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Routing Based Energy Optimization Techniques for Improving the Performance and Lifetime in Wireless Sensor Networks

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Abstract:

Wireless Sensor Networks (WSNs) plays pivotal role in numerous applications. However, the inadequate energy resources of wireless nodes posture a substantial challenge to the complete enactment and lifespan of WSNs. To address this issue, routing-based energy optimization techniques have emerged as crucial components in the design and management of WSNs. This work provides an overview of key strategies and approaches aimed at improving performance and prolonging the lifetime of WSNs through efficient routing schemes. The first focus of this abstract is on energy-efficient routing protocols. Traditional routing protocols may not be suitable for WSNs due to their resource constraints. Therefore, novel routing algorithms, such as energy-aware and load-balancing protocols, are explored to optimize energy consumption. These protocols aim to intelligently distribute the communication load among sensor nodes, minimizing energy wastage and thereby enhancing the overall network efficiency. Various data aggregation strategies, including spatial and temporal techniques, are discussed for their potential in enhancing energy efficiency in the network. Additionally, the work highlights the significance of dynamic and adaptive routing mechanisms. The effectiveness of the proposed routing-based energy optimization techniques is evaluated through simulations and real-world experiments. Performance metrics such as network lifetime, throughput, energy consumption, and packet delivery ratio are considered to assess the impact of these techniques on WSNs. The work concludes with a discussion of challenges, future research directions, and the broader implications of these energy optimization techniques for the advancement of Wireless Sensor Networks.

Keywords: *Efficient Routing Schemes, Energy-Aware Protocol, Energy Conservation, Energy Optimization Techniques, Environmental Monitoring, Industrial Automation, Load-Balancing Protocol, Network Lifetime, Wireless Sensor Networks (WSNs).*

1. Introduction:

WSNs are inherently dynamic, with network conditions changing over time. Adaptive routing protocols adjust their strategies based on the real-time network state, optimizing energy consumption and prolonging the network's operational lifetime. Furthermore, the abstract delves into the integration of data aggregation techniques within routing protocols. Data aggregation involves the combination of similar or correlated data from multiple sensor nodes before transmission, reducing redundant information and conserving energy [1].

WSNs have materialized as a pivotal technology for monitoring and collecting data in diverse applications, ranging from environmental monitoring to industrial automation. These networks consist of a multitude of sensor nodes that collaborate to gather and transmit data to a central sink or base station. However, the constrained energy resources of sensor nodes pose a significant challenge to the longevity and efficiency of WSNs [2].

The energy consumption in WSNs is primarily attributed to communication activities, including data transmission and reception. As a result, developing effective energy optimization techniques is crucial to extend the operational lifetime of the network and enhance its overall performance. Routing plays a central role in determining how data is transmitted within the network, making it a key area for implementing energy-efficient strategies [3].

This paper explores routing-based energy optimization techniques aimed at improving both the performance and lifetime of WSNs. By intelligently managing the routing protocols and mechanisms, it is possible to mitigate energy consumption, balance the energy load among nodes, and ultimately prolong the network's operational lifespan.

1.1 Challenges in WSN Energy Management:

- **Limited Energy Resources:** Sensor nodes in WSNs are typically powered by batteries, which have finite energy capacities. Efficient energy management is critical to prevent premature node failures and ensure long-term network operation [4].
- **Dynamic and Unpredictable Environments:** WSNs often operate in dynamic and unpredictable environments. Fluctuations in data traffic, environmental conditions, and network topology necessitate adaptive routing strategies to handle these changes effectively [5].
- **Heterogeneous Node Characteristics:** Sensor nodes in WSNs may have varying energy levels due to factors such as placement, hardware differences, or uneven energy consumption. This heterogeneity needs to be considered when designing energy optimization techniques.
- **Data Aggregation and Transmission Overheads:** The process of aggregating and transmitting data incurs additional energy overhead. Minimizing unnecessary transmissions and optimizing data aggregation techniques are essential for energy-efficient WSNs [6].

1.2 Objectives of Routing-Based Energy Optimization:

- **Prolonging Network Lifetime:** The primary goal is to extend the operational lifetime of the WSN by reducing energy consumption. This involves designing routing protocols that intelligently distribute the energy load and minimize energy-intensive operations [7].
- **Enhancing Network Performance:** Improving the overall performance of the WSN involves optimizing data delivery, reducing latency, and ensuring reliable communication. Routing strategies should be designed to achieve these objectives while considering energy constraints [8].

- **Adaptation to Dynamic Environments:** Effective routing-based energy optimization techniques should be adaptable to dynamic and unpredictable changes in the WSN environment. This adaptability ensures that the network remains robust and efficient under varying conditions.
- **Balancing Energy Consumption:** Uneven energy consumption among sensor nodes can lead to premature node failures and degraded network performance. Routing protocols should aim to balance energy consumption, promoting uniform depletion of energy resources across the network [9].

In the subsequent sections of this paper, we will delve into existing routing-based energy optimization techniques, their strengths and limitations, and propose novel approaches to address the challenges outlined above. The ultimate aim is to contribute to the development of energy-efficient WSNs capable of sustaining prolonged operation in diverse and dynamic environments.

2. Literature Review:

1. **Routing Protocols for Energy Efficiency:** Numerous routing protocols have been proposed to enhance energy efficiency in WSNs. Classic protocols like LEACH and its variants focus on forming clusters to reduce the energy consumption during data transmission. Other protocols, such as TEEN and APTEEN introduce adaptive mechanisms to adjust the sensing and communication thresholds based on the environmental conditions, leading to energy savings [10].
2. **Data Aggregation Techniques:** It plays a pivotal role in minimizing the amount of data transmitted, thus reducing energy consumption. Various data aggregation techniques, including spatial and temporal correlation-based aggregation, have been proposed. These techniques exploit the redundancy in sensed data to consolidate information before transmission. However, challenges remain in balancing the trade-off between data accuracy and energy savings [11].
3. **QoS-Aware Routing:** Quality of Service (QoS) is a critical aspect of WSNs, especially in applications where real-time data is essential. QoS-aware routing protocols, such as SAR (Secure and QoS-Aware Routing), aim to provide reliable and timely data delivery while considering energy constraints. These protocols dynamically adapt to changing network conditions to maintain the desired level of service [12].
4. **Cross-Layer Design Approaches:** Cross-layer design approaches integrate information from multiple layers of the communication protocol stack to optimize energy efficiency. By considering interactions between the physical, data-link, and network layers, these approaches can make more informed decisions regarding routing and data transmission. However, the complexity of cross-layer designs requires careful consideration to avoid introducing vulnerabilities and maintaining interoperability [13].
5. **Machine Learning-based Routing:** Recent research has explored the application of machine learning (ML) techniques to optimize routing decisions in WSNs. ML models,

such as reinforcement learning and neural networks, can learn from historical data to predict optimal routes and adapt to dynamic environmental changes. Integrating machine learning into WSNs introduces the potential for intelligent, self-optimizing networks [14].

6. **Energy Harvesting and Hybrid Energy Sources:** To overcome the limited energy resources of battery-powered nodes, researchers have investigated the integration of energy harvesting mechanisms, such as solar or kinetic energy, into WSNs. Hybrid energy sources coupled with adaptive routing algorithms enable nodes to operate for extended periods without manual intervention. However, the effectiveness of these solutions depends on the availability and predictability of the energy sources [15].
7. **Security Considerations in Energy-Efficient Routing:** As WSNs become integral to critical applications; the security of routing protocols becomes paramount. Ensuring the confidentiality and integrity of data, as well as preventing attacks on the routing infrastructure, is crucial. Secure routing protocols, such as SPREAD (Secure and Privacy-Respecting Energy-Efficient Aggregation in WSNs), have been proposed to address these security concerns without compromising energy efficiency [16].
8. **Simulation and Evaluation Tools:** Researchers commonly employ simulation tools like NS-2, NS-3, and OMNeT++ to evaluate the performance of routing-based energy optimization techniques. These tools enable the modeling of various network scenarios, facilitating the assessment of proposed protocols under different conditions [17].

The literature on routing-based energy optimization techniques for WSNs reflects a diverse range of approaches. While classic protocols laid the foundation for energy-efficient routing, recent advancements, such as machine learning integration and security considerations, showcase the evolving landscape of WSN research. The challenges of balancing energy consumption, adapting to dynamic environments, and ensuring reliable data delivery continue to drive innovation in this field. Future research should focus on practical implementations and real-world deployments to validate the efficacy of these techniques in diverse WSN applications [18].

The collection of data by the cluster heads results in large consumption of energy. To reduce this energy loss, the authors propose a method called the centroids method. In this method the initial clustering is done by the pillar k means algorithm resulting in the placement of centroids away from distribution resulting in efficient clustering. After clustering the initial centroids act as aggregators. These functions both as aggregators and routers initially. This helps in increasing the lifetime of the network [19].

These literature references provide a broad understanding of the routing and clustering-based energy optimization techniques in wireless sensor networks for improving the lifetime of 5G networks. They cover key algorithms, protocols, and surveys that are relevant to this research area, enabling a comprehensive review of existing techniques and insights for further exploration.

3. PROPOSED WORK:

3.1 Clustering and Routing:

The clustering and routing process consists of two phases which are the cluster set-up phase and the data transmission phase. During the transmission process, the cluster heads aggregate data from the nodes in their respective clusters and then sends it to the base station, directly or through a relay node [20].

3.2 Cluster Head Selection:

The above-said process can be formulated as an optimization problem and mathematically expressed as,

$$\mathrm{Ft}_{\mathrm{CH}} = \alpha \times \mathrm{R}_{\mathrm{energy}}^{\mathrm{CH}} \text{ --- } (1)$$

Where, $\mathrm{R}_{\mathrm{energy}}^{\mathrm{CH}}$ is the ratio of the average energy of the Cluster heads to the average energy of normal sensor nodes in the current round. By maximizing $\mathrm{R}_{\mathrm{energy}}^{\mathrm{CH}}$ nodes with higher energy levels are selected as Cluster heads.

3.3 Relay Node selection:

If the base station is at a distance more than the threshold, then it is necessary to select a relay node and transmit the data through the relay node. The relay node in the proposed method is chosen based on the following two criteria. The first criteria are that the node with the highest residual energy should be selected and the second criteria are that the node nearest to the base station is selected among the nodes with higher residual energies [21].
If there are 't' potential relay nodes RN1, RN2, RN3 ………… RNt, between the Cluster head and Base station, then the equation for selection of Relay node may be expressed as,

$$\mathrm{Ft}_{\mathrm{RN}} = \beta \times \mathrm{R}_{\mathrm{energy}}^{\mathrm{RN}} + (1-\beta) \times \mathrm{R}_{\mathrm{location}}^{\mathrm{RN}} \cdots \text{------------------------- } (2)$$

Where, $\mathrm{R}_{\mathrm{energy}}^{\mathrm{RN}}$ is the ratio of average residual energy Relay nodes to average residual energy of Sensor Nodes. Maximizing $\mathrm{R}_{\mathrm{energy}}^{\mathrm{RN}}$ results in the selection of a node with higher energy as a relay node. $\mathrm{R}_{\mathrm{location}}^{\mathrm{RN}}$ represents the location of the node which is nearest to the base station.

3.4 Energy Consumption Analysis:

Let us assume that there are 'n' clusters and the number of nodes in every cluster is 'm'. The energy consumed by a sensor node for signal transmission and reception plus the occasional sleep phases can be computed as follows:

$$\mathrm{E}_{\mathrm{sn}} = (1-\mathrm{ps})[\mathrm{E}_{\mathrm{tx}}(\mathrm{l},\mathrm{d}) + \mathrm{E}_{\mathrm{rx}}(\mathrm{l})] + \mathrm{p}_{\mathrm{s}}\mathrm{E}_{\mathrm{s}} \text{ -------------------------- } (3)$$

The data that is aggregated by the Cluster Head is then transmitted to the Cluster head nearer to the base station or directly to the base station. Depending on the distance between the cluster head and base station, the free space model or multipath model is selected.
Hence energy dissipated by the Cluster head is

$$E_{ch} = E_{tx}(l, d) + mE_{rx}(l) + ml(E_{da}) \text{ --- } (4)$$

Where 'm' is the number of sensor nodes in a cluster. $'E_{da}'$ is the energy dissipated per bit due to data aggregation. Therefore, energy dissipation within a Cluster is given as

$$E_{Cluster} = E_{ch} + mE_{sn} \text{ --- } (5)$$

Therefore, the total Energy consumed is given as

$$E_{total} = E_{Cluster} \times n. \text{ -------------------------------------- } (6)$$

Where ‘n’ is the number of Clusters.

4. PROPOSED METHODOLOGY:

The following procedures will make up the proposed method.

1. It is believed that the base station is located in the middle of each cluster.
2. After that, about 20 clusters are created, each with four to six nodes.
3. Every cluster has a sequential number between 1 and 20.
4. Every node's energies are calculated.
5. Assign the cluster head position to the node in each cluster that has the highest energy.
6. The nodes gather the data and send it to the cluster heads (CH). The data is sent to the Base Station (BS) by the CHs.
7. The cluster head positioned between the source cluster head and the base station is chosen as an intermediate node for data transmission if the distance between the cluster head and the base station exceeds the threshold.
8. In the event that there are more than two clusters between, the cluster head with the highest energy will be chosen as the intermediate cluster head, through which data will be transmitted to the base station.
9. The cluster heads' energies decrease when the first communication is over, and there's a chance that there are more energies in another node. Similar to male deer, the node with the second-highest energies assumes leadership in all odd-numbered clusters while the same cluster heads continue in even-numbered clusters.
10. Communications resume, and in the odd-numbered clusters, the cluster head rotates following each cycle.

11. The node with the second-highest energy becomes the cluster head after a few rounds, and the process continues until the energy of the cluster head of the even-numbered clusters is depleted, or hits its threshold. The female clusters are comparable to this.
12. In this manner, data is transferred for a longer period of time from the source to the destination and communication occurs. A distinctive feature of this kind of communication is the two distinct energy-saving strategies employed in the two clusters.

A total of one hundred nodes are dispersed at random within a 300 m × 300 m square. Random energies are prearranged among these nodes. At the beginning, roughly 100 nodes are dispersed at random throughout a fixed 300 m by 300 m region. After that, groups are created, each containing four to six nodes. It is presumed that each alternate cluster consists of female clusters. This process is ongoing in every cluster with an odd number. It is thought that these clusters are comparable to male clusters. In an analogous manner, in clusters with even numbers, the node with the second-highest energy assumes control when the energy of the cluster head with the highest energy hits a certain threshold.

5. RESULTS ANALYSIS:

Simulation of this scenario with the proposed technique is implemented in NS2. Two ray ground propagation models are considered. For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. The threshold is 0.2 mJ for every node Number of alive nodes; energy consumption and network lifetime are recorded. For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. The threshold is 0.2 mJ for every node.

Table1. Parameters Considered for Simulation

S. N.	Model Constraints	Standards
1	Total Nodes	100
2	Application Area	300m ×300m
3	Type of the Channel	Wireless
4	Acceptance Power	1mw
5	Transferring Power	2mw
6	Package Size	1000bits
7	Considered Parameters	Total Alive Nodes, Energy Consumption, and Network Lifetime.

The figures below offer a graphical representation of performance comparisons between projected and existing techniques in terms of various parameters. Fig.1 shows that the model proposed runs for 595 rounds for the longest time in comparison with the existing method. Fig.2 shows that the nodes for the existing methods die earlier in comparison with the proposed one in terms of efficiency. The observation graph for Fig. 3 indicates that the recommended method consumes less power in comparison with the existing techniques. It shows that the projected work has a larger life span in comparison with existing techniques.

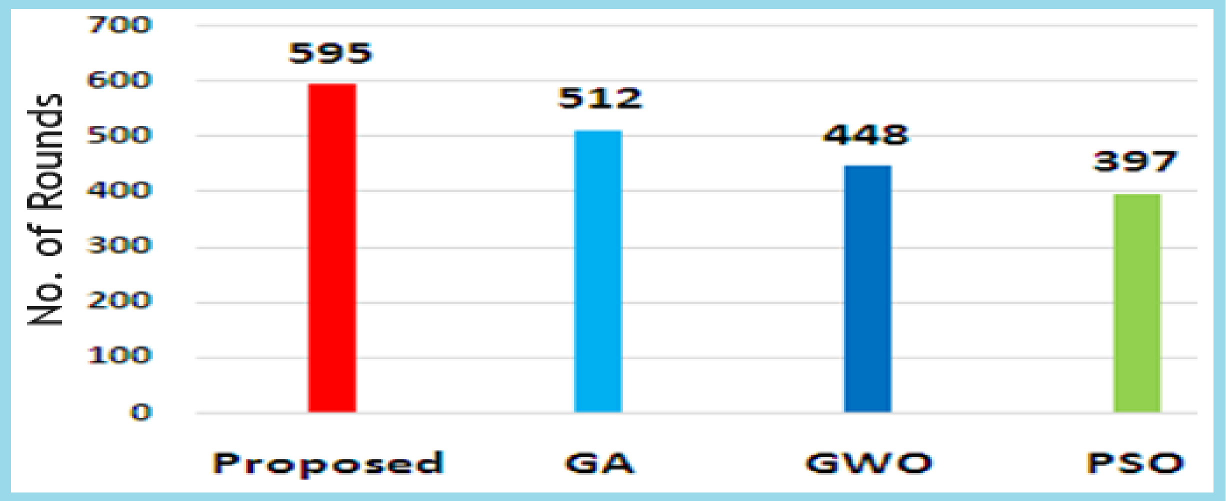

Figure 1: Comparison of Network Lifetime

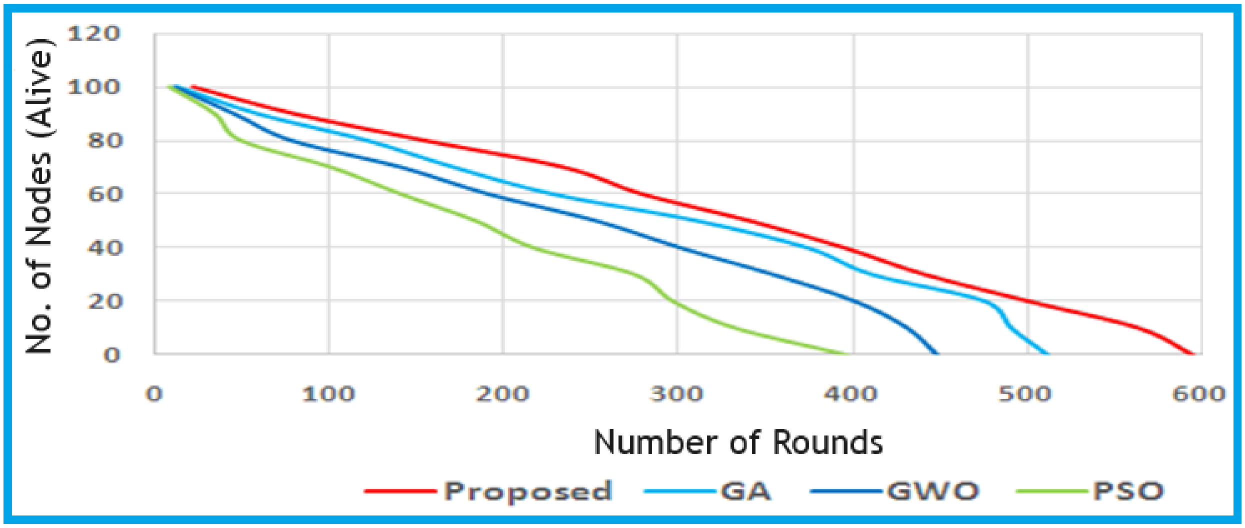

Figure 2: Number of Alive Node

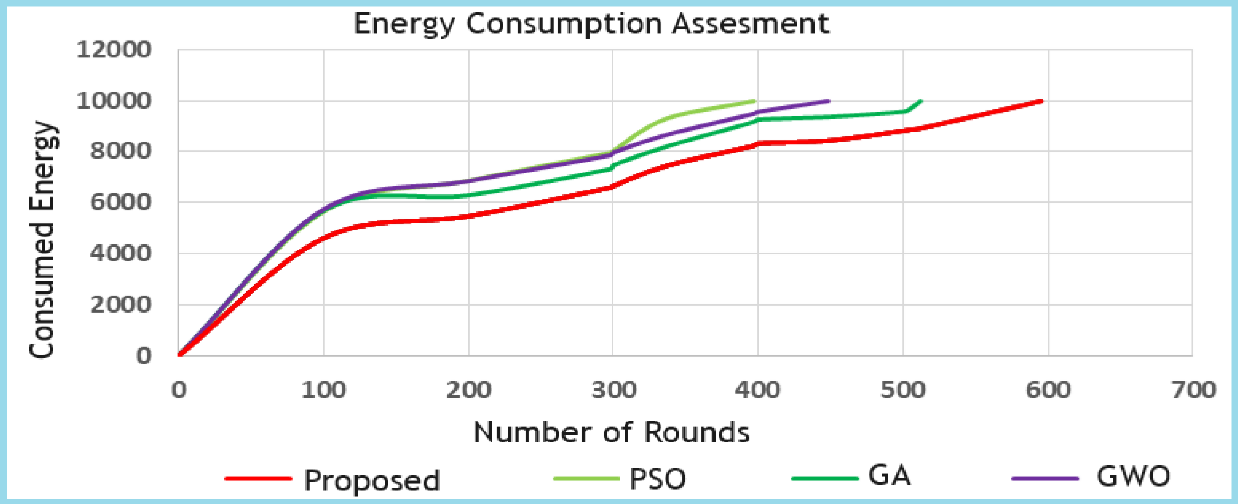

Figure.3: Energy Consumption Assessment

6. Conclusion & Future Scope:

6.1 Conclusion:

In the context of Wireless Sensor Networks, the research and development in routing and clustering-based energy optimization strategies for wireless sensor networks is essential to achieving efficient and sustainable network operations. The literature review offers insightful information on the developments in this field, including ground-breaking algorithms, thorough surveys, and potential future paths. The lifespan and energy efficiency of 5G networks can be increased by utilizing these strategies and carrying out ongoing research, which will allow for the networks' effective implementation across a range of applications and domains.

6.2 Future Scope of the Work:

WSN-based energy optimization strategies, such as routing and clustering, are essential for extending the lifespan and increasing the efficiency of 5G networks. Additionally, hybrid approaches that blend clustering and routing algorithms have been studied. By combining the advantages of clustering and routing, these methods improve energy optimisati on in 5G networks. To ensure effective energy utilization throughout the network, they adaptively use multi-hop routing for inter-cluster communication and clustering for localized data aggregation. Furthermore, adaptive energy optimization based on traffic patterns and real-time network conditions appears to be possible with the combination of machine learning approaches and clustering algorithms.

Author contributions:

Conceptualization, SA and GSSR; methodology, SA; software, AKL; validation, SA, SA, AKL and GSSR; formal analysis, SA; investigation, GSSR; resources, SA; data curation, SA; writing—original draft preparation, GSSR and SA; writing—review and editing, SA; visualization, GSSR; supervision, SA; project administration, SA, AKL; funding acquisition, GSSR. All authors have read and agreed to the published version of the manuscript.

Conflict of interest:

The authors declare no conflict of interest.

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