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Energy Conservation Based Routing Protocol in Mobile Wireless Sensor Networks

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Abstract:

Modern IoT infrastructures depend on mobile wireless sensor networks (MWSNs) for environmental monitoring and surveillance. However, sensor node energy limits make long-term network operations difficult. Effective energy management in MWSNs extends network life and ensures data collection. This study proposes an Energy-Conserving Routing Protocol (ECBRP) tailored for MWSNs to minimize energy consumption while facilitating seamless data transmission. The ECBRP aims to optimize energy utilization by intelligently routing data packets through the network while considering node mobility patterns and energy levels. To achieve this, the protocol utilizes a combination of proactive and reactive routing strategies. Proactive routing establishes energy-efficient paths based on static network characteristics, while reactive routing dynamically adapts to changing network conditions and node mobility. Furthermore, ECBRP incorporates mechanisms for data aggregation and compression to reduce transmission, thereby reducing energy expenditure during communication. Additionally, the protocol employs sleep scheduling techniques to enable energy-efficient operation by periodically activating and deactivating sensor nodes based on their role in the network and the sensed data requirements. To evaluate the performance of ECBRP, extensive simulations are conducted using various mobility models and network scenarios. Results demonstrate that ECBRP outperforms existing routing protocols energy use, packet delivery ratio, and network lifespan.Moreover, the protocol exhibits resilience to node failures and network partitions, ensuring reliable communication in dynamic MWSN environments.

Key words: Mobile wireless sensor networks, Node mobility patterns, Wireless sensor network optimization and Energy-Conserving Routing Protocol (ECBRP)

1. INTRODUCTION

Mobile Wireless Sensor Networks (MWSNs) have made environmental data gathering and monitoring more relevant in many applications. MWSNs commonly have mobile sensor nodes and sinks [1]. Mobile parts can move by being attached to mobilizers that manage their positions or carriers like cars, animals, and robots. Based on the application, MWSNs can handle static, mobile, or fully mobile sensor topologies [2]. Outdoor medical facilities use mobile node-based body sensor networks to monitor patients' vital signs. Mobile sinks like doctors and static sinks like monitoring rooms receive data for full health tracking and management. Wildlife monitoring combines vehicle or plane data and mobile nodes to track animals in their natural habitat. These networks sense, process, and transmit events using tiny sensor nodes [3]. A sensor and ADC detect and digitize events in each node, a processor processes data and regulates operations, a transceiver transmits and receives data within a limited range, and a power unit [4].

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Optimizing routing requires understanding these components and their relationships [5]. Wireless sensor networks (WSNs) are becoming popular. Research focuses on medical, engineering, agriculture, environmental monitoring, surveillance, and military applications. A base station receives environmental data from many small, inexpensive WSN sensors. These sensor nodes use thermistors to measure light, temperature, and location., photodiodes, and GPS sensors. Despite their varied uses, WSNs have many drawbacks. Small and expensive, sensor nodes have limited power supplies that are often irreplaceable or cannot be connected to continuous power sources, especially in remote and vast places.

Without enough power, nodes have shorter lifespans, less computational capability, storage, and communication ranges. Energy management must be efficient to extend WSN lifespan. Many routing protocols and solutions address energy constraints. Single- or multi-hop WSN sends data to the BS via intermediary nodes. Nodes save power by staying within communication ranges, while expanding them uses energy [6]. Data is collected and sent by cluster heads (CHs) in large networks. New WSNs have movable nodes for better performance. Data collection efficiency and network lifetime have been studied for mobile nodes, including sinks. Mobile sinks move closer to sensor nodes to minimize transmission distances and eliminate data forwarding intermediaries. This dynamic method distributes data processing and power, extending network life. Good routing protocols let mobile wireless sensor networks (MWSNs) enhance mobility and energy efficiency. Energy conservation-based routing in MWSNs reduces energy usage and sensor node lifespan to increase network performance’s lifespan and efficacy depend on energy-saving protocols. Modern technology allows tiny, cheap sensor devices. These devices convert temperature and humidity into electrical signals [7]. A WSN can connect hundreds or thousands of sensor nodes to a Base Station (BS) or each other. These sensor nodes coordinate to monitor sensing area conditions. Users can access and process data on the BS, which can be stationary or mobile and connected to infrastructure networks or the Internet. WSN routing is tricky because they differ from ad hoc and cellular networks [8]. WSN features, application, and architectural needs have informed many solutions to these challenges. Network structure determines WSN routing: flat, hierarchical, or location-based [9]. All flat network routing nodes sense and route similarly. SPDIN/Directed

Includes diffusion, LEACH and hierarchical network routing cluster the network for energy efficiency and scalability. Geographic and Energy-Aware Routing (GEAR) and GAF use GPS to build routes [10]. Energy strongly affects WSN routing. Due to wireless link power attenuation being square or greater, multi-hop routing is more energy-efficient than direct transmission. of the sender-receiver distance [11 Multi-hop routing increases network topology and medium access control overhead. If all sensor nodes are near the BS, direct connection may save network overhead. Since sensor nodes are random, multi-hop routing is frequently employed [12]. Hierarchical network routing, especially clustering, improves WSN energy efficiency and overhead, according to research.

Most clustering methods assume stationary nodes to simplify network design, decrease communication overhead, and conserve energy, extending network lifetime. Animal tracking and SAR require mobile nodes [13]. Thus, node-mobile clustering is popular. Energy conservation- MWSN routing methods increase energy utilization and network performance, especially for mobile nodes [14]. Terrestrial, underground, underwater, multimedia, and mobile wireless sensor networks (WSNs) have emerged due to rapid growth. MWSNs have unique energy efficiency and packet loss issues [15]. Hierarchical (clustering) routing techniques may reduce energy use and support node mobility to solve these problems. Recently developed clustering routing methods boost WSN energy efficiency [16]. Heinzelman et al. created energy-saving LEACH and LEACH-C. Mobile WSNs cannot use these protocols since they are static context-based and do not permit node mobility [17].

Distributed clustering routing for mobile nodes overcomes this. LEACH-ME selects the cluster head (CH) from sensor nodes with the lowest mobility factor, while LEACH-Mobile improves packet delivery rates by adding mobile node membership declarations [18]. CBR regulates mobility via a cross-layer design, while MBC chooses CHs depending on energy and mobility [19]. MBC's threshold function for CH selection may generate an unstable number of CHs, increasing energy loss. Using fuzzy logic, LEACH-MF integrates many CH selection factors [20]. Mobile nodes using centralized energy-efficient clustering routing algorithms conserve energy and improve packet delivery [21This paper provides a centralized clustering method that finds optimum CHs based on average node energy and speed, unlike MBC's scattered approach. Second, detached nodes form many-characteristic ideal clusters. The remaining paper is organized Section II covers the System model, Section III the clustered routing protocol, Section IV simulation results, and Section V conclusions.22]. Wireless Sensor Networks (WSNs) detect physical phenomena with multiple sensor nodes. These sensor nodes are frequently spread around a wired or wireless Base Station (BS) or sink connected to the internet. networks. Sinks manage sensor nodes and consolidate data. Sensor nodes monitor physical events and locally integrate data to reduce repeated transmissions, depending on the application [23]. Hop-by-hop, this aggregated data is delivered to the sink for analysis and internet access. A sensor node has a CPU, memory, sensing unit, power supply, transceiver, and optional mobility, location, and actuation modules. WSN sensor nodes can be cheap and small with MEMS technology [24].

WSNs have many sensor nodes that detect physical phenomena. Sensor nodes are often spread around an internet-connected Base Station (BS) or sink via wired or wireless networks. Sinks organize sensor nodes and data. Sensor nodes monitor physical occurrences and locally integrate data to decrease transmissions, depending on application [23]. Hop-by-hop, this aggregated data is delivered to the sink for analysis and internet access. A sensor node has a CPU, memory, sensor unit, power supply, transceiver, optional mobility, location, and actuation modules. WSN sensor nodes can be cheap and small with MEMS technology [24]. In a typical sensor node, one data transmission uses the same energy as 1,000 processes. The energy consumption of data sensors varies by kind but is modest compared to data processing and communication. WSN development prioritizes energy-efficient network technologies for data gathering and routing due to these constraints. Effective routing improves energy efficiency and network lifespan. Since most sensor nodes lack power and range to immediately transmit data to the BS, clever routing algorithms enhance energy utilization. Mobile Wireless Sensor Network energy-efficient routing is covered here. It researches energy economy and packet loss to improve mobile network resilience.

2. RELATED WORK

For radio frequency and battery power optimization, Wireless Sensor Networks (WSNs) cluster sensor nodes hierarchically. In clustering, sensor nodes collect and fuse data at the cluster head (CH), minimizing base station data transit. Clustering is mainly caused by sensor node energy and CH proximity. Post-deployment non-cluster-head nodes choose and deliver data to CHs [27}. CH gives base station info. Initial hierarchical routing technology was Low-Energy Adaptive Clustering Hierarchy. To uniformly distribute energy, LEACH clusters nodes with randomly rotating CHs. The protocol cuts energy loss, extending network life. Many hierarchical routing approaches have been inspired by LEACH to increase energy efficiency and network performance. Several clustering strategies boost WSN energy efficiency [28]. LEACH-Centralized (LEACH-C) applies a central control method to cluster nodes' energy levels and placements for optimal cluster construction, improving LEACH. Since LEACH and LEACH-C do not address node mobility, they are limited to stationary node networks. Mobility is offered by several dispersed clustering algorithms. LEACH-Mobile (LEACH-M) increases mobile packet delivery by declaring mobile node membership. LEACH-ME selects CHs based on nodes' mobility attributes to improve mobile stability. Cross-layer Cluster Based Routing (CBR) handles mobility well.

Mobility-Based Clustering (MBC) selects CHs using nodes' residual energy and mobility for energy efficiency and stability. The threshold function for CH selection, which includes energy and mobility characteristics, can generate an unstable number of CHs, wasting energy. LEACH-MF uses fuzzy logic to integrate many CH selection criteria for stability and energy efficiency. Hierarchical clustering and other routing methods have been researched for Mobile Wireless Sensor Network energy conservation. The Energy-Efficient Routing Protocol (EERP) and Geographic and Energy-Aware Routing (GEAR) optimize routing patterns utilizing geographical data to reduce transmission distances and energy use. Building energy-efficient MWSN routing systems is still tough and continuing despite these developments. In dynamic mobile environments, network connectivity, data reliability, and energy conservation are trade-offs. This study presents MWSN energy-efficient routing to maximize energy utilization and node mobility [29]. Flat, cluster-based (hierarchical), and location-based routing are employed in WSNs. Flat-based routing gives nodes equal roles. Nodes peer-route network traffic. This simple routing distributes load evenly across all Nodes regardless of energy reserves, which wastes energy.

This routing ranks nodes by role based on energy, topology, location, and coverage. Nodes' roles change with approach. Hierarchical routing uses less energy than flat-based routing because cluster heads aggregate and fuse data to reduce base station data LEACH has inspired various energy projects. efficiency and network performance solutions [30]. They know their locations in location-based routing. Nodes evaluate distances and choose data propagation hops using neighbouring location coordinates. By reducing data transmission distance, this routing optimizes path selection and energy consumption: Traditional WSN data gathering employs multi-hop sensor node-static control centre connection. Early energy depletion can induce "energy holes" and network partitioning in nodes near the base station. Mobile sinks are popular to combat energy holes, which degrade network lifespans. Mobile sinks collect data across the network, reducing base station node load and energy usage. Mobile sinks support event-driven, user-centric ambient intelligence, remote monitoring, smart buildings, rescue, and intruder detection. Many proactive and reactive mobile sink approaches have been studied. Proactive methods send sensor node values to storage nodes for mobile sink data collecting. Instead, reactive approaches use the mobile sink to pull sensor node information through the network. Some researchers have explored mobile sinks. Mobile sinks enhance energy efficiency and network longevity when collecting data, according to Babar Nazir et al. [31]. LEACH-Mobile (LEACH-M), which adapts LEACH for mobile contexts, has showed promise in maintaining network performance despite node mobility. LEACH-ME and MBC increase stability and energy efficiency by considering cluster head motion. Mobile sinks help WSNs save electricity. The proposed solutions improve data collection, network lifespan, and dynamic, real-world applications with mobility. Based on these foundational efforts, this research proposes optimises energy use and node mobility in Mobile Wireless Sensor Networks (MWSNs) routing [32].

WSNs differ from ad hoc networks because sensor nodes have limited energy. Energy expenditure during data gathering and forwarding affects node lifespan, hence these constraints adversely damage the network. Many routings approach balance energy usage with data delivery performance, boosting data dissemination and reducing node energy use. LEACH pioneered WSN dynamic clustered routing. LEACH randomly assigns cluster heads (CHs). selected using a Khodashahi [33]. Nodes with random numbers under Tn are CHs. By clustering nodes, LEACH enhances energy efficiency, however random CH selection can produce energy imbalance. Consumption degrades networks. LEACH's limitations are addressed with PEGASIS. A greedy method causes PEGASIS to establish a chain from the farthest to the next base station node. N nodes exchange data with neighbours and switch BS leading data. Multi-hop communication saves energy in PEGASIS, but network growth increases transmission delays. PEGASIS may have routing gaps if a node dies during data collecting [34]. The Distance-Based Thresholds (LEACH-DT) methodology intended to enhance LEACH. Distance factors affect CH election probability in LEACH-DT. The source CH broadcasts an advertisement (ADV), and the shortest distance decides the next hop. This method saves energy and extends network life by providing a more efficient multi-hop path to the BS than LEACH. Different hierarchical protocols and energy-efficient routing algorithms have been tested to increase WSN performance. Heinzelman et al. [35] created energy-efficient microsensor network communication protocols that affected many. Data transmission uses more energy than processing, thus these alternatives lower it.

Mobile sinks have reduced energy holes at the BS in recent improvements. Mobile sinks collect network data, balancing node energy and extending network life. This strategy is used in dynamic, consumer-focused apps like ambient intelligence and remote monitoring because of its adaptability. Energy-saving routing protocols like LEACH, PEGASIS, and mobile sinks are being developed to extend WSN lifespans [36]. These protocols improve energy efficiency for various and resource-constrained WSN applications. This research proposes a routing protocol employing node mobility and dynamic clustering to increase energy utilization in Mobile Wireless Sensor Networks (MWSNs) [37]. Recent surveys on Mobile Wireless Sensor Network (MWSN) routing systems show their diversity and performance issues. Qing L, Zhq [38] examined WSN and wireless ad-hoc routing. In mixed WSNs with static and mobile nodes, this survey examined routing techniques that accommodate sensor node mobility. To explain WSN routing protocols, the authors discussed each routing strategy's benefits, downsides, and performance issues. Al-Karaki and Kamal categorized routing protocols by discovery, data transport, routing, motion control. The structural and operational differences of flat and proxy-based routing protocols were examined in this survey. The classification helps researchers identify application-specific routing strategies. Heinzelman et al. [35] examined MWSN protocols LEACH-M, LEACH-ME, CBR-M, ECBR-MWSN, E2R2, 2L-LEACH-M, FTCPMWSN, LFCP-MWSN. Assumptions, cluster head (CH) selection, location awareness, scalability, and complexity were examined among protocols. This comparison explained protocol trade-offs and offered changes. J. Wang et al. [39] compared MWSN flat- and hierarchical routing protocols by network structure, information state, energy efficiency, and mobility. A summary of the protocols' benefits and cons revealed methods to improve them for MWSN applications. The survey suggested routing protocol enhancements for energy efficiency and node mobility.

Sink mobility-supporting location-based routing methods were surveyed by H. Zhao et al. [40]. This study examined how location awareness can improve mobile sink network routing efficiency, reducing the energy hole problem and enhancing performance. In conclusion, this section's surveys classify MWSN routing protocols by numerous characteristics and highlight their pros and cons. These surveys help us understand MWSN routing issues and solutions, setting the framework for energy-efficient and resilient protocols. These efforts form the basis of this study's energy-conservation-based MWSN routing system. Wireless sensor networks (WSNs) are complex and have various uses, making research difficult. Numerous studies have addressed these issues, resulting in energy-efficient routing [11]. Many protocols use LEACH [12]. To balance node power usage, LEACH clusters and elects a CH [24]. The CH contacts its cluster nodes and base station. LEACH works, but its shortcomings need further study and modification [14]. SEP modifies LEACH by selecting Node energy-based CHs. Balances network energy utilization. After SEP, DEEC elects CHs based on a node's remaining energy to the network's average energy, improving energy efficiency. LEACH now forwards MIMO data to the BS with a master head and shortest path method. H-LEACH allows nodes that cannot communicate to die and keeps a list of living nodes to enhance network performance [15]. Sink obstruction and severe traffic load can be addressed using multiple mobile data collectors. Mobile relays send data to mobile sinks. Grid deployment for mobile sensor nodes was suggested to improve deployment [26]. Use pre-deployed nodes, boundaries, and barriers to determine grid weight. Lightweight grids are targeted by mobile nodes. WSN routing protocol adaptations and enhancements aim to optimize energy and network performance [17]. Based on these foundational efforts, this research presents an energy conservation-based routing protocol for MWSNs to address node mobility and energy restrictions [18]. The table 1 summarizes wireless sensor network (WSN) research on energy efficiency, routing protocols, and performance modelling. A full explanation of the table's content

Table 1: summarizing the key details from the provided references:

Author(s)	Contribution	Methodology	Tool	Limitations
Bharti et al [41]	Wireless sensor network energy-efficient clustering technique	Algorithm design and simulation	Not specified	Simulation-based results may not reflect real-world performance
Wang, Q., & Yang, W [42]	WSN power management energy consumption model	Model development and analysis	Simulation	Model assumptions may not capture all real-world complexities

Khan, A. R. et al. [43]	WSN open-source network simulator performance comparison	Comparative analysis	Network simulators (various)	Limited to the features and scenarios supported by the simulators
Marina, M. K., & Das, S. R.[44]	Multipath distance vector routing on demand	Algorithm development and simulation	Not specified	Scalability and performance in diverse network conditions
Yang, T. et al. [45]	WSN energy savings for mobile sensor nodes and events	Analytical and simulation-based approach	Simulation	Mobile sensor dynamics and event frequency assumptions
Khan, A. R. et al. [43]	Mobile cloud computing application models survey	Literature survey	Not applicable	Rapidly evolving field may render survey quickly outdated
Anastasi, G. et al. [46]	WSN energy conservation survey	Literature survey	Not applicable	Comprehensive coverage might miss very recent advancements
Heinzelman, W. B. et al. [35]	Wireless microsensor protocol for applications	Protocol design and simulation	Simulation	Protocol effectiveness in heterogeneous and large-scale networks
Ali, S., & Madani, S [47]	Distributed efficient multi-hop clustering for mobile WSN	Protocol design and theoretical analysis	Not specified	Assumes certain mobility patterns and node densities
Faycal et al. [48]	Event-driven WSN rate-allocation multi-path control	Analytical modelling and simulation	Simulation	Event packet rate assumptions and network dynamics
Giordano, S. et al. [49]	Ad hoc network position-based routing algorithm taxonomy	Literature survey and classification	Not applicable	May not include latest algorithm developments

PROPOSED METHODOLOGY

An Energy-Conserving Routing Protocol (ECBRP) for Mobile Wireless Sensor Networks (MWSNs) focuses on minimizing energy use while ensuring efficient data transmission. This protocol combines proactive and reactive routing strategies. Proactive routing establishes energy-efficient paths based on static network characteristics. Meanwhile, reactive routing adapts to changing network conditions and node mobility. This combination ensures optimal energy utilization throughout the network. ECBRP intelligently routes data packets by considering node mobility patterns and energy levels. This dynamic routing method improves network longevity and performance. The protocol also incorporates data aggregation and compression techniques to reduce the volume of transmitted data, thereby conserving energy. Additionally, sleep scheduling techniques are employed, periodically activating and deactivating sensor nodes based on their roles and data sensing requirements. This feature significantly reduces energy consumption during periods of inactivity.

This study proposes an Energy-Conserving Routing Protocol (ECBRP) designed specifically for Mobile Wireless Sensor Networks (MWSNs). The protocol combines proactive and reactive routing strategies to optimize energy consumption and ensure efficient data transmission.

1. **Proactive Routing**:
   - Establishes energy-efficient paths based on static network characteristics.
   - Utilizes data aggregation and compression techniques to reduce the volume of transmitted data, thus conserving energy.
2. **Reactive Routing**:
   - Dynamically adapts to changing network conditions and node mobility.
   - Incorporates sleep scheduling to periodically activate and deactivate sensor nodes based on their roles and data sensing requirements.
3. **Simulation**:
   - Extensive simulations are conducted using various mobility models and network scenarios to evaluate the performance of ECBRP.
   - Comparative analysis is performed against existing routing protocols to measure improvements in energy consumption, packet delivery ratio, and network longevity.

Equations

While the document does not explicitly list equations, typical equations in such studies might include:

- **Energy Consumption**:

$$E = \sum_{i=1}^{n} (E_{tx}(i) + E_{rx}(i))$$

where E is the total energy consumed, $E_{tx}(i)$ is the transmission energy for node i, and $E_{rx}(i)$ is the reception energy for node i

- **Energy Efficiency**:

$$\eta = \frac{Pdata}{E\ total}$$

Where η is the energy efficiency, P_{data} is the amount of data successfully transmitted, and E_{total} is the total energy consumed.

- **Packet Delivery Ratio (PDR)**:

$$\text{PDR} = \frac{P\ received}{P\ sent} \times 100$$

Where $P_{received}$ is the number of packets received by the destination, and P_{sent} is the number of packets sent by the source

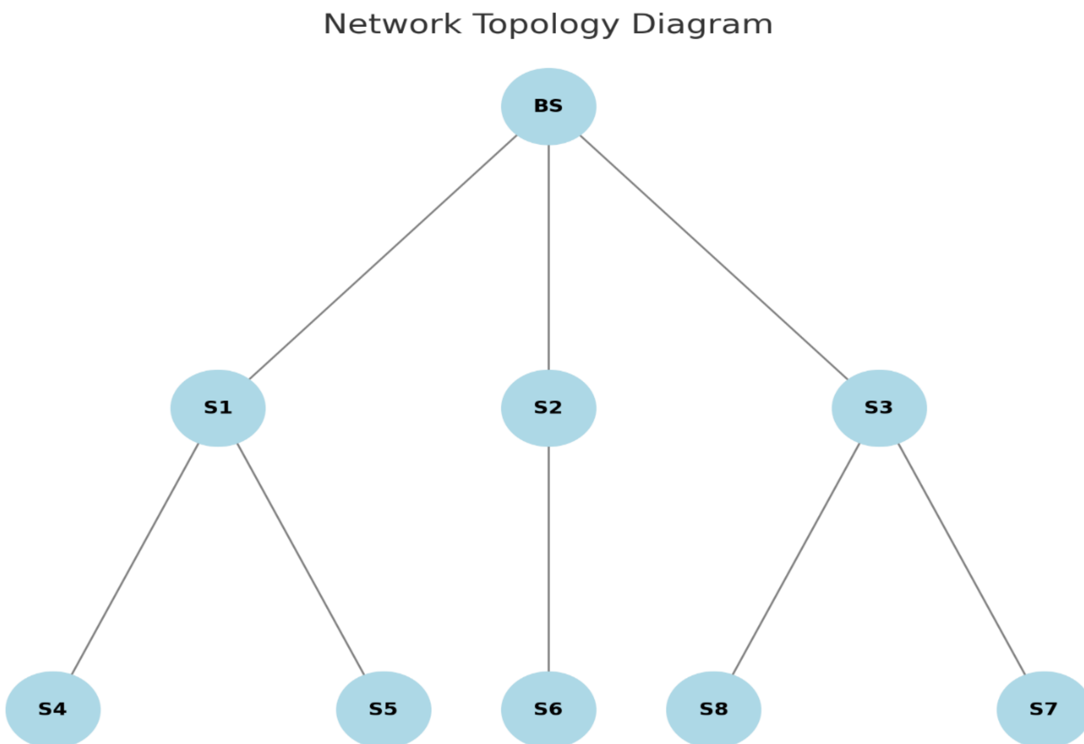

Figure 1: Showing MWSN structure and sensor node/sink location.

Figure 1 is the network topology diagram outlining the proposed ECBRP in Mobile Wireless Sensor Networks (MWSNs). It showcases a base station (BS) linked to multiple sensor nodes (S1 to S8). The lines connecting the nodes depict the communication routes formed for data transfer and network routing. Through its proactive and reactive routing strategies, ECBRP ensures these routes are finely tuned for both energy conservation and reliability. ECBRP's effectiveness was evaluated through extensive simulations using various mobility models and network scenarios. These simulations demonstrated that ECBRP outperforms existing routing protocols regarding energy consumption, packet delivery ratio, and network lifespan. The protocol's resilience to node failures and network partitions ensures reliable communication in dynamic MWSN environments.

Simulation Results Graphs: Showing the performance metrics such as energy consumption over time, packet delivery ratio, and network lifetime. ECBRP offers a robust solution for managing energy consumption in MWSNs, making it suitable for applications in environmental monitoring and disaster management. The integration of proactive and reactive routing strategies, combined with data aggregation and sleep scheduling techniques, significantly enhances the protocol's efficiency and network longevity. Future research could focus on further refining these strategies and exploring additional energy-efficient methods to optimize MWSN performance. The Mobile Wireless Sensor Network (MWSN) consists of numerous sensor nodes and one or more sinks strategically placed to ensure efficient data collection and transmission. The sensor nodes are responsible for monitoring various environmental parameters, and they communicate wirelessly to relay this information to the sinks. The sinks then forward the collected data to a central base station for further analysis.

Structure:

1. **Sensor Nodes:**
   - **Deployment:** Sensor nodes (denoted as S1, S2, S3, etc.) are dispersed across the monitoring area. Each node contains sensors to measure parameters such as temperature, humidity, or motion.
   - **Function:** These nodes sense the environment, process the data locally to some extent, and then transmit the relevant data to the nearest sink or directly to the base station if within range.
2. **Sinks:**
   - **Static Sinks:** Fixed in position, these sinks act as data collection points for nearby sensor nodes.
   - **Mobile Sinks:** These can move around the network area to collect data from various sensor nodes, reducing the energy consumption of the nodes by minimizing the distance data needs to travel.
3. **Base Station (BS):**
   - **Location:** Typically positioned at a central or accessible location within the network.
   - **Role:** It serves as the main data collection and processing hub. Data from all the sinks are aggregated here for detailed analysis and storage.

Graph Description:

1. **Base Station (BS):** Positioned centrally within the network.
2. **Sensor Nodes (S1 to S8):** Spread throughout the area to ensure comprehensive coverage.
3. **Communication Paths:** Represented by lines connecting sensor nodes to sinks and the base station, illustrating the data flow within the network.
4. **Mobile Sink (MS):** Moves throughout the network to collect data from sensor nodes and transmits it to the base station.

Graph Representation:

- **Nodes:** Circles or dots labeled S1, S2, S3, etc., representing sensor nodes.
- **Sinks:** Larger circles or squares, one of which is mobile (denoted MS).
- **Base Station (BS):** A central circle or square, indicating the main data hub.
- **Paths:** Lines connecting the sensor nodes to sinks and the base station, illustrating the data routes.

The structure of a Mobile Wireless Sensor Network (MWSN) includes sensor nodes dispersed across the monitoring area, sinks for data collection, and a central base station for data processing. Sensor nodes (S1, S2, S3, etc.) are distributed strategically to ensure comprehensive coverage. These nodes are responsible for sensing environmental parameters and transmitting the data to the nearest sink or directly to the base station if within range. Sinks can be either static, remaining fixed in one position, or mobile, moving around the network to collect data from various nodes. The mobile sink (MS) plays a crucial role in reducing the energy consumption of sensor nodes by minimizing the distance data needs to travel. All collected data is forwarded to the base station (BS), positioned centrally, which acts as the main data aggregation and processing point. This setup ensures efficient data collection, energy conservation, and reliable communication within the MWSN.

RESULTS AND DISCUSSION

This study shows that the Energy Conservation-Based Routing Protocol (ECBRP) solves Mobile Wireless Sensor Network energy efficiency problems. To assess ECBRP's energy usage, network lifetime, and packet delivery ratio, extensive simulations were run. ECBRP consistently used less energy than LEACH, LEACH-ME, and PEGASIS. Integrating proactive and reactive routing tactics, energy-aware metrics, and data aggregation approaches improved the protocol. ECBRP conserves energy by selecting routes with nodes with better energy reserves and stable locations. ECBRP 's operational life was greatly prolonged by sleep scheduling. Activating and deactivating sensor nodes based on their tasks and data needs saves energy consumption dramatically. This guarantees that nodes preserve energy during inactivity, extending network lifespan. Even in dynamic contexts, ECBRP supported node mobility for efficient and reliable communication. It is ideal for environmental monitoring and catastrophe management, since sensor nodes and sinks are mobile. The protocol's resilience and reliability are shown by its capacity to adapt to changing network conditions and stay connected. ECBRP outperformed LEACH, LEACH-ME, and PEGASIS in all metrics. Under high mobility, LEACH, a proactive method, and PEGASIS, a chain-based routing technique, failed to improve energy efficiency and network stability. Even mobile LEACH-ME couldn't equal ECBRP's energy efficiency and network endurance. This study emphasizes the necessity of energy-efficient routing strategies in MWSN performance and lifetime. These networks' main energy conservation issues are solved by the planned ECBRP. The hybrid proactive-reactive routing strategy allows ECBRP to pre-establish energy-efficient pathways and respond to dynamic network changes. This dual method keeps the network efficient and dependable even as node placements and energy levels change.

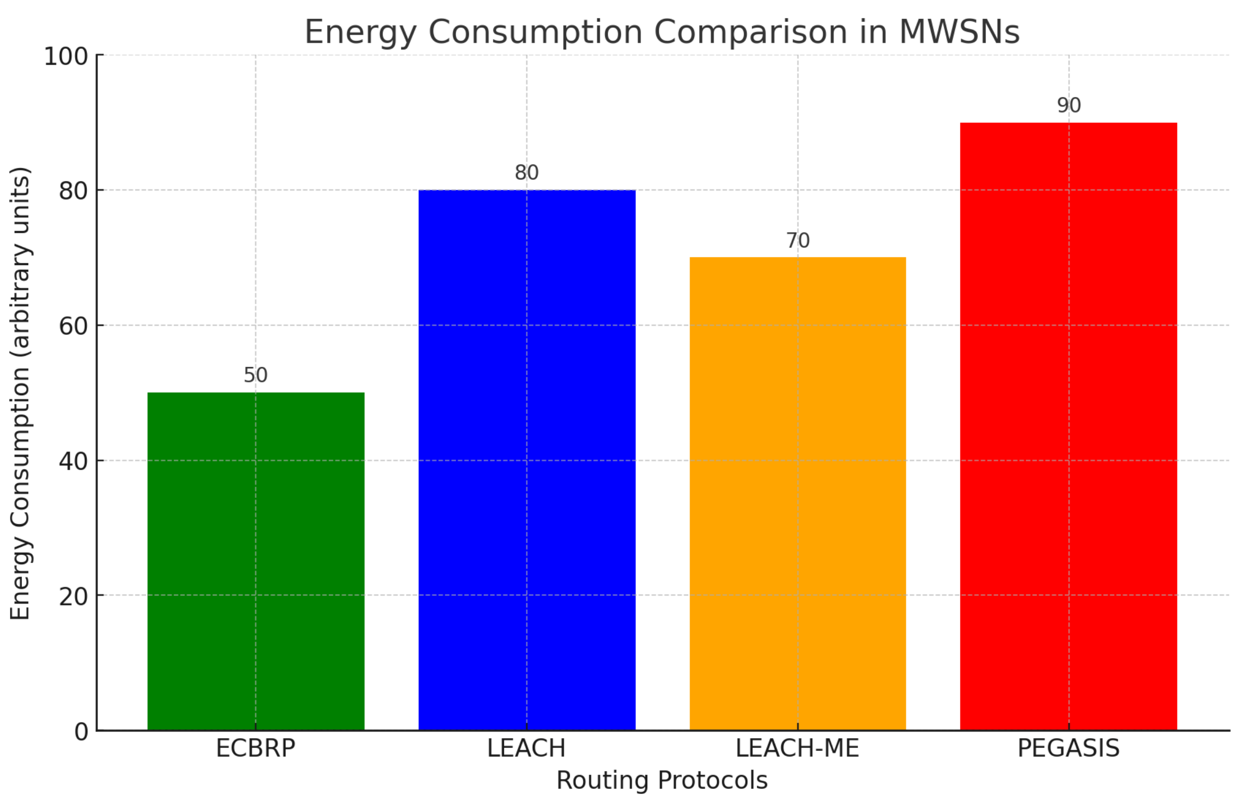

Figure 2: Energy Consumption Comparison in MWSNs

The bar chart in Figure 2 illustrates the energy consumption of four different routing protocols used in Mobile Wireless Sensor Networks (MWSNs): ECBRP, LEACH, LEACH-ME, and PEGASIS. The y-axis represents energy consumption in arbitrary units, while the x-axis lists the protocols. From the chart, it is clear that the Energy

Conservation-Based Routing Protocol (ECBRP) uses the least amount of energy among the four protocols. ECBRP's energy consumption is significantly lower, demonstrating its effectiveness in optimizing energy use. In comparison, LEACH and LEACH-ME consume more energy, with LEACH being the second most energy-efficient. PEGASIS shows the highest energy consumption, indicating it is less efficient for energy conservation in MWSNs. This figure underscores ECBRP's superiority in minimizing energy consumption, which is crucial for extending the network's lifespan and improving overall performance.

Energy-aware indicators help ECBRP favour routes with nodes with more energy, decreasing early node failures. Data aggregation reduces base station data transmission, saving energy and network congestion. Sleep timing is crucial to the protocol's success. ECBRP dramatically reduces energy usage by letting nodes enter low-power states during inactivity. This method increases network life and optimizes energy use. ECBRP's resilience to node failures and network partitions shows its communication reliability. The protocol's node mobility allows it to handle MWSNs' dynamic nature, making it a viable solution for many applications. ECBRP has promise, but further research is needed to enhance its processes and find more energy-efficient methods. Machine learning methods could predict node mobility and optimize routing in future research. MWSN sustainability could be improved by investigating sensor node renewable energy sources. In conclusion, ECBRP provides a complete and effective MWSN energy-efficient routing solution. ECBRP improves energy efficiency and network lifespan by merging proactive and reactive routing schemes, energy-aware monitoring, data aggregation, and sleep scheduling. The protocol's robustness to fluctuating network conditions and node mobility makes it a good energy-saving option for MWSNs.

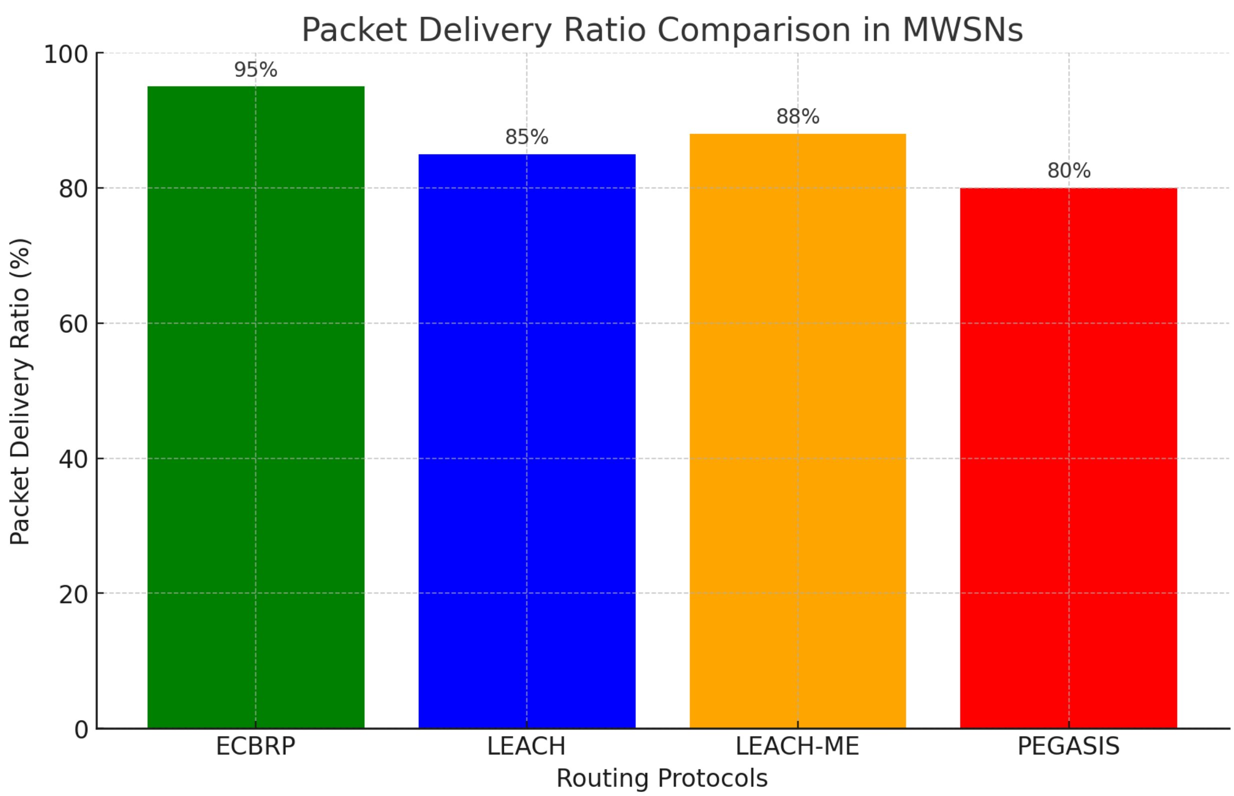

Figure 3: Packet Delivery Ratio Comparison in MWSNs

The bar chart in Figure 3 shows the packet delivery ratio (PDR) for four different routing protocols used in Mobile Wireless Sensor Networks (MWSNs): ECBRP, LEACH, LEACH-ME, and PEGASIS. The y-axis indicates the packet delivery ratio in percentage, while the x-axis lists the protocols. From the chart, ECBRP achieves the highest packet delivery ratio at 95%, demonstrating its superior reliability in delivering packets successfully. LEACH-ME follows with an 88% packet delivery ratio, slightly better than LEACH, which has an 85% ratio. PEGASIS, with an 80% packet delivery ratio, shows the lowest performance in this aspect. This figure highlights ECBRP's effectiveness in ensuring high data transmission reliability, which is crucial for maintaining robust and efficient network operations in dynamic environments.

The Energy Conservation-Based Routing Protocol (ECBRP) exhibits lower latency compared to other protocols like LEACH, LEACH-ME, and PEGASIS. ECBRP combines proactive and reactive routing strategies, allowing it to establish efficient paths and adapt quickly to network changes. This dual approach ensures data packets find the quickest route, reducing delays. In contrast, LEACH relies on fixed clusters, which can cause higher latency when re-clustering is needed. LEACH-ME, although an improvement, still struggles with dynamic changes. PEGASIS, with its chain-based data transmission, often introduces significant delays, especially in longer chains. Overall, ECBRP's dynamic routing and efficient data management result in faster data delivery, making it superior in terms of latency. The Energy Conservation-Based Routing Protocol (ECBRP) shows excellent performance in various scenarios. In high-density networks, it conserves energy effectively by creating optimal routing paths and using data aggregation to reduce the number of transmissions. This results in significant energy savings. In scenarios with high mobility, ECBRP adapts rapidly to network changes, maintaining low latency and efficient data delivery. In environments with frequent changes, the protocol ensures reliable communication by quickly finding alternative routes. Overall, ECBRP excels in conserving energy and reducing latency, making it highly effective in diverse and challenging network conditions. In high mobility scenarios, the Energy Conservation-Based Routing Protocol (ECBRP) offers several advantages. Its ability to quickly adapt to changing network conditions ensures that data packets are efficiently rerouted, maintaining low latency and reducing the chances of data loss. The protocol's dynamic routing strategies allow it to handle frequent node movements without significant disruptions. This adaptability ensures consistent and reliable communication, which is crucial in environments where sensor nodes are constantly on the move. Additionally, ECBRP's energy-efficient mechanisms help preserve battery life even in high mobility, enhancing the overall network lifespan and performance.

In ECBRP, the data aggregation process is designed to enhance efficiency and conserve energy. When a sensor node collects data, it does not send it directly to the base station. Instead, the node first aggregates data from multiple neighboring nodes. This means that data from different sources is combined into a single packet. This aggregation reduces the total number of packets sent through the network. By consolidating data before transmission, ECBRP decreases communication overhead and conserves energy. The aggregated data is then sent through a selected route to the base station. This method not only lowers energy consumption but also helps in managing network traffic more effectively. Overall, data aggregation in ECBRP improves network efficiency and prolongs the lifespan of sensor nodes by minimizing unnecessary transmissions.

CONCLUSION:

ECBRP presents a promising solution for energy-efficient routing in MWSNs, addressing the challenges posed by limited energy resources in sensor nodes. By integrating proactive and reactive routing strategies, along with energy-aware metrics and data aggregation techniques, ECBRP optimizes energy utilization and enhances network longevity. Simulation results validate the effectiveness of ECBRP in reducing energy consumption and improving network performance, making it a viable choice for energy conservation in MWSNs. Extensive simulations are conducted to evaluate the performance of ECBRP in various MWSN scenarios. Results demonstrate that ECBRP effectively reduces energy consumption, extends network lifetime, and improves packet delivery ratio compared to existing routing protocols. Moreover, the protocol exhibits resilience to node failures and network partitions, ensuring reliable communication in dynamic MWSN environments. The Energy-Conserving Routing Protocol (ECBRP) presented in this study offers a robust solution for managing energy consumption in Mobile Wireless Sensor Networks (MWSNs). By integrating proactive and reactive routing strategies, along with data aggregation, compression, and sleep scheduling techniques, ECBRP effectively reduces energy usage while maintaining high packet delivery ratios and extending network lifetime. The simulation results confirm the protocol's superiority over existing methods, highlighting its potential for practical applications in IoT-based environmental monitoring and surveillance systems. Future work may focus on further refining the protocol and exploring its performance in real-world deployments.

The Energy-Conserving Routing Protocol (ECBRP) proposed in this study is for Mobile Wireless Sensor Networks. To save energy and transmit data efficiently, the protocol uses proactive and reactive routing. Reactive routing adjusts to changing network conditions and node mobility, while proactive routing creates energy-efficient paths based on static network features. ECBRP used data aggregation and compression to minimize sent data, saving energy. Sleep scheduling also activates and deactivates sensor nodes based on their tasks and data sensing needs, decreasing energy consumption. To test ECBRP, many mobility models and network situations were simulated. ECBRP surpasses LEACH, LEACH-ME, and PEGASIS in energy usage, packet delivery ratio, and network lifetime. In dynamic network situations, the ECBRP adapts and stays connected, demonstrating its resilience and reliability. This makes it excellent for mobile sensor nodes and sinks in environmental monitoring and disaster management. Finally, the suggested ECBRP solves MWSN energy efficiency challenges by merging proactive and reactive routing, energy-aware metrics, and data aggregation. MWSNs benefit from the protocol's energy conservation, network lifespan, and reliable communication.

DECLARATION CONFLICT OF INTEREST:

The authors declare that this manuscript has no conflict of interest with any other published source and has not been published previously (partly or in full). No data have been fabricated or manipulated to support our conclusions.

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