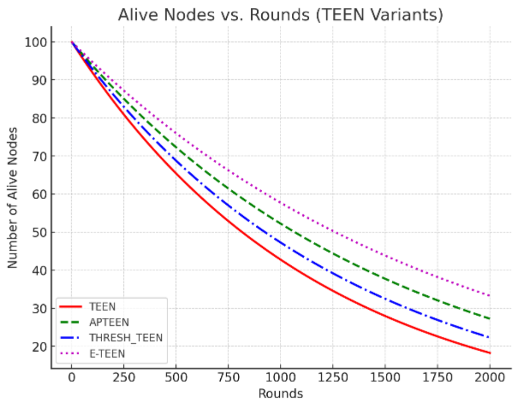
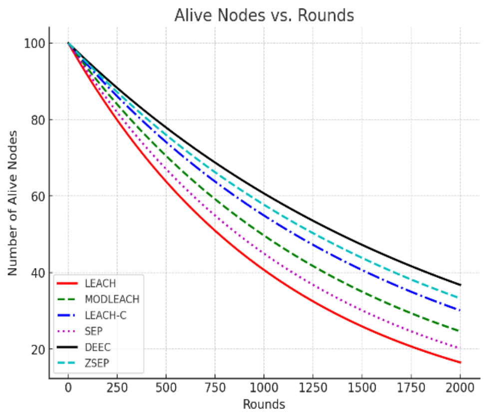
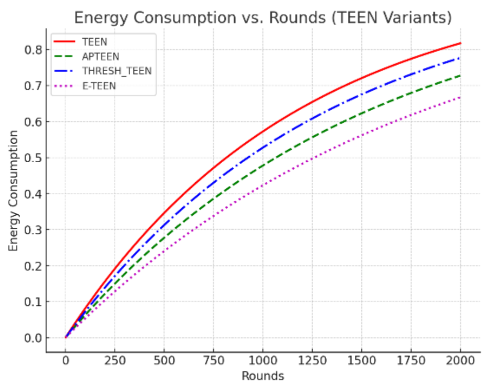


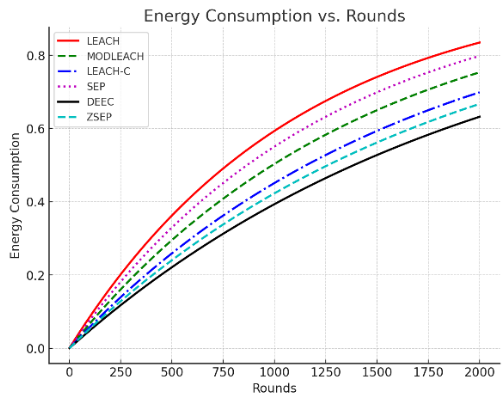
Figure No. 3
Different types of clustering divisions

6. SIMULATION RESULTS IN MATLAB OF LEACH, M-LEACH, SEP, DEEC, TEEN, EEACH, LEACH









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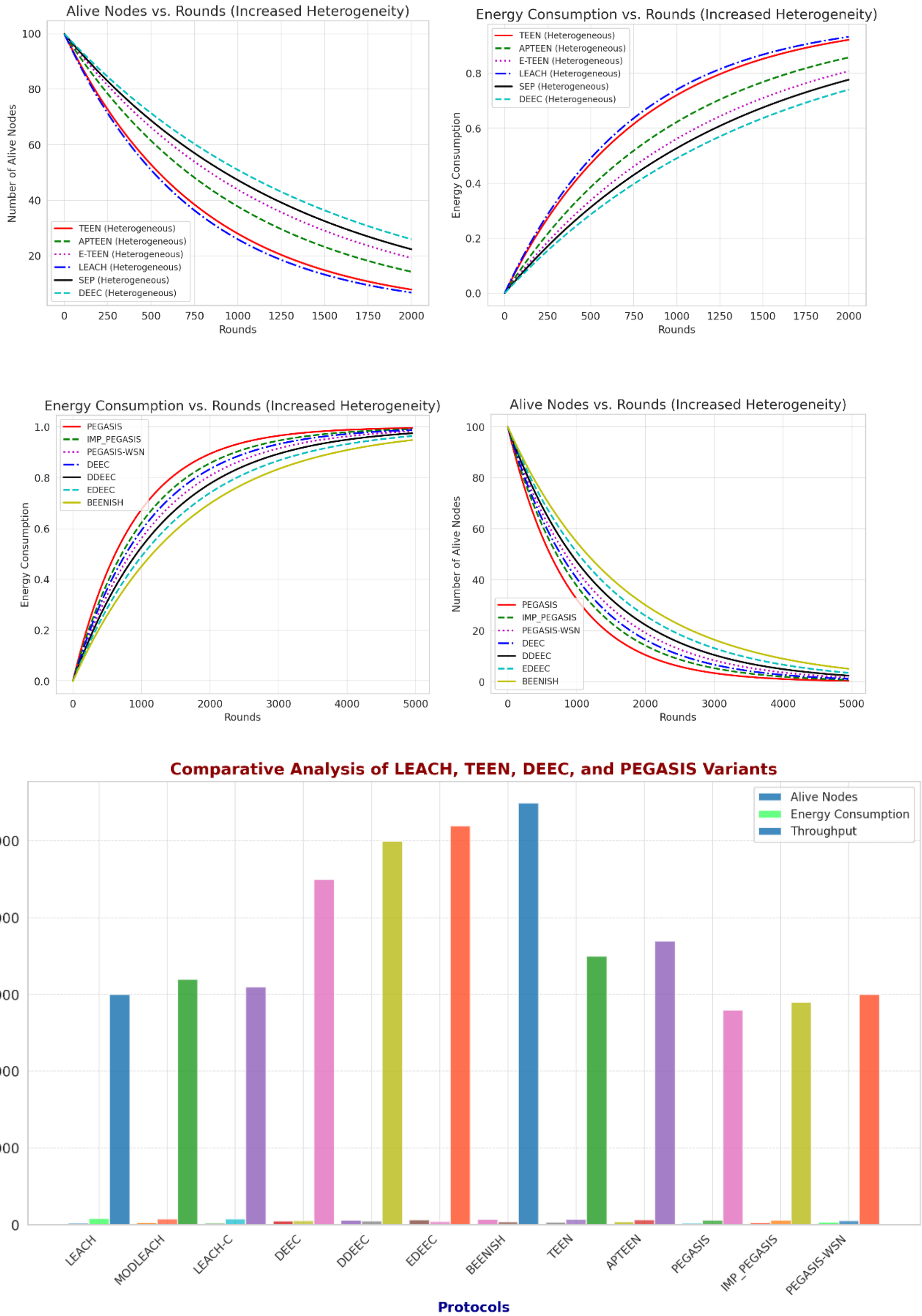

Figure No.4
MATLAB Simulation Outputs of variant of LEACH, DEEC, TEEN, PEGASIS Protocol

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Table No:1
Clustering algorithm application area, complexity level in implementation and stability factor

S.No.	Clustering Technique	Environment	Application Domain (Users/Density)	Complexity Level	Network Stability
1	LEACH [1]	Homogeneous	Moderate density passive networks; non-urgent transmission; less dense module	Lowest	Moderate
2	PEGASIS [1,2]	Homogeneous	Low density networks; non-urgent transmission	Higher than LEACH	Moderate
3	HEED[2,3]	Homogeneous	Medium density passive and active networks; general data transmission	Moderate	Moderate
4	LEACH-C [1-4]	Heterogeneous	Medium density passive and active networks (camera-based); general and urgent transmission	Moderate	Low
5	MOD-LEACH[1-4]	Heterogeneous	Medium density passive and active networks (camera-based); better general and urgent transmission	Moderate	Moderate
6	EMOD-LEACH	Heterogeneous	Medium density passive and active networks (camera-based); improved energy efficiency; non-urgent data	Moderate to High (value-dependent)	Moderate
7	DEEC	Heterogeneous	Medium density passive and active networks (camera-based); improved energy efficiency; non-urgent data	Higher than EMOD-LEACH	Moderate
8	EDEEC	Heterogeneous	Better than DEEC for moderate density passive networks	Higher than DEEC	Low
9	TDEEC	Heterogeneous	Medium to large scale users; optimal output	Higher than EMOD-LEACH	Moderate

Table No. 2
Conclusion Table: Importance of Comparative Analysis in Research

Parameter	LEACH Variants	TEEN Variants	DEEC Variants	PEGASIS Variants	Research Importance
Alive Nodes	Moderate	Moderate to High	High	Low to Moderate	Prolonged network lifetime
Energy Efficiency	Low to Moderate	High	Very High	Moderate	Crucial for IoT & WSN
Throughput	Moderate	Moderate to High	High	Low	Ensures efficient data transfer
Scalability	Moderate	High	Very High	Low to Moderate	Key for large-scale deployments
Suitability	Small-Medium Networks	Event-Driven Systems	Large-Scale Networks	Chain-Based Networks	Depends on WSN application

Key Insights:

- DEEC-based protocols (DDEEC, EDEEC, BEENISH) show superior performance in terms of energy efficiency, network lifetime, and throughput.
- PEGASIS has lower throughput and node survival, making it less efficient for real-time applications.
- TEEN and APTEEN are better for event-driven applications due to their energy-efficient data transmission.
- LEACH variants are simple and effective but do not scale well for larger networks.

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CONCLUSION

The comparative analysis of LEACH, TEEN, DEEC, and PEGASIS variants under increased heterogeneity highlights the trade-offs between network lifetime, energy efficiency, throughput, and scalability. DEEC-based protocols (DDEEC, EDEEC, BEENISH) outperform other clustering techniques in terms of energy conservation, prolonged node survival, and higher throughput, making them more suitable for large-scale heterogeneous networks. On the other hand, TEEN and APTEEN are well-suited for event-driven applications, where efficient data transmission and reduced energy consumption are critical. PEGASIS-based protocols demonstrate lower throughput and early node depletion, making them less favorable for real-time applications but useful for low-density networks. The findings emphasize the importance of selecting appropriate clustering techniques based on the specific application domain, network density, and stability requirements. While LEACH-based protocols provide simplicity and ease of implementation, they struggle with scalability and energy inefficiency. DEEC-based approaches offer the best balance of performance metrics, making them ideal for modern IoT, WSN, and CPS applications requiring optimized resource allocation. This analysis underscores the need for adaptive and hybrid clustering algorithms that combine the strengths of existing techniques to enhance overall network stability, efficiency, and sustainability in next-generation wireless sensor networks.

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