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# Comparison of Energy Efficient Meta and Non-Metaheuristic Clustering for Wireless Sensor Networks

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**Abstract:** Wireless Sensor Networks (WSNs) have emerged as a crucial technology, facilitating the collection and dissemination of data across a wide range of applications, from monitoring the environment to automating industrial processes. However, the limited energy resources of sensor nodes present substantial challenges to the sustainability and efficacy of these networks. In response, researchers have devised and explored numerous non-meta-algorithms aimed at optimizing energy consumption, data transmission, and network longevity, all of which contribute to the enhancement of cooperative communication modules. This comprehensive analysis undertakes a thorough investigation and comparative assessment of various prominent clustering algorithms within the realm of WSNs, offering valuable insights for advancing cooperative communication. By delving into the practical implementations, underlying mathematical principles, strengths, weaknesses, real-world applications, and avenues for enhancement of these algorithms, our objective is to present a holistic perspective on their contributions to bolstering energy efficiency in WSNs.

**Keywords*:*** Clustering, Wireless Sensor Networks, Energy, LEACH, Cooperative Communication

## I. INTRODUCTION

Cooperative communication in wireless communications refers to the practice of multiple wireless devices working together to improve the quality of communication between them. The need for cooperative communication arises due to some of the limitations of traditional wireless communication.

Cooperative communication in wireless communications refers to the collaboration between multiple wireless devices to improve the overall performance of the network. It involves sharing information, resources, and processing capabilities among these devices to overcome various challenges and achieve better efficiency, reliability, and coverage. The need for cooperative communication arises due to several reasons:

1. Mitigating Signal Attenuation and Fading: In wireless communications, signals are susceptible to attenuation (weakening) and fading (fluctuations in signal strength) as they travel through the air. By establishing cooperative relaying between devices, the signal can be retransmitted from one device to another, effectively extending the communication range and reducing the impact of signal attenuation and fading.

2. Enhancing Coverage: In large-scale wireless networks or areas with challenging terrains, it may be difficult for a single device to cover the entire area effectively. Cooperative communication enables devices to act as relays for each other, allowing signals to reach farther distances and expanding the coverage area.

3. Improving Signal-to-Noise Ratio (SNR): Cooperative communication can improve the SNR at the receiver's end by combining signals from multiple devices. This helps in reducing errors and increasing the reliability of communication, especially in noisy environments.

4. Increasing Data Rates: Cooperative communication allows for the parallel transmission of data from multiple devices, leading to increased data rates and higher overall network capacity.

5. Overcoming Interference: Wireless networks often suffer from interference caused by other wireless devices operating in the same frequency band. Cooperative techniques, such as interference-aware relaying, can help mitigate the impact of interference and improve communication performance.

 

6. Energy Efficiency: In some scenarios, devices with limited battery power may struggle to transmit signals over long distances. Cooperative communication allows energy-efficient relay nodes to take part in data transmission, reducing the energy consumption of individual devices.

7. Resilience and Fault Tolerance: Cooperative communication can enhance the robustness of wireless networks. If one device fails or experiences a weak signal, other cooperative devices can step in and relay the data, ensuring fault tolerance and network resilience.

8. Adaptive Resource Allocation: Cooperative communication enables intelligent resource allocation, where devices can dynamically allocate bandwidth, power, and processing capabilities based on network conditions and requirements.

9. Supporting Multi-User Communications: In scenarios with multiple users trying to communicate simultaneously, cooperative techniques can help coordinate and optimize transmissions, reducing interference and maximizing overall network throughput.

Overall, cooperative communication in wireless networks is a powerful approach to tackle various challenges and enhance the performance, reliability, and efficiency of modern wireless communication systems. It plays a crucial role in realizing the full potential of wireless technologies in various applications, including cellular networks, ad-hoc networks, and the Internet of Things (IoT). Overall, cooperative communication is essential for improving the performance, reliability, and efficiency of wireless communication systems. It enables devices to work together to overcome the limitations of traditional wireless communication, thereby enhancing the user experience and enabling new applications and services.

Wireless Sensor Networks (WSNs) have garnered significant attention for their wide-ranging applications in fields such as environmental monitoring, healthcare, and industrial automation. Nonetheless, the intrinsic energy limitations within these networks present a formidable challenge.

Given that sensor nodes are often reliant on battery power and are positioned in remote or inaccessible locales, the efficient management of energy resources becomes of paramount importance. In response, a diverse array of algorithms has been proposed to tackle this issue and ensure the sustained functionality of the network. This review paper seeks to delve into and compare these non-meta-algorithms, shedding light on their operational mechanisms, strengths, weaknesses, and areas of applicability.

In the realm of WSNs, intricate electro-mechanical components, referred to as sensor nodes, form the backbone of the network. These nodes establish connections through RF signals with powerful sinks known as base stations (BSs). Communication within these networks can take the form of single-hop or multi-hop transmission. Functionality-based categorizations divide sensor networks into two primary types: proactive and reactive networks.

Proactive networks operate passively, making them suitable for data aggregation tasks where nodes periodically gather and transmit data at regular intervals. On the other hand, reactive networks, in contrast to their passive counterparts, prompt sensor nodes to respond immediately only to changes in pertinent parameters of interest. Reactive networks find particular utility in time-sensitive applications. To enhance the lifespan of sensor networks, collaborative interactions among sensor nodes emerge as an efficient strategy.

**Characteristics of WSNs:**

- Wireless communications and fragile connections
- Limited reliability and vulnerability of sensor nodes to failure
- Dynamic topology and inherent self-organization
- Multi-hop routing with hop-by-hop communications
- Deployment in hostile and challenging environmental conditions [2, 10, 11]
- Collaborative behaviour among sensor nodes and other WSN devices
- Broadcast-style inter-node communications
- Scalability facilitated by ease of extension and configuration
- Direct engagement, contact, and interaction with the physical environment
- Predominantly tailored for specific single-purpose applications
- Adaptive power management and stability across diverse operational environments
- Continuous and automatic operation without interruptions

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- Ability to manage communication in mobile node scenarios
- Constrained by hardware limitations inherent to sensor nodes

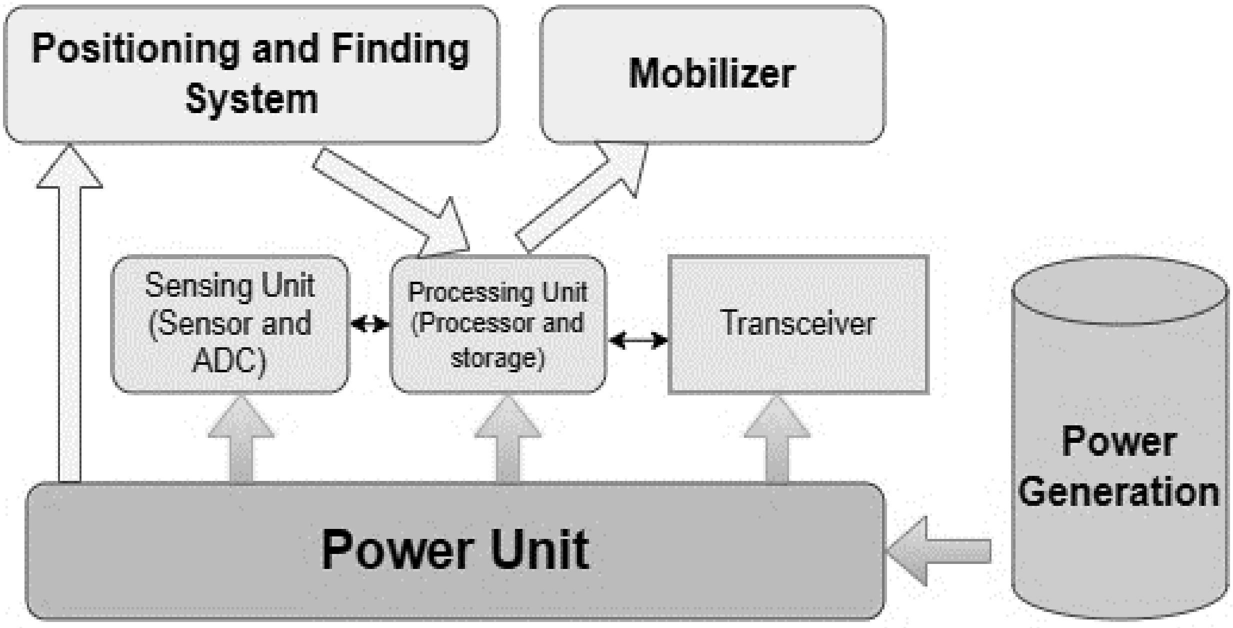


Fig.1 A typical set-up of Sensor within an WSN

## II. CLUSTERING AND ITS FEATURES

Clustering constitutes an effective strategy to mitigate communication costs and conserve energy resources within Wireless Sensor Networks (WSNs). This approach involves the organization of sensors into groups, where the responsibility of transmitting aggregated data is vested solely in the designated group head, also known as the cluster head [6].

It manifests as an implementation of a hierarchical network structure, where higher-level nodes, such as cluster heads, bear augmented responsibilities, differentiating them from the nodes at lower levels within the hierarchy [5][6]. This hierarchical concept parallels that of a hierarchical network, with cluster heads positioned at elevated levels.

These cluster heads are entrusted with the task of accumulating sensory attributes from the member nodes situated at lower levels. Subsequently, the cluster heads execute data aggregation, pooling together the sensory information, and transmitting the aggregated data either to higher-level cluster heads or directly to the base station, which could potentially serve as the sink node [5][6].

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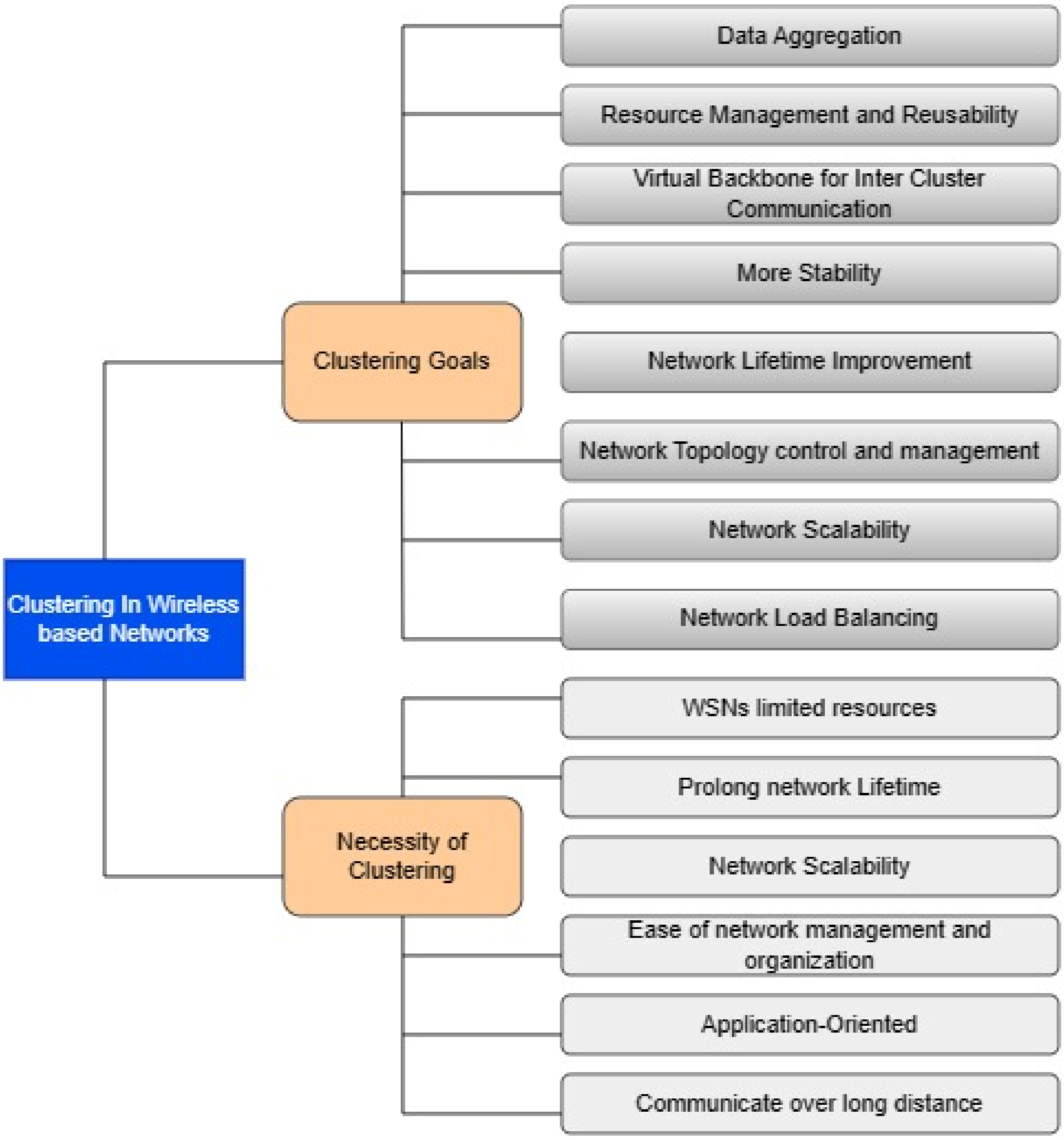


Fig.2 Clustering Goals and Requirement

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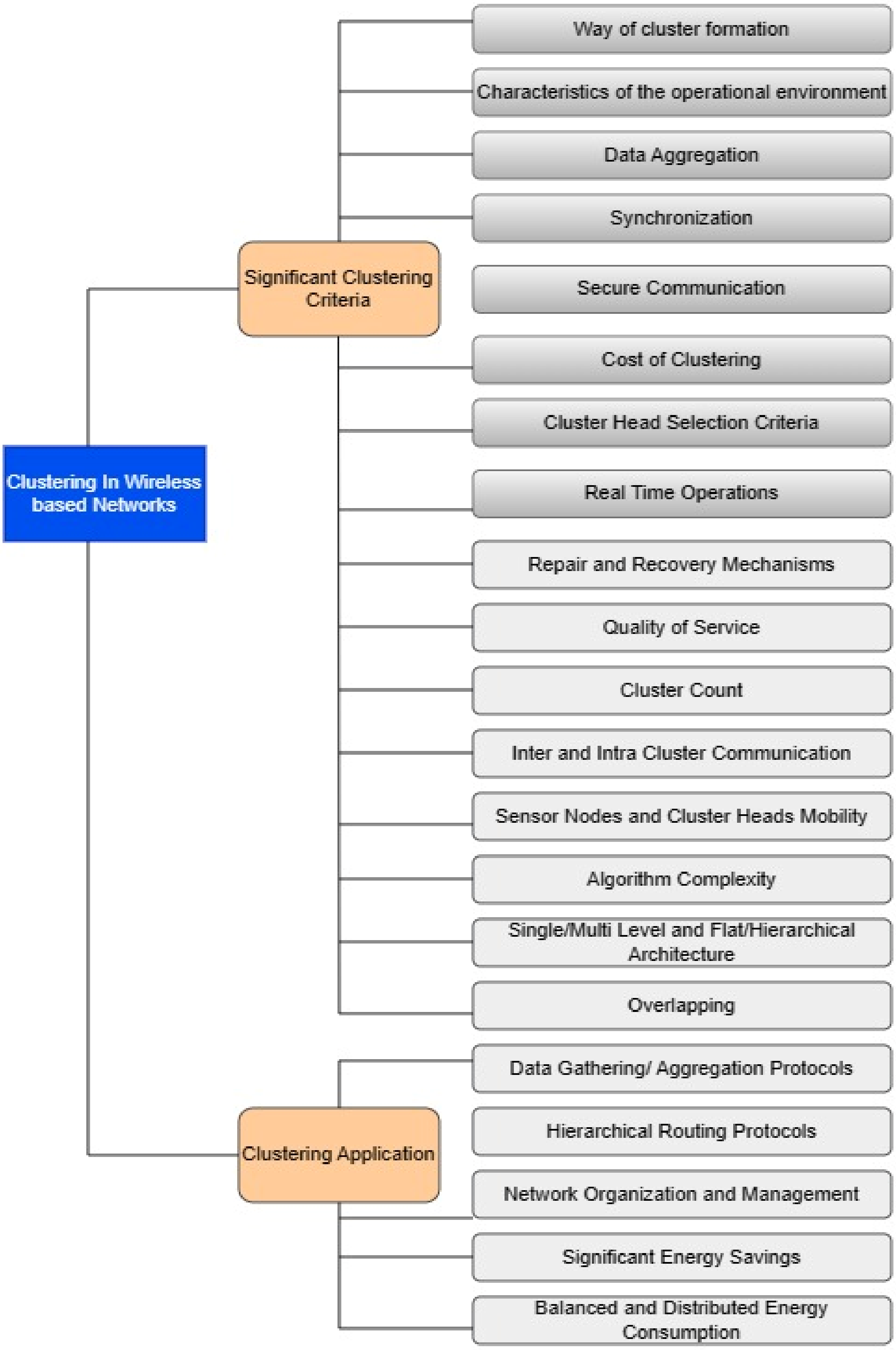


Fig.3 Clustering Criteria and Applications

International Multidisciplinary Research Journal Reviews (IMRJR)
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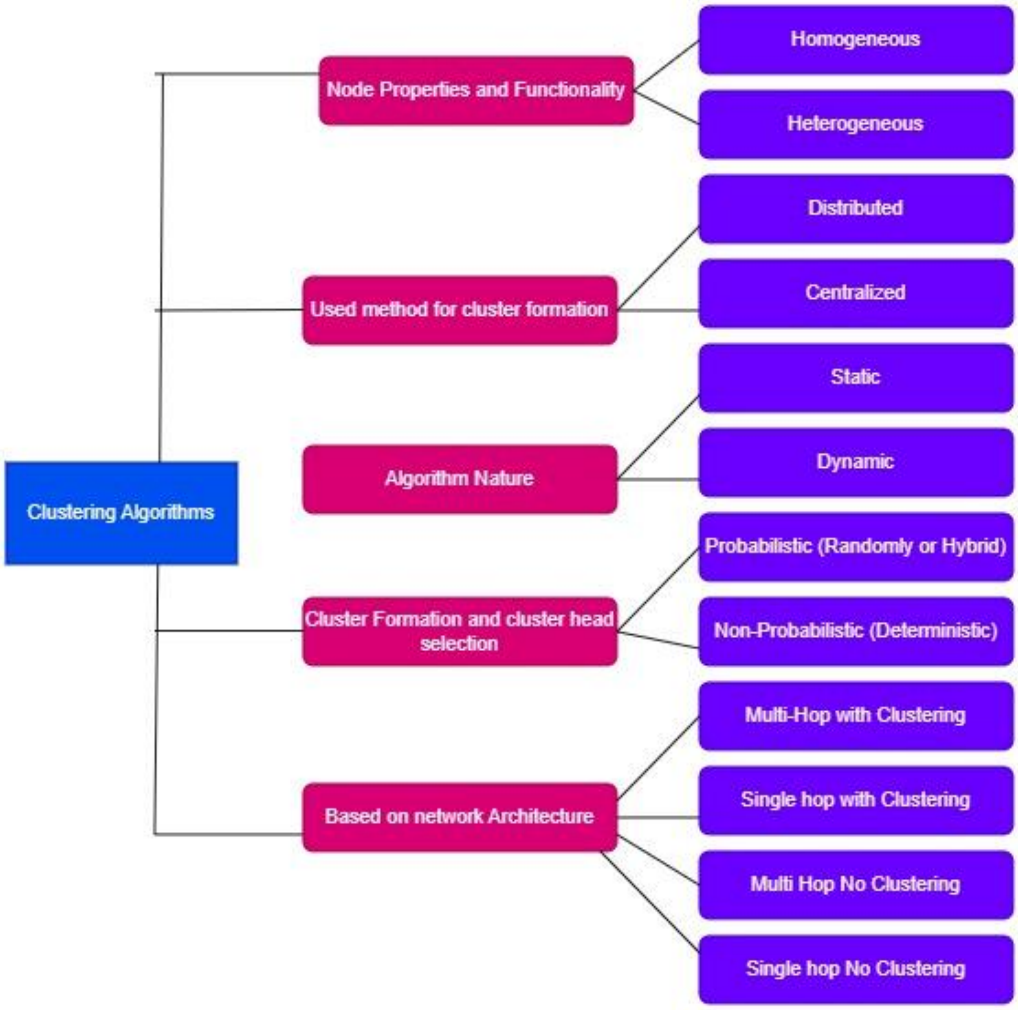


Fugure.4 Types of Clustering in WSN

## III. DIFFERENT NON-META CLUSTERING ALGORITHMIC EXPLORATION AND THEIR COMPARATIVE ANALYSIS

❖ ***LEACH (Low-Energy Adaptive Clustering Hierarchy)***

The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol, proposed by Heinzelman et al. [1], is a pioneering solution for energy-efficient communication in wireless sensor networks (WSNs). This protocol addresses the energy constraints of sensor nodes by employing a hierarchical clustering scheme. In LEACH, nodes self-organize into clusters, with each cluster having a designated cluster head responsible for data aggregation and transmission to a base station. The key innovation lies in probabilistically selecting cluster heads for each round, which redistributes energy consumption across nodes and mitigates premature node failure due to energy depletion. LEACH's operation occurs in rounds, where cluster head selection probabilities are dynamically adjusted to ensure a fair distribution of energy utilization among nodes. Cluster heads aggregate data from their cluster members and transmit aggregated data to the base station, minimizing the overall transmission energy. Furthermore, the protocol promotes data aggregation at the cluster head level, reducing redundant transmissions and conserving energy. While LEACH presents significant energy savings and prolongs network lifetime, it does exhibit limitations such as the need for periodic cluster head re-election and the potential for uneven energy distribution due to probabilistic selection. Despite these challenges, LEACH's pioneering approach has inspired subsequent research, leading to various enhancements and adaptations, such as LEACH-C [2] and LEACH-V [3], which have addressed some of the protocol's shortcomings.

**Implementation:** LEACH employs a hierarchical clustering approach where nodes self-organize into clusters, with each cluster having a cluster head (CH). CHs are responsible for aggregating and transmitting data to the sink.

**Mathematical Approach:** The probabilistic method used for selecting CHs involves nodes calculating a probability threshold based on their energy levels. Nodes that exceed this threshold become CHs for a particular round.

**Advantages:** LEACH's randomized CH selection balances energy consumption across nodes and prolongs network lifetime. It reduces the impact of CH failures by frequent re-election.

**Disadvantages:** Frequent cluster reformation introduces overhead, potentially impacting network stability. The algorithm doesn't inherently consider node heterogeneity or communication cost.

**Applications:** LEACH finds **Application**s in scenarios where sensor nodes are randomly **Dis**tributed, such as environmental monitoring and habitat surveillance.

**Improvement Needs:** Enhanced CH selection mechanisms could address energy imbalances and reduce overhead caused by frequent re-elections.

❖ **PEGASIS (Power-Efficient Gathering in Sensor Information Systems)**

PEGASIS (Power-Efficient Gathering in Sensor Information Systems) addresses the critical challenge of energy optimization in wireless sensor networks. In this research paper, the authors propose a novel hierarchical data aggregation protocol, PEGASIS, designed to prolong the network's overall lifespan by significantly reducing energy consumption during data transmission. The protocol employs a chain-based topology, wherein sensors are organized in a linear fashion, and data is successively transmitted from one sensor to another until reaching a designated sink node. PEGASIS introduces a dynamic switching mechanism that alternates between two transmission modes: short-range and long-range. This adaptability helps mitigate energy imbalances and prolong the network's operational time. Additionally, PEGASIS optimizes data fusion by allowing intermediate nodes to aggregate information before transmitting it to the sink, reducing redundant data transmission and conserving energy. Simulation results demonstrate the superiority of PEGASIS over existing protocols in terms of energy efficiency, network longevity, and data transmission reliability. By significantly mitigating energy consumption and balancing the energy dissipation among sensor nodes, PEGASIS presents a promising solution to the energy limitations of sensor networks. The protocol's innovative hierarchical structure, dynamic transmission modes, and efficient data aggregation contribute to its potential applicability in various domains, such as environmental monitoring, surveillance, and industrial automation, where energy efficiency is paramount for sustainable and prolonged network operations. PEGASIS introduces a chain-based communication paradigm, where nodes relay data to their immediate neighbours. The last node transmits aggregated data to the sink.

**Mathematical Approach:** The algorithm is primarily structured around the linear chain topology. Each node forwards data to the next node in a predetermined sequence.

**Advantages:** PEGASIS significantly reduces energy consumption by minimizing data transmission **Dis**tances. The absence of complex cluster head selection reduces overhead.

**Disadvantages:** Potential communication delays arise due to sequential data forwarding. Energy imbalances can occur as middle nodes consume more energy.

**Application**s: PEGASIS is apt for linear deployments, such as monitoring rivers, pipelines, and roads, where data needs to traverse a specific path.

**Improvement Needs:** Hybrid approaches, combining PEGASIS with other algorithms, can address communication delays and enhance overall robustness.

❖ ***SPIN (Sensor Protocols for Information via Negotiation)***

SPIN introduces a novel approach to data dissemination, employing a cluster-based architecture. Sensors are organized into clusters, and within each cluster, a coordinator facilitates the negotiation process. Before data transmission, sensors engage in negotiation to determine which node should transmit its data first, based on factors like energy levels and data urgency. This cooperative process helps mitigate collisions and reduce energy wastage. By implementing a dynamic sleep-wake mechanism, SPIN reduces energy consumption during idle periods. Sensors strategically enter sleep mode to conserve energy and awaken when needed for communication, further prolonging the network's operational lifetime. Simulation results validate the protocol's effectiveness, showcasing its superiority in terms of energy efficiency and network longevity compared to conventional approaches.

International Multidisciplinary Research Journal Reviews (IMRJR)
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SPIN's negotiation-based architecture, cluster organization, and dynamic sleep-wake mechanism offer promising solutions to the energy constraints of wireless sensor networks. The protocol's focus on collaboration and data exchange prior to transmission fosters efficient communication and resource allocation. These attributes make SPIN a potential candidate for various applications such as environmental monitoring, healthcare, and smart cities, where optimized energy utilization is paramount for sustained network performance.

**Implementation:** SPIN introduces a data-centric communication paradigm, where nodes request specific data attributes from their neighbours.

**Mathematical Approach:** Nodes generate queries for data attributes they need. Neighbouring nodes respond with relevant data, optimizing communication.

**Advantages:** SPIN reduces unnecessary data transmission, conserving energy and bandwidth. It excels in scenarios with high data correlation.

**Disadvantages:** Overhead due to query-response exchanges can become significant in dense networks with frequent data changes.

**Application**s: SPIN is effective in scenarios where data correlation is high, such as habitat monitoring and environmental tracking.

**Improvement Needs:** Adaptive negotiation strategies and refined query-response mechanisms could enhance efficiency and scalability.

❖ ***Directed Diffusion***

The Directed Diffusion method of clustering in wireless sensor networks stands as a pioneering approach to enhance communication efficiency and energy conservation. This innovative technique, elucidated in research literature, aims to optimize data dissemination and aggregation within sensor networks by capitalizing on the inherent characteristics of the network topology and data-driven interactions. Directed Diffusion leverages a gradient-based communication paradigm, where data flows from the source node towards the sink node through a directed path formed by a network of sensor nodes. Unlike traditional flooding-based methods, Directed Diffusion focuses on controlled data propagation, preventing unnecessary data redundancy and reducing energy consumption. The network is divided into clusters, with each cluster comprising a source node, which is responsible for initiating data dissemination, and a set of follower nodes that forward and aggregate the data. A distinctive feature of Directed Diffusion is its ability to adaptively adjust the data dissemination rates based on data relevance and event dynamics. Nodes engage in data exchanges through gradient-driven interests and gradients, which convey data preferences and guide the data flow towards the sink node. This decentralized and data-centric approach facilitates efficient event detection and response, promoting energy conservation and prolonging network lifetime. Simulation results underscore the method's effectiveness in minimizing energy consumption and prolonging network longevity. By strategically disseminating and aggregating data, Directed Diffusion mitigates information bottlenecks, reduces transmission collisions, and addresses the energy constraints inherent in wireless sensor networks.

The Directed Diffusion method's dynamic and adaptive nature, along with its focus on controlled data propagation, positions it as a valuable solution for applications such as environmental monitoring, surveillance, and disaster management. Its capacity to harness the network's structure and data characteristics contributes to efficient communication, making it a promising avenue for advancing the field of wireless sensor networks.

**Implementation:** Directed Diffusion establishes gradients for data interests, and nodes propagate data along the paths of increasing gradients.

**Mathematical Approach:** Each node maintains an interest gradient guiding data propagation. Nodes adjust gradients based on received data.

**Advantages:** Directed Diffusion adapts to dynamic network conditions, optimizing energy-efficient data routing.

**Disadvantages:** Potential gradient loop formation could lead to inefficient data routing.

**Application**s: Directed Diffusion suits **Application**s with dynamic data needs and changing network topologies, such as mobile tracking scenarios.

**Improvement Needs:** Advanced loop prevention mechanisms and efficient gradient adjustment techniques are necessary.

International Multidisciplinary Research Journal Reviews (IMRJR)
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❖ ***DMAC (Dynamic Medium Access Control)***

Dynamic Medium Access Control (DMAC) emerges as a pivotal advancement in the realm of wireless sensor networks by addressing the intricacies of clustering with enhanced efficiency. DMAC introduces a novel approach to Medium Access Control (MAC) protocol design, specifically tailored for clustered sensor networks. This method operates by dynamically adjusting the contention window size based on the varying traffic loads within the clusters. By doing so, DMAC mitigates collisions and contention, promoting improved channel utilization and reduced energy wastage. The protocol integrates seamlessly with clustering algorithms, aligning with the hierarchical organization of sensor nodes into clusters led by cluster heads. DMAC's innovation lies in its adaptability to the dynamic nature of sensor network environments. As network conditions fluctuate, the protocol intelligently tunes its parameters to accommodate changes, ensuring optimal data transmission without compromising energy conservation. By synchronizing the contention window adaptation with cluster scheduling, DMAC maximizes both energy efficiency and data delivery reliability.

**Implementation:** DMAC employs a duty cycle mechanism, where nodes alternate between active and sleep states to minimize collisions.

**Mathematical Approach:** Nodes synchronize their sleep-wake cycles to reduce collisions and idle listening.

**Advantages:** DMAC reduces collision and idle listening overhead, making it suitable for sporadic data transmissions.

**Disadvantages:** Synchronization overhead can be significant, particularly in dense networks.

**Application**s: DMAC is fitting for **Application**s where nodes transmit data intermittently, like environmental events monitoring.

**Improvement Needs:** Enhanced duty cycle adjustment algorithms that handle dynamic traffic variations could improve efficiency.

❖ ***2.6. RPL (Routing Protocol for Low-Power and Lossy Networks)***

RPL (Routing Protocol for Low-Power and Lossy Networks) introduces a pivotal solution for clustering in sensor networks by optimizing routing strategies. Specifically designed for resource-constrained environments, RPL employs a hierarchical structure where nodes are organized into clusters, enhancing network efficiency. This protocol operates efficiently in scenarios with low-power and lossy communication links, prevalent in sensor networks. RPL employs a rank-based approach, where nodes are assigned ranks based on their distance from the root node. This aids in forming a directed acyclic graph (DAG) that enables efficient data dissemination. Cluster heads play a pivotal role in RPL's clustering strategy, facilitating intra-cluster communication and forwarding data to the root node. By adhering to the RPL protocol, sensor networks can achieve efficient clustering, optimized routing, and reduced energy consumption. RPL's adaptability to dynamic network conditions and its focus on low-power and lossy environments positions it as a valuable solution for various applications like industrial automation, smart cities, and environmental monitoring, where effective clustering and communication are paramount for network performance.

**Implementation:** RPL forms a Directed Acyclic Graph (DAG) structure for data routing in low-power, lossy networks.

**Mathematical Approach:** Nodes select parents based on routing metrics, such as Expected Transmission Count (ETX), optimizing paths towards the sink.

**Advantages:** RPL optimizes data routing paths for energy efficiency and adapts to dynamic network conditions.

**Disadvantages:** Complexity related to DAG construction and maintenance introduces overhead.

**Application**s: RPL is ideal for scenarios with sparse connectivity and high loss rates, like critical infrastructure monitoring.

**Improvement Needs:** Fine-tuning of parent selection metrics and dynamic adaptation of DAG structure could enhance performance.

❖ ***GAF (Geographical Adaptive Fidelity)***

Geographical Adaptive Fidelity (GAF) revolutionizes clustering in sensor networks through its geographic-based approach. GAF leverage’s location information to create clusters, where nodes in close proximity form clusters, promoting efficient local communication.

International Multidisciplinary Research Journal Reviews (IMRJR)
A Peer-reviewed journal
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Nodes with higher fidelity act as cluster heads, maintaining higher data fidelity and relaying information to sink nodes. This dynamic clustering approach enhances network efficiency, reduces energy consumption, and accommodates changing network topologies. GAF's reliance on geographic characteristics ensures adaptive and scalable clustering, making it suitable for various applications, including environmental monitoring and precision agriculture.

**Implementation:** GAF introduces location-based data transmission, adapting data fidelity based on node-sink **Dis**tance.

**Mathematical Approach:** Nodes set data fidelity thresholds based on their **Dis**tance from the sink. Data fidelity decreases with **Dis**tance.

**Advantages:** GAF optimizes energy usage by tailoring data transmission fidelity to communication cost.

**Disadvantages:** Balancing data accuracy requirements and managing aggregated data are challenges.

**Application**s: GAF suits scenarios with varying data accuracy needs across geographical areas.

**Improvement Needs:** Dynamic adaptation of fidelity thresholds and efficient aggregation techniques could improve accuracy.

❖ ***SEP (Stable Election Protocol)***

The Stable Election Protocol (SEP) presents a fundamental advancement in wireless sensor networks by introducing an effective mechanism for selecting stable cluster heads in energy-constrained environments. Designed to extend network lifespan and enhance energy efficiency, SEP offers a dynamic clustering approach. SEP divides the network into rounds, with each round beginning by nodes announcing their energy levels. Nodes with higher energy reserves become candidates for cluster head selection, while nodes with lower energy levels opt to join clusters led by these stable cluster heads. This two-phase process ensures that cluster heads are well-distributed across the network and are consistently balanced in terms of energy consumption. Once cluster heads are chosen, SEP employs a threshold-based approach to maintain their stability. If a cluster head's energy level drops below a predefined threshold, a re-election process takes place, ensuring that fresh, more energetic nodes take over the cluster head role. SEP's significance lies in its ability to prolong network longevity by evenly distributing energy consumption among nodes and reducing the overhead associated with frequent re-elections. By promoting stability among cluster heads, SEP optimizes energy utilization, communication efficiency, and network lifespan. This protocol finds applications in various domains, including environmental monitoring, smart cities, and industrial automation, where energy-efficient and prolonged sensor network operations are imperative.

**Implementation:** SEP introduces stability-based cluster head (CH) selection, promoting balanced energy consumption and prolonged network lifetime.

**Mathematical Approach:** Nodes with energy above a threshold elect themselves as CHs, ensuring network stability.

**Advantages:** SEP addresses early energy depletion among CHs, improving overall network stability.

**Disadvantages:** Broadcasting energy levels introduces overhead, and stability criteria might not suit dynamic scenarios.

**Application**s: SEP is applicable where stable communication and energy **Dis**tribution are crucial, like critical infrastructure monitoring.

**Improvement Needs:** Enhanced stability criteria and adaptive CH selection mechanisms could enhance performance in dynamic networks.

❖ ***TEEN (Threshold-sensitive Energy Efficient sensor Network protocol)***

The Threshold-sensitive Energy Efficient sensor Network (TEEN) protocol is a pivotal advancement in wireless sensor networks, focusing on energy efficiency and real-time data communication. TEEN's innovative design caters to applications requiring timely data updates while conserving sensor node energy. TEEN introduces a threshold-based approach to data transmission. Nodes set a threshold value based on the significance of their sensed data. When the threshold is exceeded, the node transmits the data to the sink node. This adaptive mechanism ensures that only pertinent data is communicated, mitigating unnecessary transmissions and reducing energy consumption. TEEN also employs a sleep-wake cycle to further conserve energy. Nodes alternate between active and sleep states based on their data's significance and threshold values. This duty cycling reduces constant communication, prolonging the network's operational life. TEEN is particularly valuable in applications like monitoring dynamic phenomena or environments with intermittent events. Its balance between timely data delivery and energy preservation makes it suitable for scenarios like habitat monitoring, disaster management, and healthcare systems.

**International Multidisciplinary Research Journal Reviews (IMRJR)**
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By prioritizing data based on thresholds and employing efficient duty cycling, TEEN contributes to sustainable sensor network operations, aligning with the energy constraints of resource-limited environments.

**Implementation:** TEEN's threshold-based approach transmits data only when it crosses a predefined threshold, conserving energy.

**Mathematical Approach:** Nodes periodically monitor data and transmit when values exceed a threshold.

**Advantages:** TEEN conserves energy by transmitting only when significant data changes occur.

**Disadvantages:** Missed events are possible if data values do not exceed the threshold.

**Applications**: TEEN suits scenarios with infrequent but significant events, such as intrusion detection.

**Improvement Needs:** Adaptive threshold adjustment mechanisms could enhance event detection accuracy.

## IV. COMPARATIVE ANALYSIS

In this section, we provide a tabular chart highlighting the differences among the algorithms across five Distinct parameters: Implementation, Mathematical Approach, Advantages, Disadvantages, and Applications.

| Algorithm | Implementation | Mathematical Approach | Advantages | Disadvantages | Applications |
|---|---|---|---|---|---|
| LEACH | Clustering-based | Probability-based CH selection | Balanced energy consumption, | Frequent cluster reformation | Environmental monitoring, Precision agriculture |
| | | | prolongs network lifetime | potential overhead | Habitat surveillance, |
| | | | Distributed CH selection | | |
| PEGASIS | Chain-based data aggregation | Linear chain topology, | Significant energy reduction through | Potential communication delays | Linear deployments (rivers, roads), |
| | | sequential data transmission | minimized transmission distances | in case of chain disruption | Linear monitoring scenarios |
| SPIN | Data-centric communication | Query-response mechanism, | Reduced unnecessary data transmission, | Overhead due to query-response exchanges | Correlated data scenarios |
| | | negotiation | energy conservation | | Habitat monitoring |
| Directed Diffusion | Data-centric communication | Gradient-based data propagation | Efficient data routing, adaptation to dynamic conditions | Potential gradient loop formation without loop prevention | Dynamic environments, |
| | | | | | Mobile tracking applications |
| DMAC | Duty cycle mechanism | Periodic sleep-wake cycles, | Collisions and idle listening minimized, | Synchronization overhead, particularly | Bursty data scenarios, |
| | | dynamic adjustment | adaptive to varying data rates | in dense networks | Intermittent transmissions |
| RPL | Directed Acyclic Graph (DAG) | Objective function-based parent | Efficient routing, adaptability to | DAG construction and maintenance | Sparse connectivity scenarios, |
| | | selection | changing link conditions | complexity | Critical infrastructure monitoring |

| Algorithm | Implementation | Mathematical Approach | Advantages | Disadvantages | Applications |
|---|---|---|---|---|---|
| GAF | Location-based data transmission | Data fidelity thresholds based on | Energy-efficient data transmission | Defining fidelity thresholds and | Varying data accuracy requirements, |
| | | node-sink distance | based on distance | handling aggregated data at the sink | Large geographical areas |
| SEP | Clustering with stable CHs | Stability criteria-based CH selection | Improved energy balance, | Energy overhead due to broadcasting | Stability-critical applications, |
| | | | prolonged network stability | of energy levels | Long-term monitoring |
| TEEN | Threshold-based data reporting | Data sampling and transmission | Reduced energy consumption through | Potential missed events due to threshold | Infrequent but significant events, |
| | | based on threshold crossing | selective data transmission | values not being crossed | Intrusion detection |
| BCDCP | Base station-controlled clustering | Centralized control-based cluster | Efficient clustering, energy distribution | Centralized control introduces | Scenarios with centralized control, |
| | | formation | optimization, reduced overhead | single points of failure | Efficient base station communication |

Table.1
Comparative analysis of different non-meta clustering techniques

## V. CONCLUSION

In conclusion, this research has conducted a comprehensive investigation and comparative study of non-meta-algorithms that are utilized to increase energy efficiency in Wireless Sensor Networks, which ultimately leads to improved cooperative communication. Each algorithm possesses a distinct set of advantages and disadvantages, which enables them to be utilized effectively only in particular application contexts. The features of the network, the requirements of the Application, and the targeted energy-saving goals should all be taken into consideration while selecting an algorithm. Further investigation and invention are required to perfect these algorithms, surmount obstacles, and propel the development of energy-efficient sensor networks, as wireless sensor networks (WSNs) continue to develop and find applications in a wide variety of industries. This paper can be used as an invaluable resource by researchers, practitioners, and decision-makers who are interested in gaining insights into the landscape of energy-efficient algorithms in WSNs.

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