ANALYTICAL REPORT ON ENERGY EFFICIENT NON-METAHEURISTIC CLUSTERING IN WIRELESS SENSOR NETWORKS LEADING TO COOPERATIVE COMMUNICATION

Nishant Tripathi[1]

Dept. of Electronics and Communication Engineering, School of Electronics and Electrical Engineering, Lovely Professional University, Phagwara, Punjab (India)
Dept. of Electronics and Communication Engineering, Pranveer Singh Institute of Technology Kanpur
phd.nishant17@gmail.com

Charanjeet Singh[2]

Dept. of Electronics and Communication Engineering, School of Electronics and Electrical Engineering, Lovely Professional University, Phagwara, Punjab (India)
rcharanjeet@gmail.com

Kamal Kumar Sharma[3]

Ambala College Of Engineering and Applied Research Devsthali, Ambala Cantt – Jagadhari Road, P.O. Sambhalkha Ambala
Haryana, India
kamalsharma111@gmail.com

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.

1. 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
- Ability to manage communication in mobile node scenarios
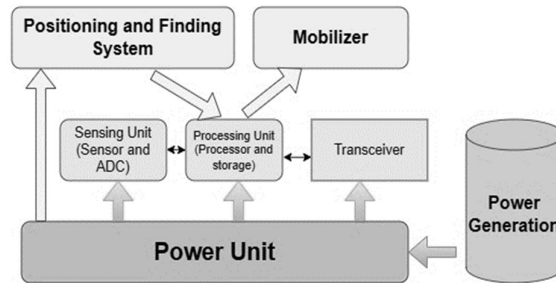- Constrained by hardware limitations inherent to sensor nodes

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

2. 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].
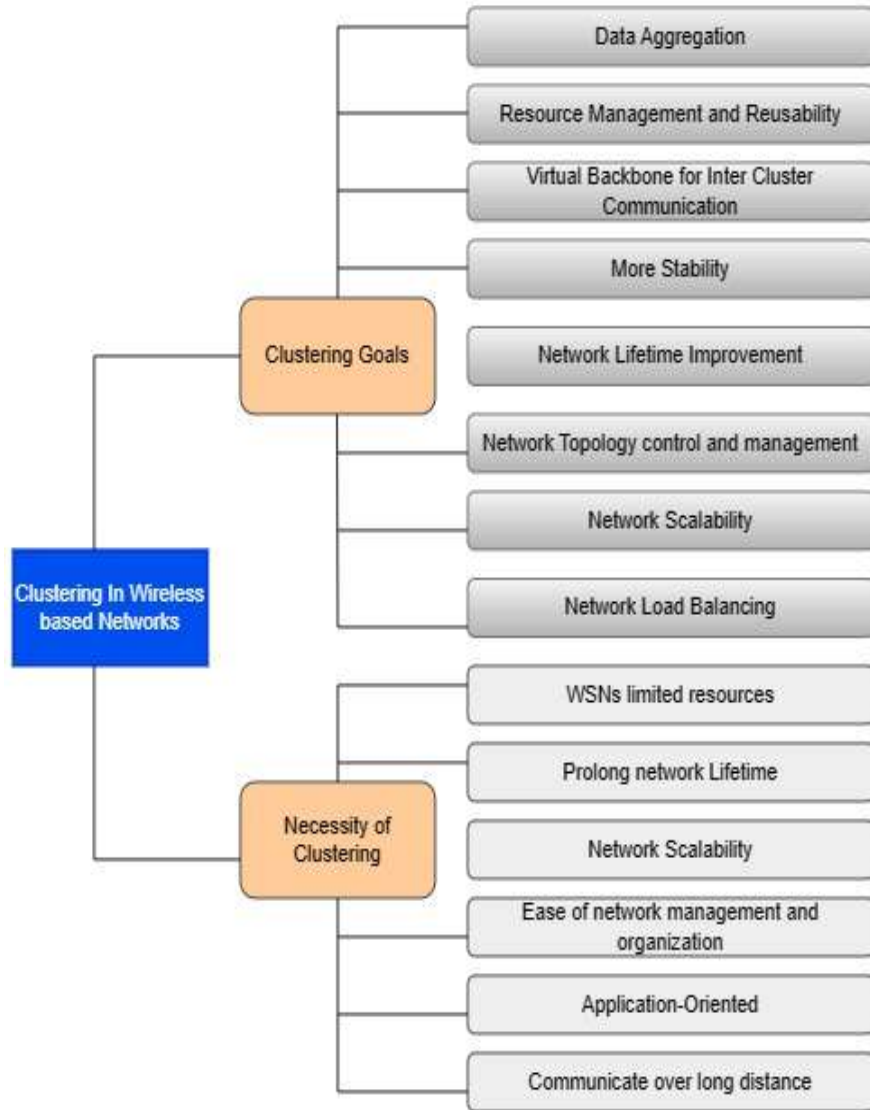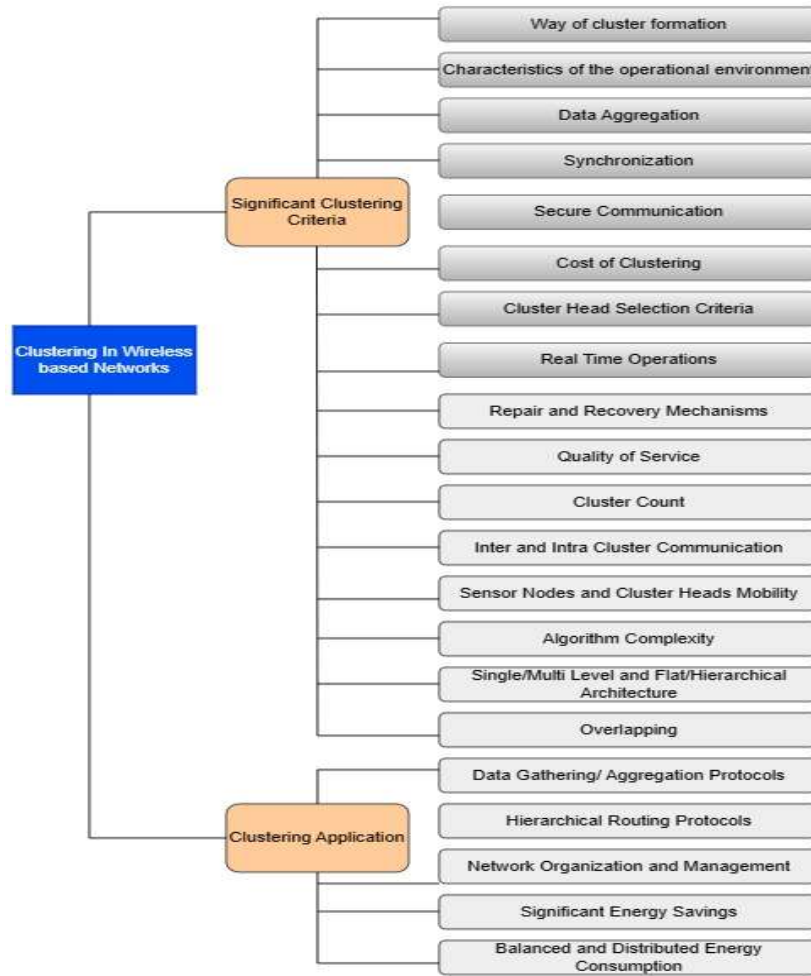
Figure.2
Clustering Goals and Requirement

Figure.3
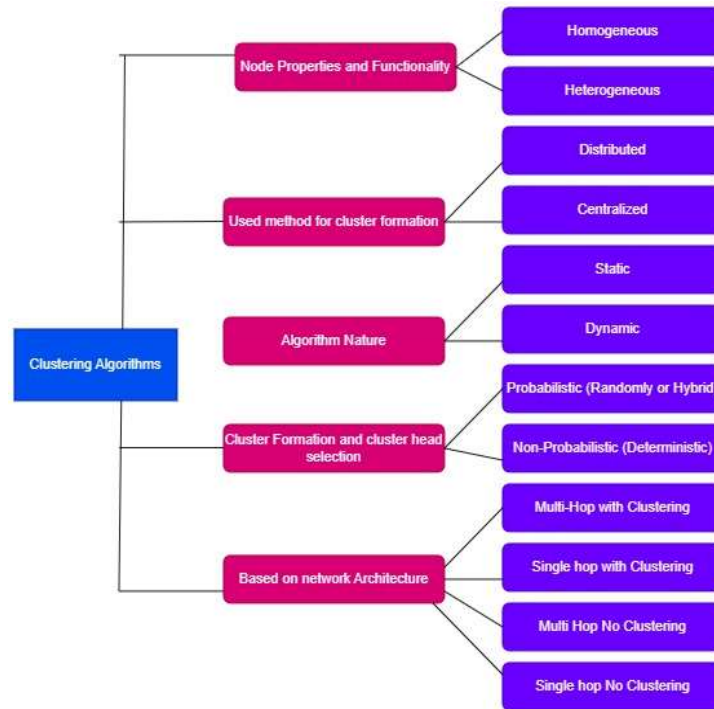Clustering Criteria and Applications

Fugure.4
Types of Clustering in WSN

3. 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 **Dist**ributed, 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.

Applications: 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.

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.

Applications: 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.

Applications: 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.

❖ *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.
Applications: 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.

Applications: 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. 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.

Applications: 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.

Applications: 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. 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.

❖ *BCDCP (Base Station Controlled Dynamic Clustering Protocol)*

The Base Station Controlled Dynamic Clustering Protocol (BCDCP) stands as an innovative solution in wireless sensor networks, addressing the challenges of energy efficiency and network management. BCDCP introduces a hierarchical approach to clustering, with a focus on maximizing energy conservation and communication efficiency. In BCDCP, sensor nodes are organized into clusters, and each cluster is overseen by a designated cluster head. However, what sets BCDCP apart is its base station's involvement in cluster head selection. The base station, which acts as a central entity, controls the clustering process by assessing factors such as node energy levels, distances, and data traffic. Based on this information, the base station dynamically selects and assigns cluster heads, ensuring that energy-efficient nodes with sufficient energy reserves and favourable communication conditions are chosen. BCDCP's dynamic cluster head selection optimizes data aggregation and transmission, leading to reduced energy consumption and extended network lifetime. By centralizing the decision-making process, BCDCP eliminates redundant cluster formations and minimizes energy imbalances among nodes. Additionally, this protocol supports adaptive adjustments in cluster membership and leadership, accommodating variations in network conditions and maintaining efficiency over time. BCDCP's proficiency in energy management and network optimization makes it suitable for applications such as environmental monitoring, precision agriculture, and smart cities. Its ability to integrate base station control, dynamic cluster formation, and adaptive management positions BCDCP as a significant contribution to the realm of sensor networks, addressing critical challenges associated with energy efficiency and resource constraints.

Implementation: BCDCP involves base station-controlled dynamic clustering, where the base station selects cluster heads (CHs).

Mathematical Approach: The base station initiates cluster formation, minimizing overhead associated with **Dis**tributed CH selection.

Advantages: BCDCP optimizes energy **Dis**tribution and minimizes communication overhead through centralized control.

Disadvantages: Centralized control introduces single points of failure and synchronization challenges.

Applications: BCDCP suits scenarios with centralized control possibilities and efficient base station communication.

Improvement Needs: Decentralized control mechanisms while maintaining efficient clustering could enhance BCDCP's scalability.

4. **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,

Algorithm	Implementation	Mathematical Approach	Advantages	Disadvantages	Applications
		selection	changing link conditions	complexity	Critical infrastructure monitoring
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

5. 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.

6. References

[1] Tripathi, N., Sharma, K.K. (2022). Distributed and Hierarchical Clustering Techniques Comparison in Wireless Camera Sensor Networks. In: Kaiser, M.S., Bandyopadhyay, A., Ray, K., Singh, R., Nagar, V. (eds) Proceedings of Trends in Electronics and Health Informatics. Lecture Notes in Networks and Systems, vol 376. Springer, Singapore. https://doi.org/10.1007/978-981-16-8826-3_33

[2] L. Xie and X. Zhang, "3D clustering-based camera wireless sensor networks for maximizing lifespan with Minimum coverage rate constraint," in Proc. IEEE GLOBECOM, Atlanta, GA, USA, Dec. 2013, pp. 298–303.

[3] J. Wang and X. Zhang, "AQ-DBPSK/DS-CDMA based energy-efficient and interference-mitigation scheme for 3D clustered WCSNs with minimum coverage rate constraint," in Proc. IEEE MILCOM, Baltimore, MD, USA, Oct. 2014, pp. 305–310.

[4] A. Del Coso, U. Spagnolini, and C. Ibars, "Cooperative distributed MIMO channels in wireless sensor networks, IEEE J. Sel. Areas Commun., vol. 25, no. 2, pp. 402–414, Feb. 2007.

[5] J. Wang and X. Zhang, "Cooperative MIMO-OFDM based multi-hop 3D clustered wireless camera sensor networks," in Proc. IEEE Wireless Commun. Network Conf. (WCNC), New Orleans, LA, USA, Mar. 2015, pp. 1350–1355.

[6] Aria Nosratinia ET. AL. Cooperative Communication in Wireless Networks, "IEEE Communications Magazine October 2004".

[7] Jigisha Parmar et. al. "Study of Wireless Sensor Networks Using Leach-Teen and Apteen Routing Protocols" International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064".

[8] H. Kiwan et.al. "Hierarchical networks: Routing and clustering (A concise survey)" "2013 26th IEEE Canadian Conference of Electrical and Computer Engineering (CCECE) ".

[9] Neha Rathi et. al. "A REVIEW ON ROUTING PROTOCOLS FOR APPLICATION IN WIRELESS SENSOR NETWORKS", "International Journal of Distributed and Parallel Systems (IJDPS) Vol.3, No.5, September 2012".

[10] Payal Jain et. al. "The Comparison between Leach Protocol and Pegasis Protocol based on Lifetime of Wireless Sensor Networks", "International Journal of Computer Science and Mobile Computing, Vol.6 Issue.12, December- 2017, pg. 15-19 ".

[11] Kirichek, R., Paramonov, A., Koucheryavy, A.: Flying ubiquitous sensor networks as a queening system. In: Proceedings, International Conference on Advanced Communication Technology, ICACT 2015, Phoenix Park, Korea, July 01–03, 2015

[12] Attarzadeh, N., Mehrani, M.: A New Three-Dimensional Clustering Method for Wireless Sensor Networks. Global Journal of Computer Science and Technology 11(6), April 2011. version 1.0

[13]   Hooggar, M., Mehrani, M., Attarzadeh, N., Azimifar, M.: An Energy Efficient Three-Dimensional Coverage Method for Wireless Sensor Networks. Journal of Academic and Applied Studies 3(3), March 2013.

[14]   Abakumov, P., Koucheryavy, A.: The cluster head selection algorithm in the 3D USN. In: Proceedings, International Conference on Advanced Communication Technology, ICACT 2014, Phoenix Park, Korea.

[15]   Dang Thanh Hai, Le Hoang Son, Vinh Trong Le", Novel Fuzzy Clustering Scheme for 3D Wireless Sensor Networks" , "Applied Soft Computing Journal

[16]   C.-Y. Chong and S. Kumar, "Sensor networks: evolution, opportunities, and challenges," Proceedings of the IEEE, vol. 91, no. 8, pp. 1247–1256, Aug 2003.

[17]   I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," Computer Networks, vol. 38, no.4, pp. 393 – 422, 2002.

[18]   S. Murugesan, "Harnessing green it: Principles and practices," IT Professional, vol. 10, no. 1, pp. 24–33, Jan. 2008.

[19]   L. Xu, D. Delaney, G. O'Hare, and R. Collier, "The impact of transmission power control in wireless sensor networks," in Network Computing and Applications (NCA), 2013 12th IEEE International Symposium on, 2013, pp. 255–258.

[20]   A. D. Amis, R. Prakash, T. H. Vuong, and D. T. Huynh, "Maxmin d-cluster formation in wireless ad hoc networks, in INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies.   Proceedings. IEEE, vol. 1. IEEE, 2000, pp. 32–41.

[21]   M. R. Brust, H. Frey, and S. Roth kugel, "Adaptive multi-hop Clustering in mobile networks," in Proceedings of the 4th international conference on mobile technology, applications, and systems and the 1st international symposium on Computer human interaction in mobile technology. ACM, 2007, pp. 132–138.

[22]   D. Baker and A. Ephremides, "The architectural organization of a mobile radio network via a distributed algorithm, IEEE Transactions on communications, vol. 29, no. 11, pp. 1694–1701, 1981.

[23]   L. M. C. Arboleda and N. Nasser, "Comparison of clustering algorithms and protocols for wireless sensor networks in 2006 Canadian Conference on Electrical and Computer Engineering, May 2006, pp. 1787–1792.

[24]   O. Younis, M. Krunz, and S. Ramasubramanian, "Node clustering in wireless sensor networks: recent developments and deployment challenges," IEEE Network, vol. 20, no. 3, pp. 20–25, May 2006.

[25]   A. A. Abbasi and M. Younis, "A survey on clustering algorithms for wireless sensor networks," Computer Communications, vol. 30, 2007.

[26]   P. Kumarawadu, D. J. Dechene, M. Luccini, and A. Sauer, "Algorithms for node clustering in wireless sensor networks: A survey," in 2008 4th International Conference on Information and Automation for Sustainability, Dec 2008, pp. 295–300.

[27]   B. P. Deosarkar, N. S. Yadav, and R. P. Yadav, "Cluster head selection in clustering algorithms for wireless sensor networks: A survey," in 2008 International Conference on Computing, Communication and Networking, Dec 2008, pp. 1–8.

[28]   M. Zhao, Y. Yang, and C. Wang, "Mobile data gathering with load balanced clustering and dual data uploading wireless sensor networks," IEEE Transactions on Mobile Computing, vol. 14, no. 4, pp. 770–785, 2015.

[29]   P. Nayak and A. Devulapalli, "A fuzzy logic-based clustering algorithm for WSN to extend the network lifetime, IEEE Sensors Journal, vol. 16, no. 1, pp. 137–144, Jan 2016.

[30]   L. Xu, G. O'Hare, and R. Collier, "A balanced energy-efficient multi-hop clustering scheme for wireless sensor network," 7th IFIP Wireless and Mobile Networking Conference (WMNC), 2014.

[31]   G. Sirisha, R. B. Babu, and K. R. Rao, "Establishing path quality management in wireless sensor networks through cluster head determination," Indian Journal of Science and Technology, vol. 9, no. 5, 2016.

[32]   C. R. Lin and M. Gerla, "Adaptive clustering for mobile wireless networks," IEEE Journal on Selected Areas in Communications, vol. 15, pp. 1265–1275, 1997.

[33]   R. Nagpal and D. Coore, "An algorithm for group formation and maximal independent set in an amorphous computer," Cambridge, MA, USA, Tech. Rep., 1998.

[34]   W. Heintzelman, A. Chandrakasan, and H. Balakrishnan, "Energyefficient communication protocol for wireless microsensor networks," in System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conferenc on, Jan. 2000, p. 10 pp. vol.2.