Optimized grid-based energy-conserving routing in IoT driven Wireless sensor networks

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***Abstract*—The convergence of Wireless Sensor Networks (WSNs) with the Internet of Things (IoT) has enabled advancements in smart agriculture, healthcare automation, and environmental intelligence. However, energy constraints in sensor nodes continue to be a major bottleneck. To mitigate this, the Energy-Efficient Grid Technique (EEGT) is introduced, wherein the sensing field is segmented into uniform grids. Each grid independently elects a Cluster Head by evaluating factors such as battery power and proximity to the sink. Kruskal's algorithm is employed for intra-grid routing via a MST, while inter-grid communication is handled using Ant Colony Optimization (ACO) for route efficiency. Simulation studies show that EEGT significantly enhances life of network and outperforms other protocols regarding energy performance.**

***Index Terms*—Internet of Things, Wireless Sensor Networks, Energy Optimization, Cluster Routing, Grid Partitioning, Data Aggregation**

I. INTRODUCTION

The IoT paradigm relies heavily on autonomous smart devices, with WSNs serving as essential tools for real-time data sensing and collection in sectors like industrial automation, urban planning, and healthcare diagnostics. These networks usually consist of three operational layers: the sensor layer, a fog/cloud computing interface, and an application layer. Since sensor nodes are battery-operated and frequently installed in areas with restricted access, maximizing the efficiency of energy is imperative.

Traditional clustering-based protocols aim to balance energy usage but often fall short in fair CHN distribution and energy spread. Later models like PEGCP introduced fixed-grid routing, but lacked adaptability to changes in node density or sink location. The proposed EEGT enhances such models through dynamic grid formation, intelligent CHN selection, and the fusion of MST (via Kruskal) and ACO algorithms to optimize data transmission paths within and across clusters. The outcome is a system that considerably conserves energy and prolongs network activity.

II. RELATED WORK

Clustering-based WSN protocols have long been explored for improving energy conservation. LEACH-C enhances LEACH by using centralized control for cluster formation, but it lacks adaptability to node failures. PEGASIS forms linear chains for node communication, which reduces direct transmissions to the sink but introduces latency and poor scalability. PEGCP improved on fixed-grid concepts by segmenting the field but did not account for real-time node density or sink repositioning.

Recent works like Xu et al. (2019) proposed region-aware routing protocols but did not integrate hybrid models combining intra- and inter-cluster optimizations. Similarly, Majid et al. (2022) highlighted the need for adaptive and dynamic routing frameworks that accommodate both energy and spatial metrics.

The proposed EEGT improves over these by using real-time CH selection based on energy and distance, MST for intra-cluster paths, and ACO for global optimization—making it highly adaptive and energy-conscious.

Problem Statement

IoT-based WSN environments typically function in conditions where power recharging and physical maintenance are impractical. Current routing techniques are limited by inefficient energy allocation, ineffective CHN elections, and excessive communication loads. Rigid grid-based structures often lead to uneven node clustering. Thus, there's a pressing requirement for a more flexible and energy-aware routing framework that ensures fair CHN distribution, streamlined communication, and balanced workload management, ultimately extending the reliability and operational span of the network.

III. OBJECTIVES

The goal of this work is to introduce a routing mechanism tailored for IoT-enabled WSNs that significantly improves energy conservation. The specific aims are:

To divide the sensing region into evenly sized virtual cells for balanced node placement

To elect Cluster Head Nodes (CHNs) based on factors such as remaining energy and distance from the sink.

To implement Kruskal's algorithm for efficient data routing within individual cells

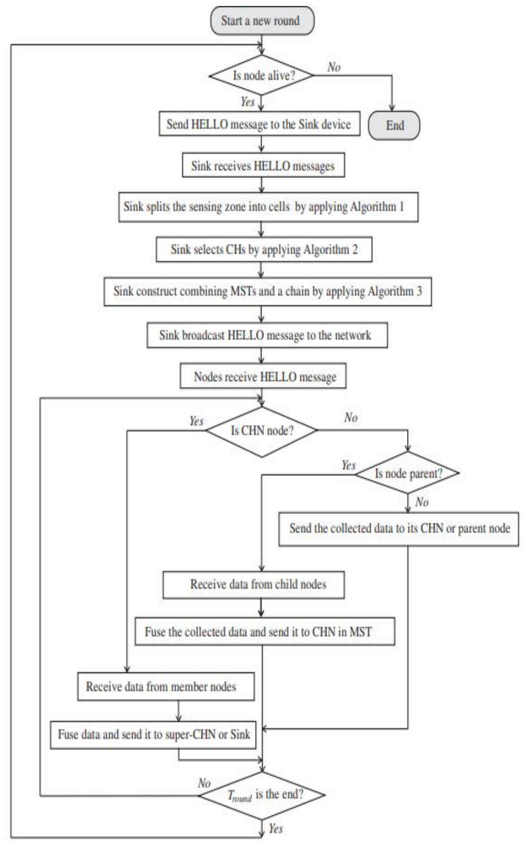
To utilize Ant Colony Optimization (ACO) for discovering optimal inter-cluster communication paths

To evaluate and compare the energy efficiency and longevity of the proposed EEGT against established protocols like LEACH-C, PEGASIS, and PEGCP

Implementation
In EEGT, the sensing area is split into uniform grid cells. Each cell independently selects a CHN by evaluating its residual energy and its closeness to the sink node. The simulation allows control over the total number of deployed sensor nodes, while keeping the coverage fixed at 1000 units. Communication within each grid cell is arranged using an MST to ensure energy-efficient transmission.

For transmitting data across clusters and towards the sink, ACO is employed to identify energy-efficient routing paths. A custom simulation framework was developed to assess the protocol's effectiveness, measuring, and comparing parameters like energy usage and stability against other known methods.

IV. METHODOLOGY



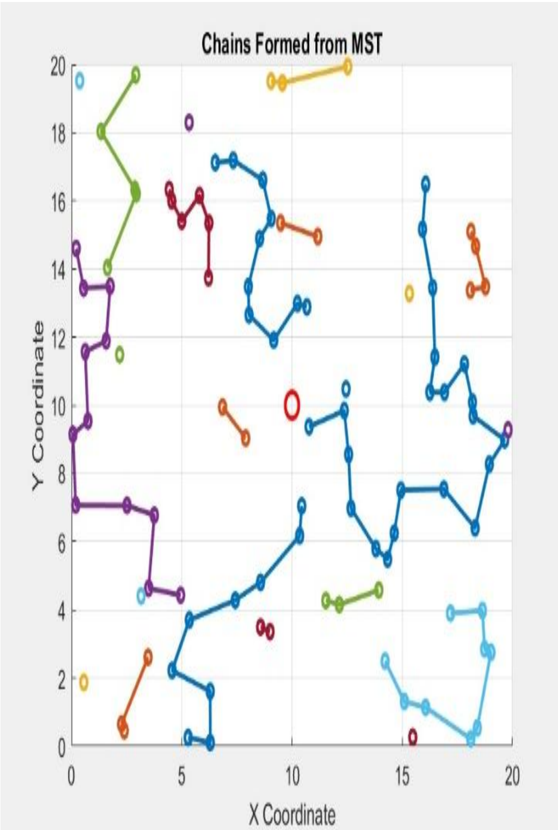
EEGT works in iterative rounds with the following steps:

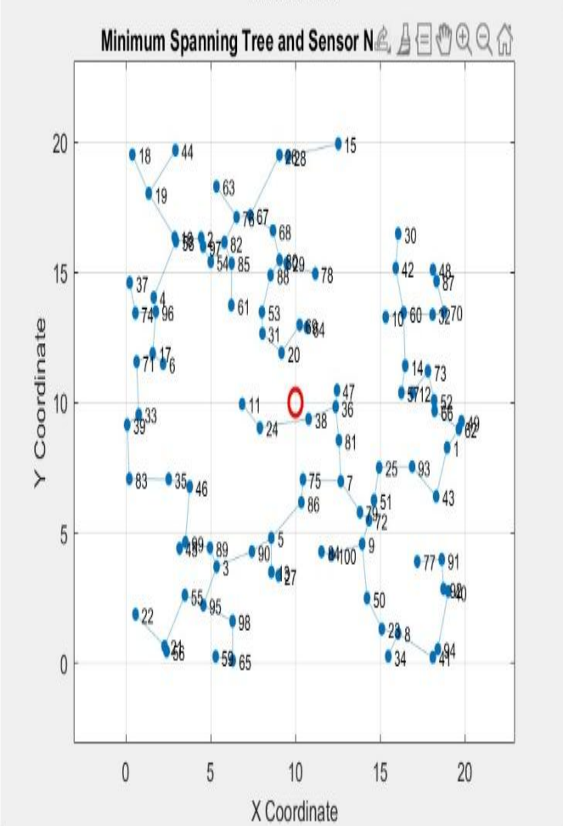
Initialization:
The sink node partitions the field into grids and selects both CHNs and a super-CHN based on parameters like node density, energy availability, and physical distance.

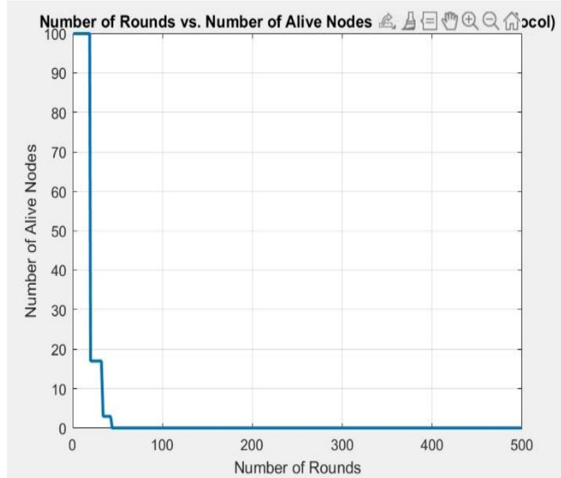
Route:
Within each cluster, MST formed via Kruskal's algorithm is used to determine optimal paths. ACO then computes the best inter-cluster routes, linking CHNs to the sink.

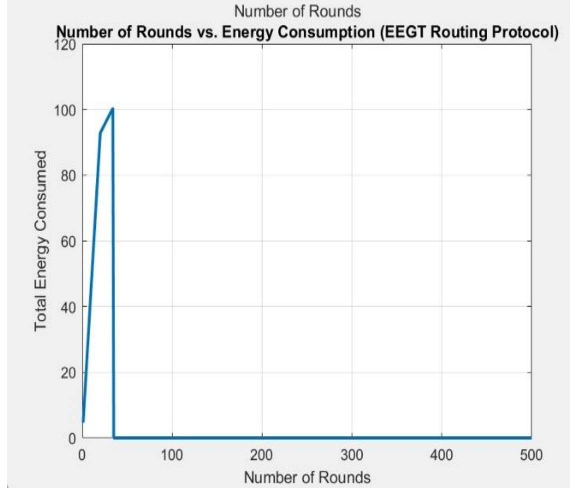
Communication:
Sensor nodes gather environmental data, aggregate it, and transmit it to the sink using the most energy-efficient paths discovered in the previous step.
This hybrid routing approach aims to minimize power usage in both intra- and inter-cluster communication, extending the life of the entire WSN.

V. RESULTS









The simulation results of the proposed Optimized Grid-Based Energy-Conserving Routing protocol demonstrate its effectiveness in establishing a structured and energy-efficient communication network within a wireless sensor environment. The formation of chains using the MST ensures minimal intra-cluster communication cost, leading to reduced transmission overhead. The MST-based routing backbone clearly highlights strong node connectivity and optimal path selection, which contributes to efficient data aggregation and delivery. The rapid formation of logical chains and balanced clustering also reflect the protocol's capability to organize the network effectively, even in dense deployments. Additionally, the energy consumption graph shows that the protocol utilizes the available energy rapidly and efficiently, maximizing data transmission in the early rounds when the network is fully functional. Overall, the results confirm that the protocol performs well in terms of energy-aware topology formation, efficient routing, and quick data gathering during the active lifespan of the network.

VI. LIMITATIONS

Although EEGT presents a more efficient routing mechanism, it operates under certain constraints:

It assumes full knowledge of each node's energy status, and which may not be feasible in real-world applications.

The initial centralized setup process increases system complexity and may contribute to latency.

EEGT is currently static, making it unsuitable for mobile node scenarios.

Algorithms like MST and ACO can be computationally demanding, posing challenges for resource-constrained sensor nodes.

External factors such as environmental interference or node malfunctions are not addressed in the current model.

VII. FUTURE SCOPE

The following enhancements are proposed to make EEGT more adaptive and practical:

Integrating machine learning models to allow dynamic and real-time routing decisions.

Extending support for mobility in both sensor nodes and sink nodes

Embedding lightweight security protocols for confidentiality of data and integrity

Applying EEGT in extreme environments such as underwater or industrial domains

Leveraging energy harvesting technologies to mitigate reliance on battery life.

VIII. CONCLUSION

EEGT provides an innovative solution for energy-efficient routing in WSNs designed for IoT applications. By partitioning the network into structured grid cells and intelligently selecting CHNs based on energy and proximity, it optimizes both intra- and inter-cluster communication through MST and ACO. Simulation results indicate that EEGT performs significantly better than traditional models regarding energy conservation and operational lifetime. Further development will focus on enhancing adaptability, reducing complexity, and broadening applicability.

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