Review study about Hierarchical Routing Protocol in wireless sensor networks

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ABSTRACT

Wireless Sensor Networks (WSNs) are crucial in various applications, including smart homes, military surveillance, health monitoring, and environmental sensing. These networks consist of distributed sensor nodes that collect and transmit environmental data to a central location for processing. However, WSNs face challenges such as limited energy resources, scalability, complexity, security, fault tolerance, and quality of service. Researchers have proposed different routing protocols tailored to WSN characteristics to address these issues. This article comprehensively overviews WSN design issues, focusing on routing protocol classification and comparative analysis. Among the hierarchical protocols, LEACH (Low-Energy Adaptive Clustering Hierarchy) is highlighted as a prominent clustering-based protocol that reduces energy consumption by forming clusters and utilizing cluster heads for data aggregation. Each addresses specific challenges and enhances network performance. The comparative analysis evaluates the protocols based on energy efficiency, network lifetime, data delivery, scalability, and security. The findings help researchers, practitioners, and network designers select appropriate routing protocols for their specific WSN applications. This article offers valuable insights into WSN design issues and presents a comprehensive classification and comparison of routing protocols. By understanding the strengths and limitations of different protocols.

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1. INTRODUCTION

Wireless Sensor Networks (WSNs) are used in various fields, such as smart homes, military surveillance, health applications, and environmental monitoring[1]. WSNs is an ad-hoc like network that work autonomously [2]. The Wireless Sensor Network (WSN) is a system of several sparsely spaced-out, reasonably priced computer nodes that transmit essential data to a centralized location for effective processing. A biological design, an information technology framework, or a physical creation can all be considered the environment [3]. There must be at least one sink or Base Station (BS) in a WSN, and the microsensor nodes are spread out randomly throughout a given region. The three main categories of sensor nodes found in WSNs are the base stations (BSs), intermediate sensor nodes (especially Cluster-Heads (CHs) in clustered networks), and source sensor nodes (normal nodes) [4]. Physical and environmental phenomena like temperature, pollution, heart rate, etc. may all be tracked using these microsensor nodes. The sensor nodes gather information and send it to the base station. After that, the user may use the internet to access the sink's data. The major goals of WSNs include: It involves three steps: (1) establishing authority over a designated region, (2) monitoring the area for activity, and (3) evaluating relevant metrics [5].

Routing is determining the appropriate path between the source and the final destination. It takes place in the network layer to guide and transfer data, to achieve high reliability and fast performance. A highly effective routing method in WSNs involves discovering the most optimal transmission path from the sender through intermediate relay nodes to the destination. This approach significantly extends the network's lifespan[6].

As mentioned earlier, accessing the locations where the sensor nodes are deployed is challenging. Therefore, it is crucial to maximize their lifespan to ensure effective monitoring. Since these nodes are powered by batteries, which have a limited lifespan, extending the overall network lifetime and adequately distributing the total energy are essential to prevent early depletion of sensor node energy. Over the past few years, numerous routing protocols have been introduced and categorized into different levels based on multiple parameters. In short, this highlights the importance of optimizing energy consumption in sensor networks[7].

This article provides a comprehensive overview of WSN design issues, routing protocol classification, and comparative analysis to guide researchers, practitioners, and network designers in choosing and implementing suitable routing protocols for WSNs. It covers design issues such as energy consumption, node deployment, routing algorithms, energy efficiency, Cluster-Head (CH) selection, and network robustness. Section 3 presents a classification of routing protocols, Section 4 provides a comparative analysis, and Section 5 summarizes the key findings from the comparative study. This article offers a comprehensive overview of WSN design issues, routing protocol classification, and comparative analysis to guide researchers, practitioners, and network designers in choosing and implementing suitable routing protocols for WSNs.

2. WSN design issues

Due to limited resources like energy, bandwidth, and processing storage, wireless sensor networks have some significant design issues, as seen in Figure 1. A network engineer should meet the following requirements when creating new routing protocols.

2.1 the use of less energy

Most wireless sensor networks use batteries as power sources. In these sensor networks, lack of energy is a big problem, particularly in hostile environments like battlegrounds and other such situations. When the battery drops below a preset battery threshold level, the performance of sensor nodes is negatively impacted. When creating sensor networks, designers need help related to energy. Millions of motes make up wireless sensor networks. Due to a partial amount of power, each node in this network has limited energy resources. The routing protocol should be energy-efficient as a result [8].

2.2 Scalability

In a WSN, the deployed sensor nodes may number tens, hundreds, or even thousands of nodes. Because of this, the routing algorithm should be scalable for various network sizes [9].

2.3 Complexity

A routing protocol's complexity may impact the performance of the entire wireless network. The cause of this is our need for more hardware expertise and the severe energy constraints we experience with wireless sensor networks[10].

2.4 Security

Personal and confidential data can be delivered through a sensor network. To prevent data from being duplicated, deleted, or altered along the way, a secure data communication[9] network is necessary for data transfer. Routing protocols should not disregard security.

2.5 Acceptance of Mistakes

The routing protocol should establish new linkages to prevent data loss about the monitored environment if one of the sensing nodes dies [7].

2.6 Information Gathering and Fusion

It is a technique for gathering data from various sensor nodes to eliminate duplications. To limit the amount of data required for delivery and corresponding energy consumption, the network works to gather packets from numerous sensor nodes[7].

2.7 Quality of service WSNs

WSNs with high service levels have been employed in various applications, some of which, like those in the military, are extremely important and demand prompt, dependable service.

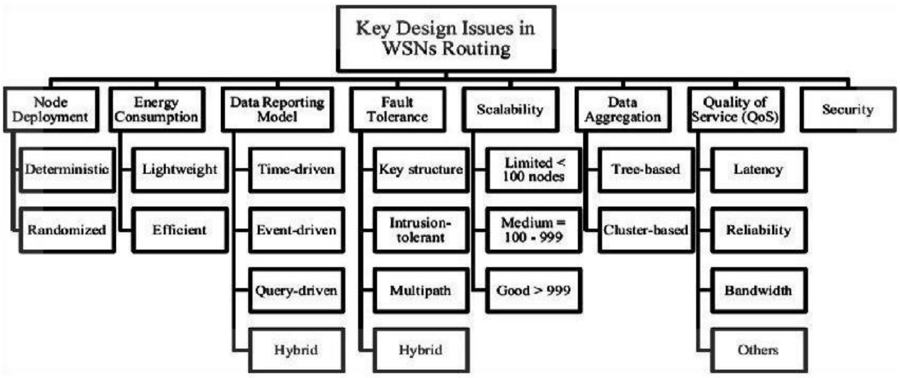

Figure 1. Schematic taxonomy of crucial design issues in WSN routing protocols [10].

3. CLASSIFICATION OF ROUTING PROTOCOLS

Algorithms and protocols that can self-organize make up a wireless sensor network. Data transmission and communication between nodes require routing methods. For WSNs, a variety of routing techniques have been suggested. There are many distinct categories for routing protocols[11], as seen in Figure 2.

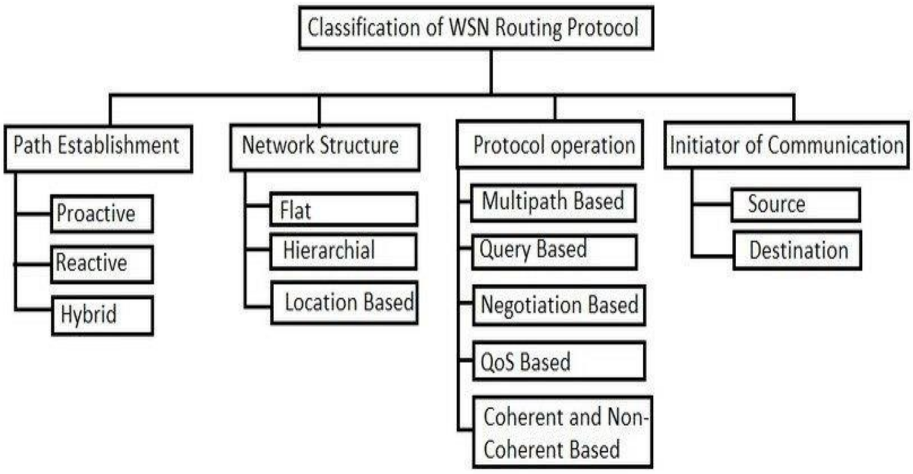

Figure 2. Classification of Routing Protocols in Wireless Sensor Networks [12]

3.1. Hierarchical Protocols

Numerous perspectives have been used to study hierarchical routing algorithms in WSNs. Clustering, which involves grouping sensor nodes, is a typical technique. This widely used data transmission technology sends sensor data to the cluster head and the base station to reduce energy usage[9]. The fundamental principle of hierarchical routing is that sensor nodes only connect directly with the cluster head or another leader node of their cluster. The task of propagating the sensor data to the sink is then carried out by these cluster heads, which might be more potent and energy-efficient devices than "regular" sensor nodes. This method can significantly reduce sensor nodes' communication and energy demands, but cluster heads will see more traffic than normal sensor nodes[13]. The primary objective of these protocols is to effectively control the energy consumption of sensor nodes by connecting them in multi-hop communication inside a particular cluster and by carrying out data fusion and aggregation prepared to reduce the number of transferred messages to the base station (sink)[14].

3.1.1. LEACH

W.B.Heinzelman has suggested it in[15]. Low-Energy Adaptive Clustering Hierarchy (LEACH) is a pioneering distributed clustering hierarchical energy-efficient protocol that effectively extends the network's lifespan by achieving a balanced energy load across sensor nodes[16]. LEACH is a wireless sensor network's most essential hierarchical and cluster-based protocol. LEACH's primary goal is to reduce the amount of energy sensor networks use [17]. It uses very little energy as a routing protocol. Each WSN is separated into a cluster in this protocol, and each set has a cluster head (CH) and several cluster relationships. A high-level network is formed by several cluster heads[14]. Nodes group together to form clusters to accomplish these goals. As seen in Figure 3, the cluster head, who is also in charge of transferring collected data to the base station, receives data from each member node of the cluster and sends it to the cluster head. As a result, the sensor node uses less energy to transfer data to the cluster head than the base station, so conserving energy[17].

LEACH operates under a round-robin system of management. The preparation and steady-state stages are the two phases into which each round of LEACH operation is divided. The setup phase starts with the election of CHs, followed by the formation of clusters, and finally, the selection of the cluster communication schedule. First, between 0 and 1, sensor nodes select a random number, m. When m falls below the threshold value T(n), the sensor node changes to the CH. Why is it impossible to fix the number of CH if the value of m is chosen randomly? The desired percentage of cluster head nodes, p, is used in the following Equation to determine T(n). The group of nodes G that have not been CH in the previous 1/p rounds is represented by the current round number, r [18].

$$T(n) = \begin{cases} \frac{P}{1-P\left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

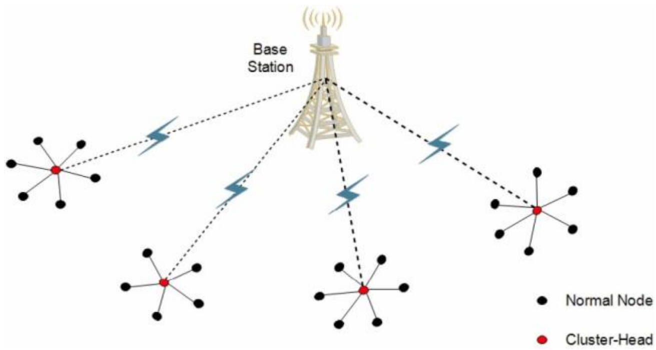

Figure 3. LEACH architecture.

3.1.2 LEACH-C

The LEACH-C algorithm represents a clustering algorithm that is centralized and implemented at the base station (BS)[15]. It selects cluster heads (CHs) based on the remaining energy of nodes and forms clusters in the network. This algorithm effectively addresses the efficiency issue of the standard LEACH procedure [19]. Nodes with more remaining energy than the average are chosen as CHs for the current round after they report their position and current power status to the sink in the first phase. The remaining nodes revert to type N. LEACH-C shares the same steady state with LEACH. LEACH-C's centralized approach improves CH distribution and selection. But the amount of data sent between the nodes and the sink shortens the network's lifespan. Having a fixed number of CHs for each turn in LEACH-C may shorten the CH lifespan compared to LEACH, which bypasses intermediate nodes and transmits data directly to the sink without regard to distance [20].

3.1.3 PEGASIS

PEGASIS (Power-Efficient Gathering in Sensor Information Systems) is a hierarchical, chain-based routing protocol in wireless sensor networks (WSN). It was developed to address the energy efficiency and network lifetime issues in WSNs[3].In PEGASIS, nodes are organized in a chain or ring structure, and each node only communicates with its immediate neighbors. The chain structure allows energy-efficient data transmission by using the intermediate nodes as relay points, reducing the distance data travels to the base station (sink).

The protocol works as follows: first, each node senses the environment and sends its data to its neighbor node in the chain. Then, the node with the most energy becomes the leader and collects the data from all the other nodes in the chain. The leader then transmits the aggregated data to the sink. In the next round, the leader role is rotated to the next node in the chain, and the process is repeated[21].

PEGASIS has shown significant improvements in energy efficiency and network lifetime compared to other routing protocols, such as LEACH. However, it has some limitations, such as forming long chains, which can lead to higher latency and lower throughput.

3.1.4 LEACH-B

LEACH-B (LEACH-Balanced) is an enhanced version of LEACH that was introduced to optimize The number of cluster heads (CHs)[22]. Unlike LEACH, which has an equal chance for all nodes to become CHs, LEACH-B uses a decentralized approach for cluster formation[23]. In the CH election stage, nodes with remaining energy are selected to become CHs in a way that ensures the optimal number of CHs. The protocol then proceeds to the cluster formation stage, followed by the data communication stage.

Initially, LEACH-B follows the same CH selection approach as LEACH, nonetheless, there is a second stage that takes leftover energy into account. LEACH-B uses Equation (2) to ensure that the number of CHs in each round is constant [22], according to which anywhere between 3% and 5% of the network's nodes fall into this category. P in Eq. (2) stands for the fraction of CHs in the network, and N for the total number of nodes. Each node knows its own location and that of the BS, but not the locations of any other nodes. If there are fewer CHs than N*P, then a normal node with enough energy will be chosen as a CH, and some CHs with low energy will be deleted. LEACH-B is superior to LEACH since it guarantees a constant number of CHs. Conclusions from Modelling [22] demonstrate that LEACH-B improves on LEACH, extending the network lifespan.

$$No.of CHs = N * P \tag{2}$$

3.1.5 E-LEACH

E-LEACH is a shortened form of ENERGY-LEACH, a protocol that enhances the cluster head selection process of the LEACH protocol. Initially, all nodes have an equal chance of becoming the cluster head (CH). However, in subsequent rounds, the node with a higher remaining energy level is selected as the CH instead of those with lower energy. This approach prolongs the network's lifespan and conserves energy compared to the LEACH protocol[14]. Figure 4 presents the architecture of the E-LEACH protocol.

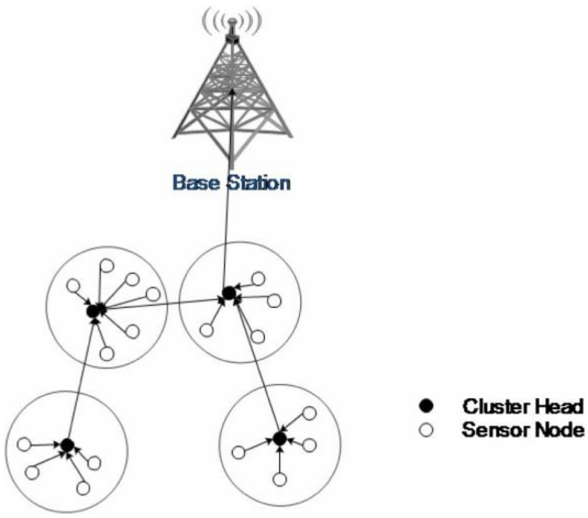

Figure 4. E-LEACH architecture.

3.1.6 LEACH-Cell

LEACH-Cell[24] is a protocol developed to improve sensor network coverage. The network is made up of "cells," and every group of seven adjacent cells has a "CH." As illustrated in Figure 5, each cell is made up of sensor nodes and a leader who is chosen from inside the cell. The cell head serves the same purposes that the CH did in the first iteration of LEACH. It generates a time-division multiple-access (TDMA) schedule, assigns a period of time to each cell member, collects data from the cell members using the TDMA schedule, and sends the compiled data to the control node (CH). The CH collects information from its CHs in the same way a cell head does, and then sends that information via the best possible route to the washbasin. Throughout its existence, the network maintains the same clustering and cell formation, with only CHs and cell heads undergoing dynamic changes. LEACH-Cell's primary function is to prevent the node's transmitter from broadcasting data while the cell head communicates with the CH. This lowers the overall cost of messages sent between nodes and the CH [25].

The revised protocol discussed here is an improved version of the original LEACH protocol. This protocol divides the network into multiple clusters, each further divided into seven sub-clusters called cells. Each cell has a head whose primary responsibility is to collect data from the normal nodes. Initially, the head of each cell is selected randomly. However, in the later stages, each old cell head calculates the remaining energy and sets a new cell head. The cells' leaders and the clusters' heads communicate directly to ensure efficient data transmission [24].

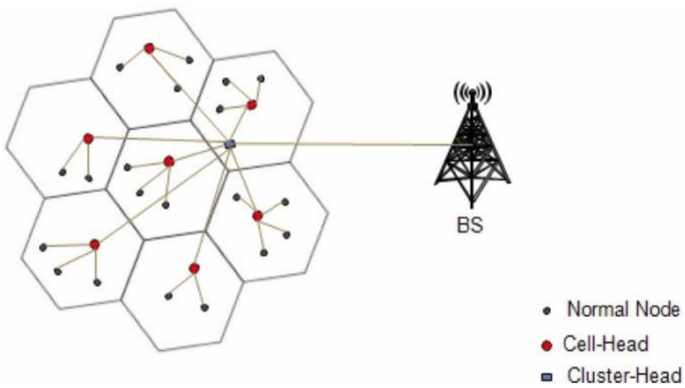

Figure 5. LEACH-Cell architecture.

3.1.7 MHT-LEACH

The MHT-LEACH (Multi-Hop Technique-LEACH) is based on the LEACH technique for discussing routing by dividing the network into two levels according to the path length between the CHs and the BS [26] procedure is now in place. MHT-LEACH's CH selection and cluster formation are similar to LEACH's initial setup. Based on the CHs' relative proximity to the washbasin, MHT-LEACH classified them as internal or exterior [27] instead of sending all CHs data simultaneously. This CH is part of the inner group that talks directly to the sink if the distance is less than d0.

On the other hand, the CH belongs to the outer group if and only if it is located above or at d0. An external CH may construct a routing table using the data in the announcement messages from internal CHs. When transmitting data to the BS or another external CH, each external CH first consults its routing database to determine the quickest route. For energy fairness in the network, the MHT-LEACH protocol splits the CHs in half and delivers data to the BS through the halves [28]. However, MHT-LEACH's effectiveness could be improved in large-scale networks[29]. The method and flowchart for the MHT-LEACH are provided for your reference.

3.1.8 BRE-LEACH

Researchers in [30] have presented a new protocol, BRE-LEACH (Balanced Residual Energy-LEACH), that improves network stability and longevity while reducing energy expenses. An energy imbalance occurs between nodes in conventional LEACH because CHs are chosen randomly without regard to the remaining energy, resulting in some nodes draining their energy faster than others. BRE-LEACH solves this issue by selecting CHs based on their remaining power and using a threshold function introduced in Equation 3 [30].

$$T_1(n) = \begin{cases} \frac{P}{1-P*(r \ mod(1/P))} * \frac{E_{res}}{E_0}, n \in G \\ 0 \qquad\qquad\qquad\qquad \text{else} \end{cases} \qquad (3)$$

The chance of the number of CHs in the entire network is denoted by P, r represents the current round, E_{res} is the residual energy of nodes, E_0 defines the starting power, and G represents the set of nodes that have not been selected as CHs in the last 1/P rounds. BRE-LEACH works, in turn, divided into four phases: Cluster setup, TDMA (Time Division Multiple Access) scheduling, Root CH selection, and Data transmission phase. After CHs are selected based on their remaining energy, each sensor node joins the cluster of the CH with the strongest received signal. CHs provide TDMA schedules for their cluster members. The algorithm selects a root CH with more than average remaining energy and closer to the sink than average to regroup data from other CHs and forward it to the sink. Non-root CHs use multi-hop routing to reach the parent CH. The architecture of BRE-LEACH is shown in Figure 6, and simulation results in [25] indicate that BRE-LEACH performs better than LEACH in reducing energy consumption costs and increasing the network lifetime by 55.73%.

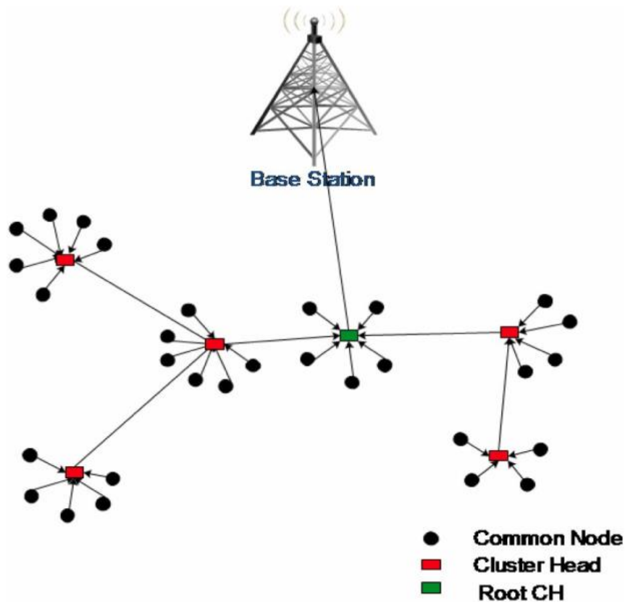

Figure 6. BRE-LEACH architecture.

3.1.9 EADCR

To extend the lifetime of WSN networks, [49] proposes EADCR (Energy Aware Distance-based Cluster Head selection and routing), which takes into account the FCM (Fuzzy C-Means), the residual energy of nodes, the Euclidean distance from the BS, and the cluster centroid. The EADCR employs the FCM technique at the BS to construct clusters. Then, each cluster uses a fitness function to choose its CH. This function relies on the node's starting energy, the node's residual energy, the Euclidean distance to the BS, and the node's distance to its CH.

CHs are chosen instantly from among the cluster's participants. Each voter chooses the most suited node to be the CH.

The authors have applied the LEACH protocol's notion of clustering based on rotation. A novel method for packet routing is proposed in the EADCR protocol, which considers both residual energy and Euclidean distance[31].

4. Comparative analysis

Table 1 below compares and contrasts the most popular routing protocols for WSNs. These protocols enhance network performance, increase network longevity, and reduce energy usage. The table summarises the critical features of each protocol, including how it handles clustering, distributes energy, compresses data, communicates, and how much of a network it covers. It is an excellent resource for determining which routing protocol would work best for a specific WSN use case.

Table 1. The Comparative Analysis.

Protocol	**Description**	**Advantages**	**Disadvantages**
LEACH	Hierarchical and cluster-based protocol	Energy conservation	Lacks centralized control
LEACH-C	Centralized clustering algorithm at the base station	Efficient CH selection	Reduces CH lifetime
PEGASIS	Hierarchical, chain-based routing protocol	Energy-efficient data transmission	Long chains may cause higher latency and lower throughput
LEACH-B	An enhanced version of LEACH with optimized CH number	Uniform number of CHs	A decentralized approach may have limitations
E-LEACH	Enhances CH selection process based on remaining energy	Prolongs network lifespan conserves energy	Not as effective as other protocols in some scenarios
LEACH-Cell	Divides network into cells and forms clusters	Enhanced network coverage	Increased complexity, more communication between nodes
MHT-LEACH	Separates CHs into internal and external groups	Energy charge equalization	Less effective in large-scale networks
BRE-LEACH	Selects CHs based on remaining power and energy balance	Reduces energy consumption costs, increases network lifetime	More complex than traditional LEACH
EADCR	Considers FCM, residual energy, and distance for CH selection	Extends network lifetime, energy-aware routing	Requires additional calculations and overhead

5. Conclusion

This study area is wide open due to the rapid development of new nanotechnology, multiple computing, and a wide range of contemporary applications. We have attempted to show what is relevant to the various routing protocols. The research on hierarchical routing protocols in Wireless Sensor Networks (WSNs) has provided valuable insights into the effectiveness and performance of various protocols. The study addressed critical challenges in WSNs, including energy consumption, node deployment, routing algorithms, energy efficiency, Cluster-Head (CH) selection, and network robustness.

The comparative analysis of routing protocols in wireless sensor networks provides valuable insights for researchers and practitioners. The protocols examined, including LEACH, LEACH-C, PEGASIS, LEACH-B, E-LEACH, LEACH-Cell, MHT-LEACH, BRE-LEACH, and EADCR, offer different approaches to address energy efficiency, network lifespan, coverage, and communication overhead.

Overall, the research on hierarchical routing protocols in WSNs contributes to the advancement of WSN technology, addressing crucial challenges and paving the way for more efficient and robust network designs in various application domains.

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