

Energy-Efficient Sustainable Multi-hop Routing Protocol

Mr. M.Ramamohan reddy¹, D.Vinodini², N.Rajyalakshmi³, G.Poojitha⁴, B.Saipraveen⁵,

N.Venkata Reddy⁶

¹Associate Professor, Dept. Of ECE, PBR VITS, Kavali, Nellore District, Andhra Pradesh, India

²⁻⁵UG Students, Dept. Of ECE, PBR VITS, Kavali, Nellore District, Andhra Pradesh, India

Abstract - Wireless Sensor Networks (WSNs) demand routing strategies that are both energy-efficient and scalable in order to extend network lifetime under stringent power limitations. This work introduces EESMRP (Energy-Efficient Sustainable Multi-hop Routing Protocol), an improved cluster-based routing scheme that combines residual energy awareness, distance-oriented cluster head selection, and multi-hop inter-cluster communication. The proposed protocol is designed to balance energy usage, minimize the overhead of long-distance transmissions, and enhance overall network stability. In EESMRP, cluster heads are chosen through a weighted decision metric that accounts for node residual energy and proximity to the base station, while multi-hop forwarding between cluster heads reduces energy exhaustion in far-located nodes. Simulation outcomes reveal that the proposed approach delivers notable gains in network lifetime, throughput, and stability period when compared with conventional clustering methods. These results confirm that EESMRP is a reliable and scalable solution for energy-constrained WSN applications.

Key Words: *Wireless Sensor Networks, Energy Efficiency, Cluster-Based Routing, Multi-hop Communication, Network Lifetime, EESMRP.*

1. INTRODUCTION

Wireless Sensor Networks (WSNs) have emerged as a transformative technology enabling continuous monitoring and data collection across a wide range of environments. These networks consist of numerous small, low-cost sensor nodes that collaborate to sense, process, and transmit information to a central base station. Due to their flexibility and ease of deployment, WSNs have become integral to modern applications such as environmental monitoring, smart cities, industrial automation, and healthcare systems.

Among the various constraints in WSNs, energy limitation is the most critical issue. Most sensor nodes are powered by batteries that are difficult or impossible to replace once deployed. Communication operations typically consume far more energy than sensing or computation in WSNs. Frequent data transmissions can quickly drain node batteries, leading to network partitioning and reduced coverage. Therefore, designing energy-efficient routing protocols has become a primary research focus.

Cluster-based routing has gained widespread attention as an effective technique to improve energy efficiency in WSNs. In this approach, sensor nodes are

grouped into clusters and a cluster head is responsible for aggregating and forwarding data to the base station. By reducing redundant transmissions and enabling data aggregation, clustering helps conserve energy and improves overall network scalability. The present work introduces EESMRP which addresses these challenges through intelligent cluster head selection and multi-hop communication.

2. LITERATURE SURVEY

The development of energy-efficient routing protocols for Wireless Sensor Networks has been an active area of research. Several clustering-based approaches have been proposed to improve network lifetime and energy utilization. According to earlier studies, sensor nodes are typically battery-powered making energy consumption a critical concern. Research highlights that a significant portion of energy is consumed during data collection, processing, and transmission [1,2].

A. Naeem et al. proposed DARE-SEP which enhances the Stable Election Protocol by integrating both residual energy and distance awareness into cluster head selection. The protocol demonstrates improved stability period, longer network lifetime, and better throughput compared to conventional SEP-based approaches [1]. Similarly, A. Hossan and P. K. Choudhury introduced DE-SEP, an enhanced clustering protocol designed for heterogeneous WSNs that incorporates distance to the base station and residual energy into the cluster head election process to achieve more balanced energy consumption [2].

S. Singh presented a multilevel network model aimed at improving energy efficiency in heterogeneous WSNs through hierarchical organization of nodes to optimize data transmission and reduce communication overhead [3]. Furthermore, T. M. Behera et al. proposed a hybrid heterogeneous routing scheme combining clustering and multi-hop communication strategies to enhance data reliability and energy efficiency for WSN-based animal tracking applications [4]. These studies indicate that combining energy awareness with distance metrics significantly improves WSN performance and motivates the development of EESMRP.

3. EXISTING SYSTEM

The energy-sustainable cluster routing method organizes sensor nodes into clusters where each cluster elects a cluster head responsible for coordinating communication and forwarding aggregated data to the base station. Cluster head selection is based on residual energy probability where nodes with higher remaining energy get higher chance to become cluster head. The CH role is rotated periodically to ensure fair energy distribution across all nodes.

Member nodes transmit their sensed data to the nearest cluster head using single-hop communication. The cluster head performs data aggregation combining multiple packets into one and forwards directly to the base station. Transmission energy depends on distance using free space model for short distances and multipath model for long distances.

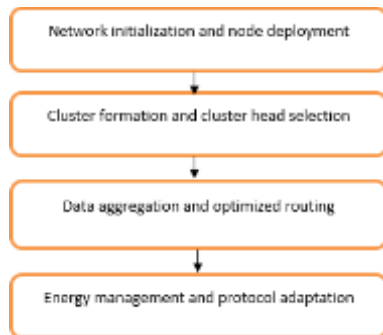


Fig 1: Flow of Existing Method

Limitations:

- ▶ Single-hop CH to BS causes high energy consumption for far nodes.
- ▶ Energy hole problem occurs near base station.
- ▶ Increased control overhead due to frequent cluster management.
- ▶ Sensitivity to parameter tuning reduces network adaptability.

4. PROPOSED SYSTEM

The Energy-Efficient Sustainable Multi-hop Routing Protocol (EESMRP) is developed to address persistent energy limitations in Wireless Sensor Networks. EESMRP introduces an energy-distance weighted cluster head selection mechanism that evaluates both residual energy and node proximity to the base station. The weighted CH selection formula gives 70% priority to residual energy and 30% to distance ensuring capable and strategically positioned nodes take leadership roles.

Multi-hop inter-cluster communication is the major enhancement of EESMRP. If a cluster head is more than 70 meters away from the base station, data is forwarded through the nearest relay cluster head instead of direct transmission. This significantly reduces long-distance transmission energy

and solves the energy hole problem by distributing forwarding responsibilities among multiple cluster heads.

Data aggregation at cluster head level combines multiple sensor packets into one single transmission reducing total number of packets sent to the base station. Periodic rotation of cluster heads distributes energy consumption fairly

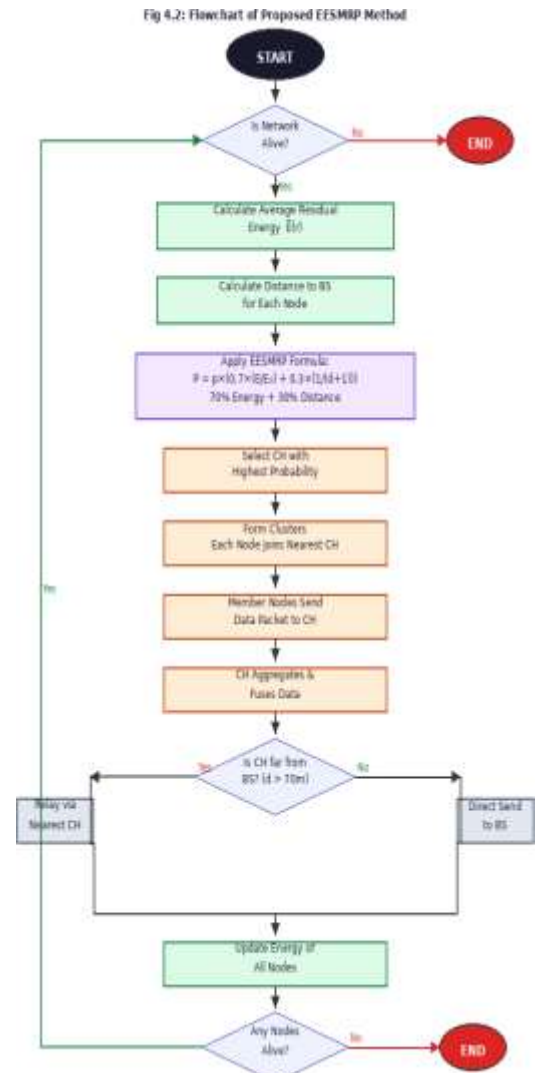


Fig 4.1: Flowchart of Proposed EESMRP Method

Fig 4.1 The flowchart shows the EESMRP method where the system first checks if the network is alive, then calculates residual energy and distance of nodes to the base station. Using a weighted formula (70% energy, 30% distance), the best node is selected as the cluster head. Nodes join the nearest CH, send data, and the CH aggregates it. If the CH is far from the base station, it uses multi-hop communication; otherwise, it sends data directly. Finally, energy is updated and the process repeats until all nodes die.

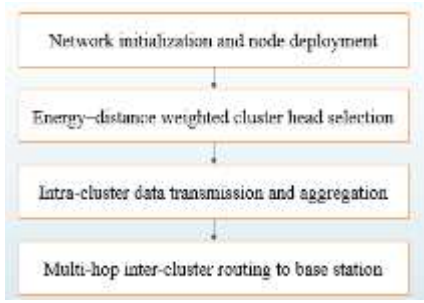


Fig 4.2: Flow Diagram of EESMRP

Fig 4.2 The EESMRP flow begins with node deployment and initialization, followed by cluster head selection based on energy and distance. Nodes then send data to their cluster head, where it is aggregated. Finally, multi-hop routing is used to transmit data to the base station, improving energy efficiency and network lifetime.

ADVANTAGES

- Enhanced scalability
- Improved energy hole mitigation
- Efficient data aggregation
- Increased network reliability

APPLICATIONS

- Industrial control
- Environmental monitoring,
- Military surveillance,
- Intelligent transportation systems and medical field.
- Furthermore, it can function independently in harsh or high-risk places where human presence is not possible
- Disaster relief operations.

5. RESULTS AND DISCUSSIONS

The simulation is implemented in MATLAB R2022b with 100 sensor nodes randomly deployed in a 100×100 meter field. Each node starts with 0.5 Joules of energy. Simulation runs for 2000 rounds comparing existing energy sustainable method with proposed EESMRP.

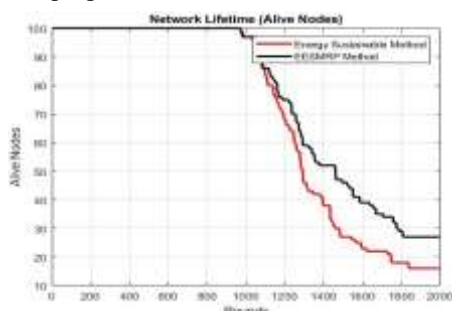


Fig 5.1 : Plot of Network Lifetime (Alive Nodes)

Fig 5.1 shows network lifetime comparison. EESMRP maintains more alive nodes for significantly longer duration due to balanced energy consumption through energy-distance weighted CH selection and multi-hop routing.

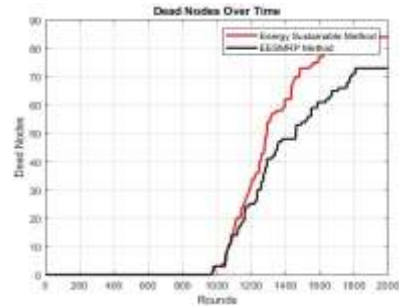


Fig 5.2: Plot of Dead Nodes

Fig 5.2 shows dead nodes comparison over 2000 rounds. EESMRP delays node death significantly by distributing energy consumption evenly through intelligent CH selection and multi-hop forwarding.

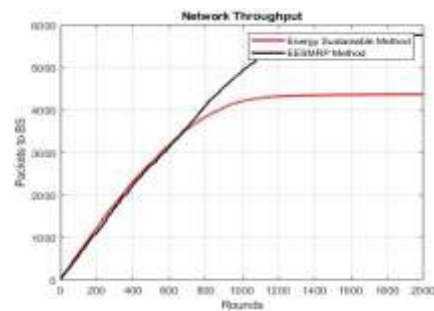


Fig 5.3: Plot of Network Throughput

Fig 5.3 shows cumulative throughput comparison. EESMRP delivers significantly more data packets to base station due to sustained node availability from energy-efficient routing decisions.

6. CONCLUSION AND FUTURESCOPE

The proposed EESMRP effectively addresses energy conservation in Wireless Sensor Networks by integrating residual energy awareness, distance-based cluster head selection, and multi-hop inter-cluster communication. The method achieves balanced energy utilization, reduces long-range transmission overhead, and enhances overall network stability. Simulation results confirm significant improvements in network lifetime, throughput, and node survivability compared to conventional clustering protocols. EESMRP provides a robust and scalable solution for energy-constrained WSN applications and offers a strong foundation for future intelligent and adaptive routing enhancements.

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