Routing Protocols Employed in Wireless Sensor Networks-A Survey.

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Abstract:- Wireless Sensor Networks (WSNs) are game-changing technologies that utilize small, wireless sensors with communication capabilities to gather real-time data from the environment. These are highly versatile and efficient in optimizing network resources. They boast of a wide coverage area and can operate for extended periods through energy-efficient protocols and edge data processing. Their applications are diverse, ranging from environmental sensing to industrial automation and healthcare, making them an indispensable part of a connected and intelligent world. Despite challenges such as scalability, data reliability, security, and node failure resilience, ongoing research is expected to further advance WSNs. They enable informed decision-making and sustainable development across various industries, cementing their role as critical technology for the future.

Keywords*: Wireless Sensor Network(WSN), LEACH, Scalability, Data reliability, latency, Energy Efficiency and Network Lifetime.*

1. Introduction

Wireless Sensor Network (WSN) is a highly efficient system that monitors conditions without the need for any infrastructure. These networks are made to track and acquire data on the physical world, including things like weather patterns, industrial processes, infrastructure conditions and more. A well-designed network of sensors comprises multiple stations that can effectively detect, referred to as sensor nodes. These nodes are designed to be compact, easy to carry around and highly portable, making them an ideal solution for a wide range of applications. Each sensor node is required to possess a transducer, microcomputer, transceiver and power source. The transducer serves the exclusive function of producing electrical signals that correspond to physical effects and phenomena detected by the node. The microcomputer is responsible for processing and storing the output of the sensors. Meanwhile, the transceiver receives commands from a central computer and sends data to it. The sensors are powered by batteries.

The utilization of Wireless Sensor Networks presents several benefits, including cost-effectiveness, wireless communication, energy efficiency, scalability and the ability to monitor physical phenomena in real-time. Wireless sensor networks can have various applications including the Internet of Things, industrial automation, automated homes, video surveillance, traffic monitoring, medical device monitoring, weather condition monitoring, air traffic control and robotic control. The impact of Wireless Sensor Networks (WSNs) in shaping a connected and intelligent world cannot be underestimated. With continuous research and development, these networks possess the potential to bring about revolutionary changes in diverse industries. They empower informed decision-making, improve system efficiency and promote sustainable development. Section 2 comprehensively address multiple routing protocol schemes along with the newest hierarchal routing protocol schemes for wireless sensor networks. Section 3 will provide a thorough comparison of the discussed hierarchial routing protocol schemes. Furthermore, Section 4 will conclude this paper. Finally, Section 5 will brief the Future Challenges.

2. Different Routing Schemes For Desigining Wsns

I. Flat routing :Flat routing treats all sensor nodes equally and allows direct communication between nodes or the base station. However, scalability and energy efficiency may become issues as the network grows.

II.Hierarchical routing : Hierarchical routing [6] is a method of organizing sensor nodes into multiple levels or tiers. In this approach, nodes are grouped into clusters, with cluster heads responsible for aggregating and forwarding data to the base station. By aggregating data at intermediate nodes, this method reduces energy consumption and communication overhead. Popular hierarchical routing protocols include Low-Energy Adaptive Clustering Hierarchy (LEACH) and its various versions. In Wireless Sensor Networks (WSNs), hierarchical routing algorithms are used to group or cluster sensor nodes into groups. Each cluster has a cluster head who is in charge of managing the cluster as a whole and collecting and delivering data from the member nodes to the base station or another cluster head at a higher level. The advantages of hierarchical routing protocols include reduced communication overhead, scalability, and energy efficiency. The following is a list of different hierarchical routing schemes used in WSNs:

A . Low-Energy Adaptive Clustering Hierarchy (LEACH) : For wireless sensor networks, the LEACH [11] (Low Energy Adaptive Clustering Hierarchy) protocol is a key routing method. The sensor nodes are organized into clusters using a hierarchical structure, and each cluster has a designated cluster head. The novel feature of the protocol is its probabilistic cluster head selection mechanism, which enables nodes to alternately serve as cluster heads to balance energy consumption. Regular nodes communicate their data to the cluster head during data collection so that it can be aggregated before being transmitted to a higher-level node or the base station. This hierarchical method is ideal for remote or energy-constrained situations because it optimizes energy consumption, increases network longevity and is cost-effective. But because cluster heads are changing often, there may be nonuniform energy distribution and overhead. • Energy conservation. • Aspect of security. • Routing protocol dependability. • Fault Tolerance. • Quality of services. As a result of LEACH's shortcomings, other improved variations, such as LEACH-C, have been developed throughout time. In order to improve energy efficiency and network longevity, these protocols continue to influence the development of wireless sensor network techniques.

B. LEACH-C (Centralized LEACH): The LEACH-C [21] (Low Energy Adaptive Clustering Hierarchy - Centralized) protocol for wireless sensor networks is an improved version of the LEACH protocol. It adds a centralized control component, commonly known as the "master" or "sink," to monitor and enhance the cluster creation procedure. Contrary to the probabilistic cluster head selection used in the original LEACH, the centralized entity in LEACH-C plays a significant role in selecting cluster heads based on elements such as node energy, communication quality and proximity to the sink. As a result, energy-consuming responsibilities are distributed more evenly, eliminating energy imbalances and extending the network's total lifespan. LEACH-C has difficulties, but it also has advantages including increased energy efficiency and enhanced communication. System complexity and potential single points of failure are increased by the addition of a centralized control entity. Additional issues include synchronization difficulties and scalability issues, particularly as the network expands. However, in situations where centralized control can be efficiently handled, LEACH-C's enhanced approach to cluster head selection and energy distribution makes it a plausible choice for enhancing wireless sensor network performance.

C. LEACH-M(Multi-level LEACH): An improved version of the LEACH protocol designed specifically for wireless sensor networks is called LEACH-M [3]. It establishes a multi-level hierarchy of cluster heads to enhance data transmission and energy efficiency. Cluster heads at each level of the hierarchy collect data from lower-level clusters, reducing the need for lengthy communications. Although the protocol expands on the original LEACH's probabilistic cluster head selection mechanism to choose several cluster heads for each cluster at various levels of the hierarchy. By easing the burden on long-distance transmissions, data aggregation takes place inside local and intermediate clusters, considerably preserving energy. This architecture extends the life of the network, especially in situations when installations are remote or energy-constrained. Despite these advantages, synchronization and scalability issues need to be addressed as well as careful parameter tweaking. The benefits of LEACH-M must be weighed against the challenges of running a multi-level hierarchy, such as potential communication costs and synchronization difficulties. The complexity of synchronizing the various cluster head levels may rise as the network scales, necessitating greater adaptability and parameter optimization. Though its practical use necessitates careful consideration of its complexities and potential difficulties, LEACH-M overall offers a promising approach for enhancing energy efficiency and prolonging the lifespan of wireless sensor networks, especially in resourceconstrained areas.

D. LEACH-HC(Low Energy Adaptive Clustering Hierarchy with Hierarchical Clustering): LEACH-HC [25] is a more sophisticated variant of the LEACH protocol. To improve energy efficiency and data aggregation, a twotier hierarchical structure made up of local clusters and superclusters is introduced. According to this plan, the supercluster heads further aggregate the data that the local cluster heads have already collected from their member nodes. This multi-level aggregation reduces long-distance data transmission while balancing energy use to optimize communication. LEACH-HC is appropriate for applications needing effective and longlasting network operation because it provides advantages such improved network stability, improved energy distribution and extended network lifetime. The protocol adds complexity, too, by handling the duallayer structure and dealing with synchronization issues. To achieve successful implementation and reduce communication costs or scalability problems, careful thought must be given. LEACH-HC essentially offers a hierarchical architecture that makes use of superclusters to enhance communication and energy efficiency in wireless sensor networks, while its actual use necessitates careful management of complexities and potential difficulties.

E. COGNITIVE-LEACH (COG-LEACH) : A development of the LEACH protocol, Cognitive LEACH [23] maximizes energy efficiency and adaptability in wireless sensor networks (WSNs) by utilizing cognitive capacities. C-LEACH integrates intelligence into numerous facets of network operation by incorporating cognitive functions. Notably, it improves cluster head selection by enabling nodes to take sensible decisions in light of current data and network circumstances. This cognitive strategy promotes longer network lifetime by producing more energy-efficient cluster formation. Additionally, C-LEACH offers dynamic clustering, which adjusts to shifting conditions while balancing energy usage and preserving network stability. By conveying important data while avoiding needless transmissions, the protocol's context-aware data aggregation optimizes energy consumption. C-LEACH attempts to increase network longevity and improve data transmission paths with cognitively assisted energyefficient routing options. In essence, C-LEACH shows how cognitive technologies have the power to transform wireless sensor networks by bringing intelligence and adaptability, ultimately resulting in more sustainable and effective network functioning in a variety of application scenarios.

F. MOD-LEACH (Modified LEACH): A more sophisticated version of the LEACH protocol called MOD-LEACH [24] was created with the goal of increasing the operational longevity and energy efficiency of wireless sensor networks. This treatment significantly improves a number of important areas. Notably, the selection of the cluster head is enhanced by giving preference to nodes with higher residual energy and better communication, leading to a more even allocation of the energy-consuming responsibilities. The selection process is further improved with the addition of an adaptive threshold for cluster head candidacy, guaranteeing that nodes with higher energy levels contribute to effective cluster formation. Additionally, MOD-LEACH improves data aggregation methods, fostering effective data collecting and transmission. The methodology considerably lowers the energy used for data communication by aggregating data at cluster heads before delivering it to higher-level nodes or the base station. Multi-hop communication between cluster heads and the base station is also included to reduce the amount of energy used during long-distance broadcasts. Overall, MOD-LEACH offers a wireless sensor network-specific energy-efficient solution that increases resource efficiency, lengthens network lifetime, and is flexible enough to accommodate a variety of application situations.

G. LEACH-Kmeans: LEACH-KMeans is a revolutionary protocol that improves the energy economy and clustering precision of wireless sensor networks (WSNs) by combining the advantages of the LEACH and KMeans algorithms. The initial network topology is produced through LEACH's random cluster head selection and the clustering arrangement is subsequently fine-tuned using K-Means. With this improvement, cluster allocations are made more optimally based on closeness, cutting down on intracluster distances and encouraging balanced energy use. LEACH-KMeans [26] enables accurate clustering while maintaining energy-efficient communication through data aggregation by cluster heads by strategically integrating these techniques. This strategy increases network performance in situations demanding accurate data collecting and extended operation, in addition to extending network durability. The success of the protocol depends on managing the integration of two different algorithms and effective parameter tweaking. The protocol seeks to reconcile energy efficiency and precise data clustering while adding complexity and addressing the drawbacks of random cluster head selection. For applications like environmental monitoring and industrial automation, where exact data aggregation and energy conservation are crucial, LEACH-KMeans has the potential to be a useful solution.

H. EE-LEACH (Energy Efficient LEACH): EnergyEfficient Low Energy Adaptive Clustering Hierarchy, or EE-LEACH [12], is a more advanced LEACH technique designed specifically for wireless sensor networks. It introduces improvements to extend operational longevity, network stability, and energy efficiency. Contrary to LEACH's random cluster head selection, EELEACH chooses cluster heads by taking into account node density, residual energy levels and proximity to the sink. By ensuring that cluster heads are chosen intelligently, this technique fosters energy balance and effective data aggregation. The advances of EE-LEACH go beyond just choosing a cluster head. It uses energy-saving data aggregation techniques to cut down on the energy needed for data transmission. Additionally, sleep scheduling techniques are used to enable nodes to save energy by periodically entering low-power modes. EE-LEACH is a promising approach for optimizing wireless sensor networks, especially in situations when energy limitations are severe and extended network operation is necessary. It does this by more evenly distributing energy usage among nodes and addressing energy-efficient communication.

I. PEGASIS (Power-Efficient Gathering in Sensor Information Systems) : A wireless sensor network protocol called PEGASIS [16] (Power-Efficient collection in Sensor Information Systems) was created to improve data collection and energy efficiency. It makes use of a chainbased communication paradigm where the sensor nodes are placed in a linear order and pass data sequentially to a designated sink node. By minimizing long-range communication, this strategy saves energy by cutting down on transmission distances. As nodes in the chain gather and transmit data, data aggregation is maximized, which is advantageous in situations where energy conservation is important. Although PEGASIS has benefits including decreased transmission overhead and energy-efficient data aggregation, there are drawbacks as well. Energy imbalance could result from the linear chain structure, with nodes closer to the sink using up energy more quickly. A single node's failure might also cause the entire communication system to malfunction. The efficiency of the protocol is influenced by variables like network structure and node distribution, which highlights the necessity of appropriate parameter adjustment and adaptation. PEGASIS essentially offers a chain-based approach to reducing energy usage in wireless sensor networks, but its implementation necessitates careful attention to energy balance and probable failure scenarios.

J. HEED (Hybrid Energy-Efficient Distributed Clustering) : A wireless sensor network protocol called HEED[17] (Hybrid Energy-Efficient Distributed Clustering) combines distributed and centralized methodologies for the most effective energy-efficient clustering. The process starts with a distributed one in which nodes group themselves into clusters according to their energy consumption and communication needs. By taking this first action, the network's energy imbalances are avoided. After that, a central "Refinement Manager" steps in to further optimize the choice of cluster heads. By minimizing early energy depletion, this hybrid strategy ensures that energy consumption is distributed equally among nodes, extending the lifespan of the entire network. By enhancing data aggregation and reducing longdistance communication, HEED's hierarchical cluster topology improves energy efficiency. But the complexity of the protocol results from combining both distributed and centralized methods, necessitating careful parameter tweaking and taking into account elements like network size and density. Overall, HEED offers a viable method for clustering wireless sensor networks that is energy-efficient and has the ability to balance energy use, lengthen network lifetime and enhance data collecting and transmission.

K. SEP (Stable Election Protocol) : For wireless sensor networks (WSNs), the Stable Election system [22](SEP) is a routing system created to increase network lifetime and stability. SEP chooses cluster heads using a probabilistic method, with nodes assessing their likelihood of becoming a cluster head based on elements like energy and node degree. This probability-based decision encourages balanced energy consumption and guards against node-to-node energy imbalances. In order to maintain stability, SEP additionally adds a threshold mechanism that restricts participation in cluster head candidacy to nodes with residual energy above a predetermined level. This helps preserve a stable network structure and avoids repeated reelections. Cluster heads in SEP efficiently collect and transmit data to higher-level nodes or the base station by aggregating data within clusters, limiting long-distance transmissions to save energy. The protocol's strength is in its capacity to boost network stability while extending network life. These objectives are jointly accomplished via SEP's probabilistic selection, threshold-based re-election and data aggregation procedures. SEP is a useful routing system for applications requiring dependable and energy-efficient wireless sensor networks, even if its efficacy depends on adequate parameter tweaking and adaptation to changing conditions.

L. EECS (Energy-Efficient Clustering Scheme) : By using a multi-level hierarchy, EECS [10] may organize nodes into different cluster levels. At each level, cluster heads collect data from member nodes and transmit it to base station or higher-level cluster leaders. By using a multi-level hierarchy, the network's scalability and energy efficiency are both improved. These hierarchical routing algorithms have many trade-offs between their energy efficiency, network stability, scalability and complexity. Which exact method is used will depend on the requirements and characteristics of the WSN deployment. Researchers are looking at and developing new hierarchical routing protocols to increase the effectiveness and potential of WSNs.

III. Location-Based Routing: The utilization of locationbased routing relies on the physical location of nodes to guide forwarding decisions. To determine their position, nodes use GPS or other localization techniques, which they then use to route data effectively to the intended destination. By forwarding data to nearby nodes, energy consumption can be reduced, but achieving accurate localization in certain environments can prove difficult.

IV. Data-Centric Routing: In data-centric routing, the focus is on the data rather than the nodes. The main objective of this approach is to disseminate queries for specific data types or attributes and route data towards the base station based on its relevance to the query. By doing so, unnecessary data transmission is reduced and network efficiency is improved. One example of data centric routing protocol is the Directed Diffusion protocol.

V. Multi-path Routing: Multi-path routing creates more than one route for transmitting data between source and destination nodes. This extra redundancy enhances the network's dependability, ability to handle faults and balance the load. It is especially beneficial in situations where wireless links are unreliable or change constantly.

VI. QoS-based Routing: QoS-based routing makes routing decisions by taking into account a variety of performance characteristics, including delay, dependability and bandwidth. This guarantees that data with particular QoS requirements, like real-time data or crucial information, is prioritized and provided with the desired quality.

VII. Geographic Routing : Geographical routing involves the forwarding of packets based on their location. The node that is closest to the destination in terms of physical distance is the one that the receiving node uses to select the next-hop node. Each routing strategy has unique benefits and drawbacks, and the choice of routing protocol depends on the particular application needs and network properties of a particular deployment of a wireless sensor network. In order to enhance network performance and address WSN-specific difficulties, researchers and engineers continue to investigate and create novel routing protocols.

3. Comparison Of Different Hierarchical Routing Schemes

Routing Scheme	Description	Performance
LEACH [11]	Serves as a fundamental protocol in the creation of energy-efficient WSNs , randomized clustering and rotating CHs offer benefits for energy balance and scalability.	Lesser energy consumption, little overhead, easy to execute, performance degradation.
LEACH-C [21]	Introduce a centralized control system to increase network stability and energy efficiency.	Better energy balancing, enhancedenergy efficiency, introduces some overhead, scalability issues.

LEACH-M [3]	Data is normally gathered and delivered to a fixed base station in traditional WSNs.	Adds mobility to the base station (sink node),mobility patterns, communication overhead, deploy ment challenges,implementation complexity.
LEACH-HC [25]	Introduces a two-tier hierarchy by incorporating the concept of superclusters, providing an additional level of organization and data aggregation within the network.	Optimizes data aggregation, communication efficiency and energy distribution, all of which contribute to extending the network's lifetime and improving overall energy efficiency. resource constraints, mobility challenges, adaptation challenges, interference and latency.
COG-LEACH [23]	Number of idle channels is used as a weight to calculate the likelihood when choosing theCluster Head.	Better longevity, maximum output ,extremely scalable, extreme complexity ,poorly balanced loads, low energy efficiency.
MOD-LEACH [24]	Has been modified by the addition of a dual transmit power level system and an effective cluster head replacement method.	Better throughput and network life. consume some of its energy if the distance is great.
LEACH-Kmeans [26]	Data-driven clustering takes the place of random selection with the goal of improving energy efficiency and cluster head distribution balance.	Enhances network longevity, algorithm complexity, communication overhead.
EE-LEACH [12]	To choose a CH, EE-LEACH employs two methods. The node will select the same value as a LEACH threshold when the remaining energy is more than 50%. The node will set another value as a threshold when the residual energy falls below 50%.	All selected CHs will directly transmit data to the BS, energy depletion.
PEGASIS [16]	Chain-based hierarchical protocol in which all sensor nodes are connected in a single chain and only touch base with their closest neighbors. The chain is intended to link each node in a particular order, forming a conduit for data transmission to the sink node.	Energy efficiency , scalability, improved network lifetime , higher latency, complexity.

HEED [17]	Combines both randomized and deterministic approaches to achieve energy efficiency.	Energy efficiency,flexibility, decentralized operation ,overhead, initial cluster formation.
SEP [22]	Uses elected cluster heads (CHs) to govern data aggregation and transmission by grouping sensor nodes into clusters.	Scale effectively, prevents early depletion of specific nodes, overhead, implementation complexity.
EECS [10]	Innovative clustering method where the CH selection and total number of bits delivered determine the network lifetime primarily.	Increase network scalability and lifetime, overhead in cluster head selection, limited scalability, uneven Energy Depletion, security Challenges.

Table-I. **Comparative Analysis of Various Hierarchical Routing Scheme**

A comparison of the many LEACH variants addressed and reviewed in this paper is presented in Table-I. There are benefits and drawbacks to any hierarchical structure. The selection of a protocol is influenced by communication latency, energy efficiency and network lifetime. To further enhance WSN functionality and energy efficiency, researchers are the requirements of the individual applications, the size of the network and the desired trade-offs between investigating novel and hybrid hierarchical routing techniques.

Upon examining multiple Hierarchical routing systems, it is observed that LEACH based protocols represent the most optimal choice to date.

4.Conclusion

The hierarchical routing approach in Wireless Sensor Networks utilizing the LEACH protocol has proven a ground-breaking solution to effectively regulate energy consumption and increase the network's lifespan. Despite several drawbacks, LEACH continues to be an important benchmark for the creation of energy-efficient WSN protocols and its influence on the development of hierarchical routing algorithms in WSNs is still felt today.

All algorithms with the exception of LEACH-C, employ a distributed clustering pattern when it comes to the clustering technique. Due to its established architecture and adequate power, LEACH-C can perform extremely large calculations. To maximize energy efficiency and lengthen network lifetime, it can execute complicated algorithms.

The majority of applications demand static sensor nodes. However, other applications such as tracking the behavior of wild animals require mobile nodes. Frequent topological change is the main problem in this field. For the mobility of both base stations and sensor nodes more thorough study needs to be done.

For effective location monitoring, the LEACH protocol's successors frequently use GPS devices. Although the cost of the GPS technology makes the sensor nodes expensive, most routing algorithms are more comfortable with using this device to reduce time complexity. To adapt hierarchical routing methods to particular application requirements and network circumstances, researchers are still investigating novel strategies and improvements.

5.FUTURE CHALLENGES

Increasing power economy and lengthening network lifetime are two important obstacles in the creation of an effective routing algorithm. Researchers have suggested a wide variety of LEACH versions to accomplish these goals. Since they use a distributed approach and a huge network, the majority of these successor algorithms are distributed in nature and scalable. Due to a centralized strategy, network scalability may not always be achieved. The following are the main objectives of the LEACH protocol's replacements:

- The best choice of cluster heads.

- Network protection.
- Energy conservation.
- Aspect of security.
- Routing protocol dependability.
- Algorithms with fault tolerance.
- An even distribution of the burden.
- Service quality.

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