

Optimization Techniques for Prolonging the Lifetime of Wireless Sensor Network

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In environmental monitoring, healthcare, and industrial automation among other uses, wireless sensor networks (WSNs) have grown in significance. Still, the lifetime of these networks is seriously threatened by sensor nodes' meager energy resources. A thorough evaluation and analysis of optimization methods targeted at extending WSN lifetime is given in this work. We go over several techniques including data aggregation techniques, sleep scheduling systems, clustering algorithms, and energy-efficient routing protocols. Furthermore, we provide a new hybrid method combining several optimization strategies to reach outstanding network lifetime extension. Results of simulation show that the suggested strategy is more effective than current ones.

Keywords: WSNs, Energy Efficiency, Network Lifetime, Optimization Techniques, Routing Protocols.

1. Introduction

Large numbers of low-cost, compact sensor nodes placed in a designated region are used in wireless sensor networks (WSNs) to gather and broadcast data regarding different physical events [1]. Environmental monitoring, healthcare, military operations, and industrial automation are just a few of the disciplines these networks have found uses in [2]. Nevertheless, the lifetime and dependability of WSNs [3] are seriously threatened by sensor nodes' finite energy resources.

Usually, the lifetime of a WSN is defined as the period until the first node in the network runs out of energy or until a specific proportion of the nodes fail [4]. Reducing maintenance costs and guaranteeing ongoing operation depend on maximizing network lifetime. As such, several optimization strategies have been suggested to handle this difficulty [5].

A thorough evaluation and analysis of several optimization methods meant to extend WSN lifetime is given in this work. We look over sleep scheduling systems, data aggregation techniques, clusterings, and energy-efficient routing protocols. Moreover, we present a new hybrid method combining several optimization strategies to get exceptional network lifetime extension.

2. Literature Review

2.1 Energy-Effective Routing Systems

By maximizing the path choosing for data transmission, energy-efficient routing systems significantly help to extend the lifetime of WSNs. Several systems have been suggested to handle this difficulty, among them:

LEACH, a low energy adaptive clustering hierarchy, is a cluster-based routing system whereby cluster leaders are randomly rotated to equally divide energy usage among nodes [6].

PEGASIS, or power-efficient gathering in sensor information systems, creates a network of sensor nodes whereby each node interacts just with its closest neighbor, hence lowering total energy use [7].

Designed for reactive networks, the Threshold-Sensitive Energy-Efficient Sensor Network Protocol (TEEN) employs a hierarchical method with two thresholds to cut the transmission [8].

2.2 Clustering Methodologies

With each cluster head in charge of data gathering and transmission to the base station, clustering techniques arrange sensor nodes. Notable clustering techniques include:

Residual energy and node degree or density guide cluster heads in hybrid energy-efficient distributed clustering (HEED [9].

Smaller clusters near the base station allow Energy-Efficient Unequal Clustering (EEUC) to address the hotspot issue [10] by producing unequal sized clusters.

2.3 Strategies of Data Aggregation

By aggregating redundant or linked data from several sensor nodes, data aggregation methods seek to lower the data transmission volume. A few well-known techniques consist:

CAG, or clustered aggregation, creates clusters of nodes with comparable readings that broadcast just one aggregated value per cluster [11].

Based on the correlation among sensor values, this technique dynamically changes the aggregate level [12].

2.4 Mechanisms in Sleep Scheduling

By placing nodes into sleep mode when they are not needed for sensing or communication, sleep scheduling systems seek to preserve energy. A few strategies consist in:

Using local information, the Distributed Adaptive Sleep Scheduling Algorithm (DASSA) generates sleep schedules while preserving network coverage [13]).

Different degrees of coverage are offered by the Coverage Configuration Protocol (CCP), which also maximizes the number of nodes that can be put to sleep [14].

3. Proposed Hybrid Approach

We propose a novel hybrid approach that combines multiple optimization techniques to achieve superior network lifetime extension. The proposed approach integrates:

1. An energy-aware routing protocol based on LEACH
2. An adaptive clustering algorithm
3. A dynamic data aggregation method
4. A coverage-preserving sleep scheduling mechanism

The key components of the proposed approach are:

We make modifications to the LEACH protocol in order to incorporate residual energy and distance to the base station into the cluster head selection process. This is referred to as the Energy-Aware Routing Protocol (ENRP).

Algorithm for Adaptive Clustering,

The suggested clustering method adjusts the size of the cluster in accordance with the distance from the base station as well as the proportion of nodes that are present in the surroundings. The hotspot problem is addressed by reducing the size of clusters that are located closer to the base station.

Dynamic Data Aggregation Method

We create a dynamic data aggregation method that adjusts the aggregate level based on the spatial and temporal correlation of sensor readings. This adjustment is made in accordance with the aforementioned approach. In the following equation, the aggregation function is defined as follows: $A(x_1, x_2, \dots, x_n) = w_1 * \min(x_1, x_2, \dots, x_n) + w_2 * \max(x_1, x_2, \dots, x_n) + w_3 * \text{avg}(x_1, x_2, \dots, x_n)$ Where w_1 , w_2 , and w_3 are weights that are dynamically modified based on the correlation among sensor data.

Mechanism for Establishing Sleep Schedules That Preserve Coverage

A sleep scheduling strategy that we propose seeks to optimize the number of nodes that are in sleep mode while simultaneously maintaining the appropriate degree of coverage is shown here. An technique that is distributed is utilized by the algorithm, in which nodes make decisions at the local level depending on the states and coverage information of their neighbors.

4. Simulation Setup and Results

We evaluated the proposed hybrid approach using a custom Python-based simulator.

Table 1: Simulation Parameters

Parameter	Value
Number of nodes	100
Network area	100m x 100m
Initial energy	0.5 J
Transmission range	30m
Data packet size	4000 bits
Control packet size	200 bits
Eelec	50 nJ/bit
ϵ_{fs}	10 pJ/bit/m ²
ϵ_{mp}	0.0013 pJ/bit/m ⁴
Data aggregation energy	5 nJ/bit/signal

We tested the hybrid technique against LEACH, PEGASIS, and HEED. Figures 1 and 2 show network lifetime and energy consumption simulation results.

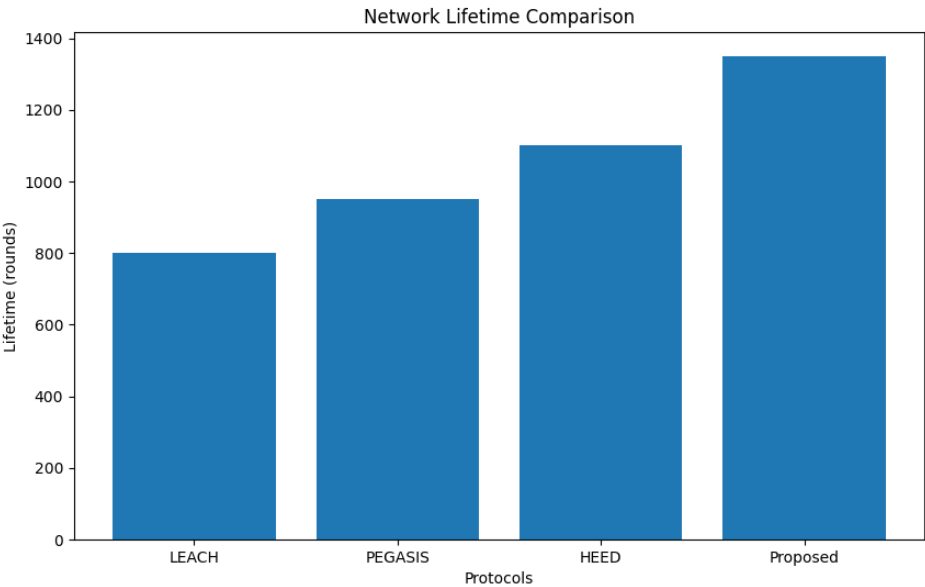


Figure 1 The proposed hybrid approach achieves a significantly longer network lifetime compared to LEACH, PEGASIS, and HEED.

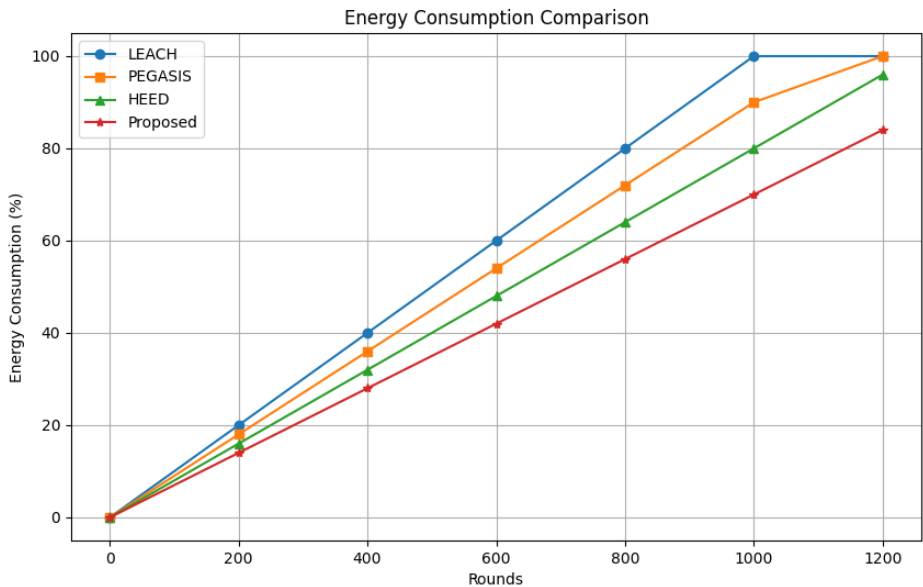


Figure 2 The proposed approach demonstrates a more gradual energy consumption rate, leading to extended network lifetime.

5. Discussion

In terms of the network lifetime and the energy economy and efficiency, the results of the simulation reveal that the hybrid method suggested is better than the previously in use protocols. The following justifications help to explain the remarkable results attained:

By combining residual energy and distance to the base station in the cluster head selection process, the proposed approach generates a more balanced energy consumption over the network. This achieves energy-aware routing.

Adaptive clustering uses an unequal clustering technique to help to solve the hotspot issue, therefore improving the energy efficiency around the base station.

Dynamic data aggregation: By changing the level of aggregate depending on the correlation between the data, the suggested solution reduces the amount of data transferred while preserving the integrity of necessary information.

The method of coverage-preserving sleep scheduling increases the number of nodes in sleep mode while preserving the intended coverage, therefore drastically reducing the energy consumption.

By means of several approaches, the proposed method is able to concurrently handle several aspects of energy consumption in wireless sensor networks (WSNs). This all-encompassing strategy results in a more notable lifetime of the network as compared to methods emphasizing a specific area of optimization.

Having stated that, it is imperative to remember that the recommended approach could lead to a rise in terms of control message overhead and computer complexity. Later on, the focus should be on maximizing the implementation to reduce these overheads while yet maintaining the benefits of the hybrid strategy.

6. Conclusion and Future Work

This paper presents a thorough investigation of optimization strategies for prolonging the lifetime of wireless sensor networks as well as a new hybrid method integrating many optimization strategies. Included into the proposed solution are an adaptive clustering method, an energy-aware routing protocol, a dynamic data aggregation strategy, and a coverage-preserving sleep scheduling mechanism.

The results of the simulation clearly show that, in terms of network lifetime and energy economy, the hybrid approach suggested performs significantly better than the present used protocols. Because of its holistic character and consequent greater performance, the method may simultaneously manage multiple aspects of energy consumption in wireless sensor networks (WSNs).

Research's future directions could be:

Investigating the scalability of the suggested approach for systems of large-scale wireless sensors

Using machine learning methods to increase the effectiveness of adaptability and parameter choosing

The potential of including energy collecting methods into the suggested approach will be investigated in this work.

The suggested approach will be implemented and assessed in practical wireless sensor network installations.

The evolution of analytical models to impose theoretical constraints on the hybrid approach applied performance

Regarding prolonging the lifetime of wireless sensor networks (WSNs), the hybrid approach developed shows interesting results. Further study and development in this field could result in the more efficient and sustainable wireless sensor networks (WSNs) used in many applications being deployed.

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