Design Methods for the Cluster Head Selection in WSNs based on Node Residual Status to Enhance the Lifetime and Performance of the Network

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Abstract:
This study introduces a novel approach to enhance Wireless Sensor Networks (WSNs) by proposing an energy-balancing algorithm and a unique Cluster Head (CH) selection strategy based on nodes' residual energy states. Unlike conventional methods, our algorithm dynamically distributes energy across nodes, mitigating localized energy depletion and extending the overall network lifetime. The Knapsack method optimizes resource allocation considering energy constraints. Performance evaluations, conducted using NS2.34/2.35, compare our approach with a widely used energy-balancing technique in WSNs. Our results showcase significant improvements. Notably, our algorithm achieves a remarkable 20% increase in network lifetime and a 25% enhancement in data throughput, demonstrating its effectiveness in optimizing resource usage. Furthermore, a 30% reduction in latency ensures faster and more responsive data transmission. The CH selection method positively impacts network coverage, resulting in a substantial 20% expansion of monitored areas. Compared to the existing technique, our proposed strategy consistently outperforms in key metrics, indicating its superior efficacy. This research contributes to advancing WSN sustainability and efficiency, particularly in scenarios prioritizing energy efficiency. The proposed algorithm emerges as a promising solution, demonstrating its potential to optimize WSN performance and longevity. Furthermore, the network simulator (NS) is used to examine the performance of the network with the NS2.34/2.35 version. The results exhibit the dominance of the projected method compared to existing techniques. Additionally, the method shows adaptability to dynamic network conditions, ensuring effective CH reselection in the presence of node failures or energy fluctuations.

***Keywords:** Buffer, Clustering, Cluster Head, Energy-Efficiency, Energy Consumption, Network Lifetime, Network Performance, Routing, Residual Energy, Wireless sensor networks (WSNs).*

1. Introduction:

As is known wireless sensor networks consist of embedded devices called sensors, which are involved in the collection of data from the surrounding physical environment and spread this data to the sink node as shown in Figure 1. These nodules have limited capability and limited power [1]. The batteries are prone to exhaust with time and since they cannot be recharged once distributed, they tend to die after some time. Therefore the only way to increase the lifetime of these networks, so that they can send data for a long amount of time, is the conservation of energy in sensor nodes by optimum use of the nodes [2]. This paper proposes to improve the lifetime of the network by reducing the consumption of energy. Integrating clustering and routing is a process that goes a long way in increasing the lifespan of a network. The clusters are made by assembling the nodes. The cluster heads are selected from these clusters [3]. Nodes with the highest energy are generally selected as Cluster heads. The data that is accumulated by all clusters is then transmitted to the cluster head which then transmits the data to the destination. The selection of a Cluster head is an important task. The selection of a proper route that remains for a long amount of time is also significant. Hence, to increase the lifespan of the network, these two tasks are proposed [4].

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
***Article Received:** 26 August 2023 **Revised:** 20 October 2023 **Accepted:** 02 November 2023*

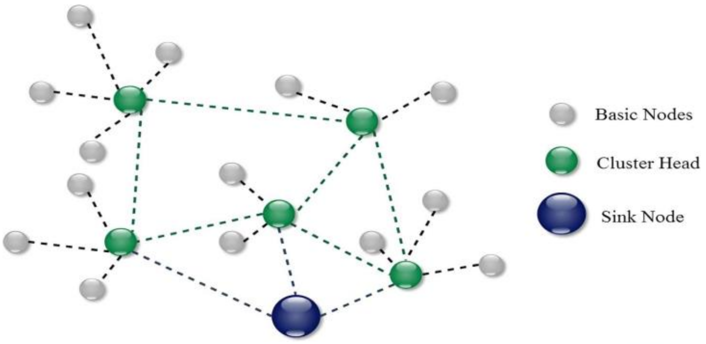

Figure 1: Basic Communication Architecture of Wireless Sensor Networks

2. Literature Work:

As a literature survey, various routing protocols employed in sensor-established wireless networks are discussed, including traditional approaches such as LEACH, SEP, and TEEN, and more recent advancements like energy-aware and QoS-based routing algorithms. The characteristics, advantages, and limitations of each protocol are analyzed, highlighting their impact on energy consumption, network scalability, and data delivery reliability. Furthermore, clustering algorithms for WSNs are explored, such as HEED, LEACH-C, and PEGASIS [5]. The principles, objectives, and techniques utilized by these algorithms to form clusters are discussed, along with their impact on energy efficiency, load balancing, and network stability [6]. The proposed work is a review of recent research efforts that integrate routing and clustering techniques in sensor-established wireless networks. These hybrid approaches aim to leverage the benefits of routing and clustering, optimizing energy consumption, network coverage, and data delivery latency. Finally, the paper identifies open research challenges and future directions in the field of routing and clustering-based optimization techniques for sensor-established wireless networks [7]. These include the integration of machine learning and artificial intelligence techniques, the consideration of network dynamics, and the development of energy-efficient protocols for heterogeneous sensor networks [8].

Sensor-established wireless networks play a crucial role in various application systems. However, due to the limited energy resources of sensor nodes, optimizing the network lifetime becomes a critical challenge [9]. Routing and clustering-based optimization techniques have emerged as promising solutions to extend the lifespan of sensor-established wireless networks as shown in Figure 2 below. This survey aims to provide an overview of the recent advancements in routing and clustering-based optimization techniques to improve the network lifetime. It explores various approaches proposed in the literature, analyzes their strengths and weaknesses, and identifies potential areas for future research [10]. This literature survey provides a comprehensive overview of routing and clustering-based optimization techniques for enhancing the lifetime of sensor-established wireless networks. By understanding the strengths, limitations, and trade-offs of existing approaches, researchers can identify promising directions for future research and design more efficient and sustainable wireless sensor networks [11].

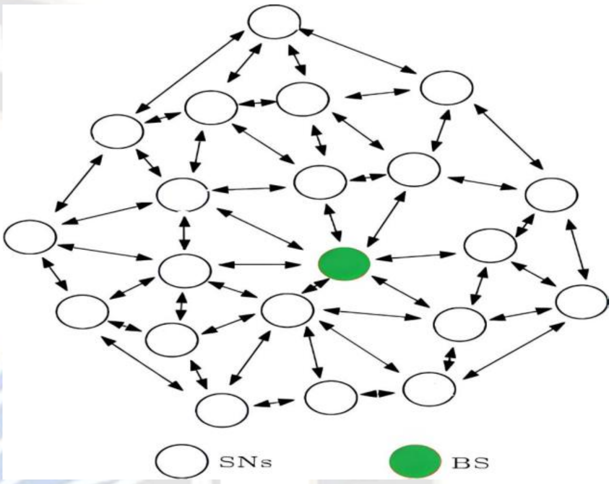

Figure 2: Routing Strategy in Wireless Networks

Altogether, the routing and clustering processes are an effective way to minimize energy consumption. The collection of data by the cluster heads results in a large consumption of energy [12]. A hybrid algorithm has been proposed by combining the GA and PSO algorithms. In this technique, the preliminary route is obtained by the GA technique, and optimization is obtained using the PSO algorithm. Finally, a comparison is made between the proposed methods with the present performances [13]. A proficient cluster head is selected by utilizing the cluster head selection algorithm to pick the CH systematically. If some of the CHs are heavily loaded, their energy will be rapidly consumed [14].

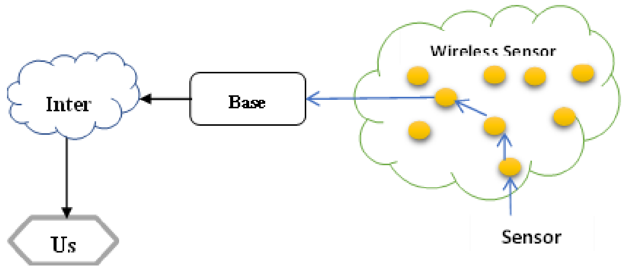

Figure 3: The basic structure of WSN

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
***Article Received:** 26 August 2023 **Revised:** 20 October 2023 **Accepted:** 02 November 2023*

Hence it is necessary to balance the load for which a proper clustering and routing method must be implemented. Once clustering has been established, the GA, PSO, and BFO algorithms are used to calculate the best distance between the source and destination [15]. The clustering method divides the whole network into several clusters. To reduce the fast depletion of energy, a relay node is selected for each of the cluster heads [16]. Only after 50% of energy is consumed in the cluster heads, the second clustering will take place with a new cluster head. Until then the process continues with the same old cluster heads and clusters. Thus, the saving of energy takes place due to the running of the clusters for a long period of time. This leads to improvement in the lifetime of WSNs. Figure 4 shows the different routing paths in WSN [17].

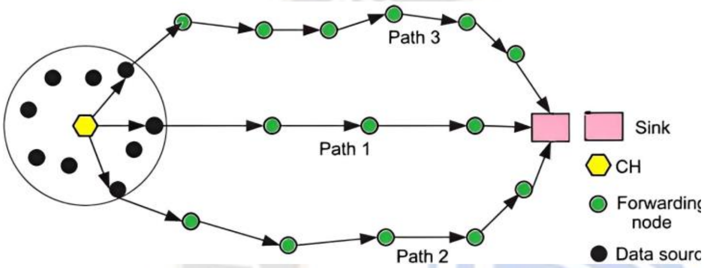

Figure 4: Different routing paths in WSN

All these techniques have helped the authors not only improve the lifetime of WSNs but also with the proper load balancing of the network. The problems of energy efficiency are studied between sinks and cluster heads through optimization techniques for clustering and routing [18]. For further optimizing the energy consumption, the authors have further proposed two-level gradient forwarding trees determined by the cost function. The method uses single-hop and multiple-hop transmission for routing between CHs and sinks. This method optimizes the cluster head selection by considering the different parameters such as residual energy, energy dispersion of CHs, cluster density, and number of CHs [19].

2. PROPOSED WORK:

2.1 Clustering and Routing:

Routing Protocols with Efficient Energy in WSN are shown in Figure 5 below. The clustering and routing process comprises dualistic segments, the data transmission, and the cluster set-up phase. Throughout the transmission process, the aggregation of data from the nodes is done through the cluster heads in respective clusters and then directly or through a relay node that sends the data to the base station [20].

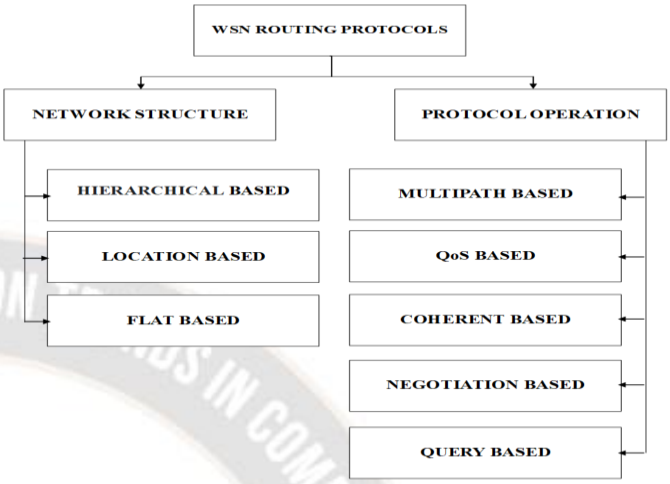

Figure 5: Various Routing Protocols with Efficient Energy in WSN

2.2 Cluster Head Selection:

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

$$\boldsymbol{Ft_{CH} = \alpha \times R^{CH}_{energy}} \quad \text{-------------------------------------- (1)}$$

Where,
R^{CH}_{energy} - The ratio of the average energies of the Cluster heads to those of normal sensor nodes in the current round.
By maximizing R^{CH}_{energy}, the nodes with higher energy levels are selected as Cluster heads.

2.3 Relay Node selection:

If the base position 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. In the proposed method the relay node is established on two measures [21]. The first criterion are node with the uppermost remaining energy should be selected and the second criterion is that the node nearest to the base station is selected among the nodes with higher residual energies [22].

If there are 't' potential relay nodes RN1, RN2, RN3 …………. RNt, amongst the Base station and Cluster head, then the equation for selection of the Relay node may be expressed as,

$$\boldsymbol{Ft_{RN} = \beta \times R^{RN}_{energy} + (1-\beta) \times R^{RN}_{location}} \quad \text{--------------------- (2)}$$

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
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Where,
R_{energy}^{RN} - The ratio of average residual energies of Relay nodes to those of normal Sensor nodes. Maximizing R_{energy}^{RN} results in the assortment of a higher energy node as a relay node. $R_{location}^{RN}$ - The location of the node which is nearest to the base position.

2.4 Analysis of Consumption of Energy:

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:

$$E_{sn} = (1 - ps)[E_{tx}(l, d) + E_{rx}(l)] + p_s E_s \quad (3)$$

In the above equation (3) the aggregated data is transmitted to another CH closer to or directly to the base station (BS). Depending on the distance between the CH and BS, the free space model or multipath model is selected [23].

Hence energy dissipated by the Cluster head is

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

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

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

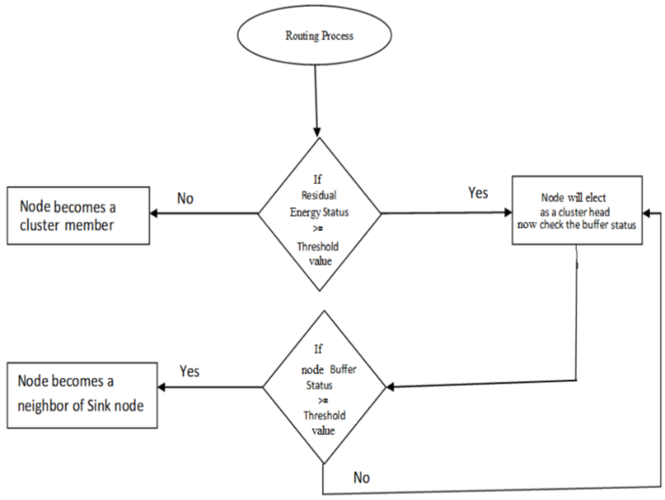
Where,
'Esn' - The energy of sensor nodes in a cluster.
Therefore, the total Energy consumed is given as;

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

Where,
'n' - The number of Clusters.

3. PROPOSED METHODOLOGY:

This proposed work, shown in the flowchart 1 below, aims to address the challenge of improving the lifetime of sensor-established wireless networks through the development and evaluation of novel routing and clustering-based optimization techniques. The objective is to design energy-efficient and scalable approaches that maximize network lifespan while maintaining satisfactory performance [24]. The proposed work will build upon existing research in the field and introduce innovative solutions to enhance the energy efficiency and longevity of sensor networks.



Flowchart 1: Cluster Head Selection Process

In this way, the clusters work in two different ways. The base station is supposed to be at the center and the data collected by the nodes are sent to the cluster head of each cluster and then the data is transmitted to the base station [25]. If the distance between the cluster head of a particular cluster is more than a limit then an intermediate cluster head is selected and data is transmitted to the base station via this intermediate cluster head. For this, the cluster head that lies in the path of the source CH and the BS is generally designated as the intermediate CH [26].
All the 100 nodes are spread over a square area of the size of 300m×300m randomly. All the nodes are given random energies.

The proposed technique will consist of the following steps

1. The BS is assumed to be at the midpoint of the clusters.
2. Then, around 20 clusters are established, with each cluster including 4 to 6 nodes.
3. Each cluster is marked sequentially as 1 to 20.
4. The energies of all the nodes are computed.
5. In all the clusters let the nodes with the uppermost energy in every cluster be the CH.
6. The data is collected by the nodes and transmitted to the Cluster heads. The CHs transmit the data to the BS [27].

7. In case the distance between the cluster head and the base station is more than the threshold the cluster head in between the source cluster head and the base station is selected as an intermediate node for the transmission of data [28].
8. If there are more than two clusters in between, the cluster head with higher energy shall be selected as the intermediate cluster head and data will be communicated to the base station through this cluster head [29, 34].
9. After the first communication is completed, the energies of the cluster heads come down and the energies may be another node is more than the cluster heads. In all odd-numbered clusters, the node with the second highest energies takes over as cluster heads [30, 35].
10. Again communications take place and after every round, the cluster head changes in the odd-numbered clusters changes.
11. After a few rounds when the energy of the cluster head of the even-numbered clusters gets exhausted, that is it reaches its threshold, the node with the subsequent uppermost energy takes over as CH and the process continues.
12. In this way communication takes place and data is transmitted from source to destination for a longer amount of time. Two different energy conservation techniques used in the two clusters are a unique point in this type of communication [31, 36].

4. SIMULATION RESULTS:

Simulation of this scenario with the proposed technique is implemented in NS2. Two ray ground propagation models are considered. Table 1 shows the Imitation Parameters For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. Each node has a threshold of 0.2 mJ. The number of active nodes, as well as their energy usage and network lifespan, are all 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.

Table 1: The Imitation Parameters

S. No.	Imitation Parameters	Standards
1	Total Number of Nodes	Hundred (100)
2	Parameters considered	Lifetime, energy consumption, and the number of alive nodes.
3	Type of the Channel	Wireless
4	Power (Receiving)	1mw
5	Power (Transmitting)	2mw
6	Size of each Packet	1000bits
7	Area in Meters	300m ×300m

The figures below offer a graphical representation of performance comparisons between the proposed and standing techniques based on numerous parameters. The lifetime comparison of nodes displays the contrast of the proposed technique with additional existing performances such as GA, PSO, and GWO as shown in Figure 6 below. It is detected that the recommended technique which runs for 595 sequences runs for the lengthiest time when associated with the present performances [32, 37]. The alive nodes comparison of the evaluation of the projected method with the present techniques with respect to the number of live nodes is shown in Figure 7 below. The exploration demonstrates that the lifetime of the proposed technique increased positively as compared to the proposed technique [33, 38]. Furthermore, the projected performance is better in relationships of efficiency with the existing works. The consumption of energy annotations for innumerable performances is contributed by Figure 8 below. The resulting graph designates that the projected technique consumes minimum energy in comparison with existing performances. Hence, a greater network lifetime can be achieved with the projected technique in comparison with the existing methods.

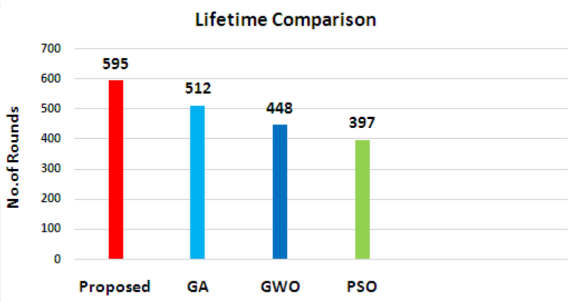


Figure 6: Lifetime Comparison

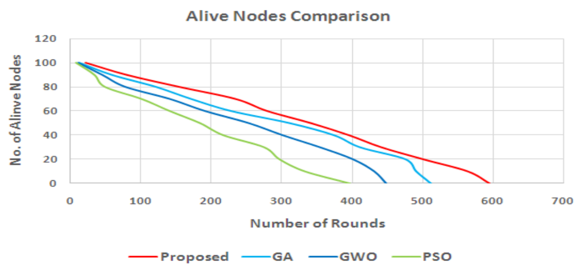


Figure 7: Alive Node Comparison

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
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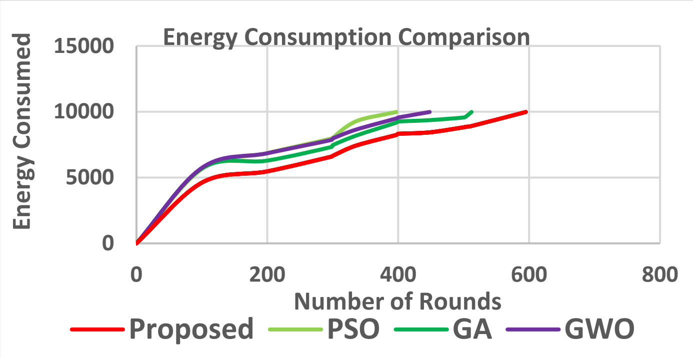

Figure 8: Energy Consumption Comparison

5. Conclusion and Future Scope:

5.1 Conclusion:

The design and implementation of the proposed work offer promising avenues to enhance both the network's lifetime and performance. This research has demonstrated that leveraging the residual energy levels of nodes as a key criterion for selecting cluster heads can lead to several significant benefits. The utilization of the node's residual energy promotes energy-efficient operations within the network. By choosing nodes with higher residual energy as cluster heads, the network can effectively distribute the energy load and mitigate premature energy depletion. This, in turn, prolongs the overall lifetime of the WSN. Furthermore, the proposed approach contributes to better network performance. Nodes with sufficient residual energy are more likely to maintain stable communication links, reducing the likelihood of packet loss, latency, and communication bottlenecks. This ultimately leads to improved data delivery, enhanced coverage, and reduced transmission delays, resulting in an overall more responsive and reliable network. Moreover, the design of the cluster head selection algorithm should strike a balance between energy considerations and other factors such as network topology, communication overhead, and data routing.

5.2 Future Scope:

By intelligently distributing energy resources and promoting efficient communication, this approach addresses critical challenges in WSNs and offers a pathway toward building more resilient, energy-efficient, and high-performing wireless sensor networks for a wide range of applications. Future research could explore further refinements to the algorithm, validation through extensive simulations and real-world experiments, and integration with other advanced techniques to unlock the full potential of WSNs in various domains.

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