



Energy-Efficient Clustering and Routing in Wireless Sensor Networks Using Particle Swarm Optimization

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Abstract

Wireless Sensor Networks (WSNs) consist of numerous sensor nodes that communicate wirelessly to collect and transmit information from a monitored environment. Due to the limited battery capacity of sensor nodes and the difficulty of replacing or recharging batteries after deployment, energy consumption is a major factor affecting network lifetime. This paper presents an optimization-based clustering and routing approach for reducing energy consumption and extending the lifetime of homogeneous wireless sensor networks. The proposed approach dynamically modifies the probability of cluster-head selection using Particle Swarm Optimization (PSO). Cluster formation is combined with shortest-path routing between cluster heads to reduce unnecessary communication distances and distribute energy consumption more efficiently. The method was implemented and evaluated using MATLAB. The experimental configuration reported in the underlying paper uses 100 randomly distributed sensor nodes. The proposed method was compared with established approaches, including LEACH and Optimized Energy Efficient Routing Protocol (OEERP). The reported results indicate lower total energy consumption, higher throughput, higher packet delivery ratio, and longer network lifetime for the proposed method under the tested conditions.

Keywords: Wireless Sensor Networks; Particle Swarm Optimization; Energy Consumption; Clustering; Cluster Head Selection; LEACH; Network Lifetime; Routing.

1. Introduction

Wireless Sensor Networks (WSNs) are composed of small sensor nodes capable of sensing, processing, and transmitting information through wireless communication. They are used in environmental monitoring, healthcare, agriculture, industrial monitoring, security, and other applications. A major limitation of WSNs is the restricted energy available to sensor nodes. Because nodes may be deployed in locations where battery replacement or recharging is difficult, energy-efficient communication is essential for maintaining network operation.

Clustering is a common strategy for improving energy efficiency. Sensor nodes are divided into groups and one node in each group is selected as a Cluster Head (CH). Member nodes send data to their CH, which aggregates and forwards information toward the Base Station (BS). Inefficient CH selection can nevertheless produce unbalanced energy consumption.

The study underlying this paper addresses this issue by dynamically modifying the probability of cluster-head selection using Particle Swarm Optimization. The proposed method also applies shortest-path routing between

cluster heads. The objectives are to reduce total energy consumption, improve network lifetime, and enhance communication performance.

2. Related Work

The paper reviews a range of clustering and routing approaches for WSNs, including LEACH, unequal clustering, multihop routing, and energy-efficient clustering methods. LEACH is a classical probabilistic clustering protocol in which cluster heads are selected in a distributed manner. Although clustering can reduce communication overhead, random cluster-head selection may result in uneven energy consumption across the network.

3. Proposed Method

3.1 Network Model

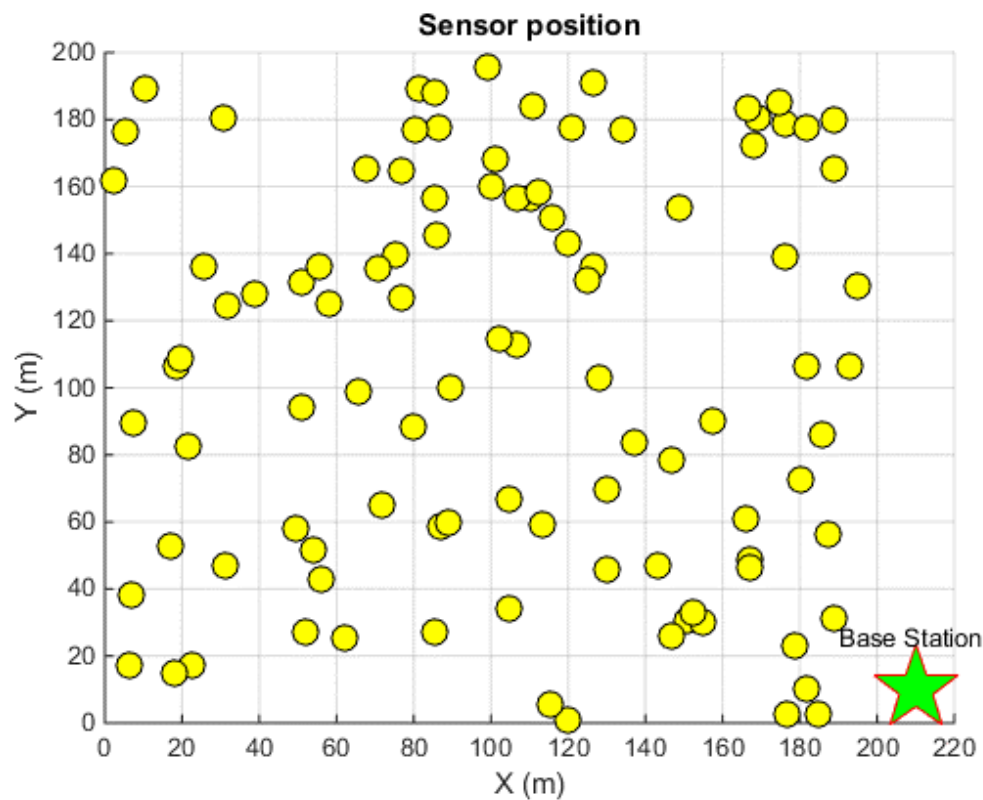


Figure 1 Sensor setup area

The proposed method considers a homogeneous WSN consisting of sensor nodes distributed within a predefined area. The network contains sensor nodes, cluster heads, wireless communication links, and a base station. The experimental setup reported in the paper uses 100 sensor nodes and MATLAB 2017a.

3.2 Energy-Efficient Clustering

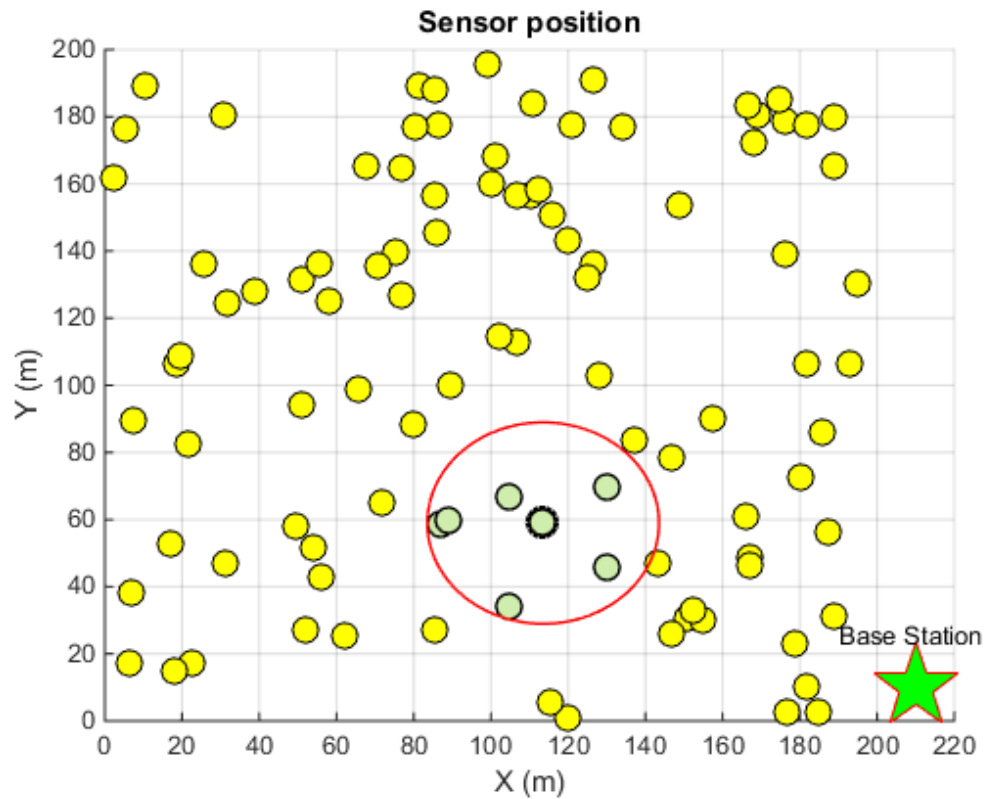


Figure 2. First cluster and cluster head

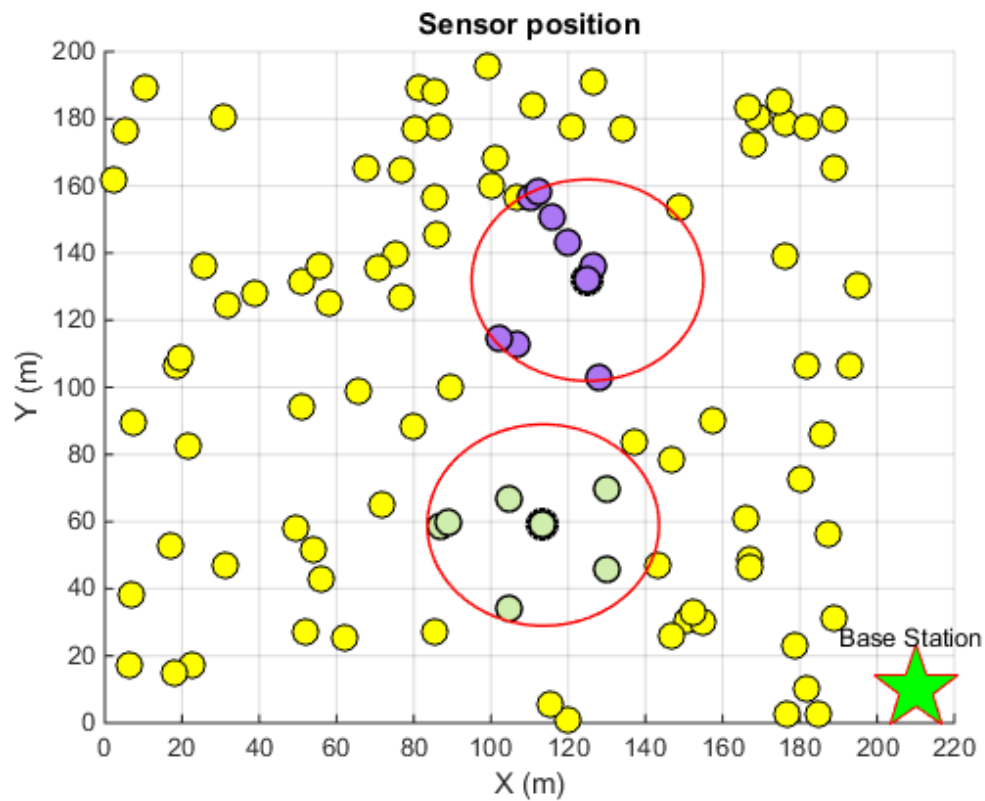


Figure 3. Second cluster and cluster head

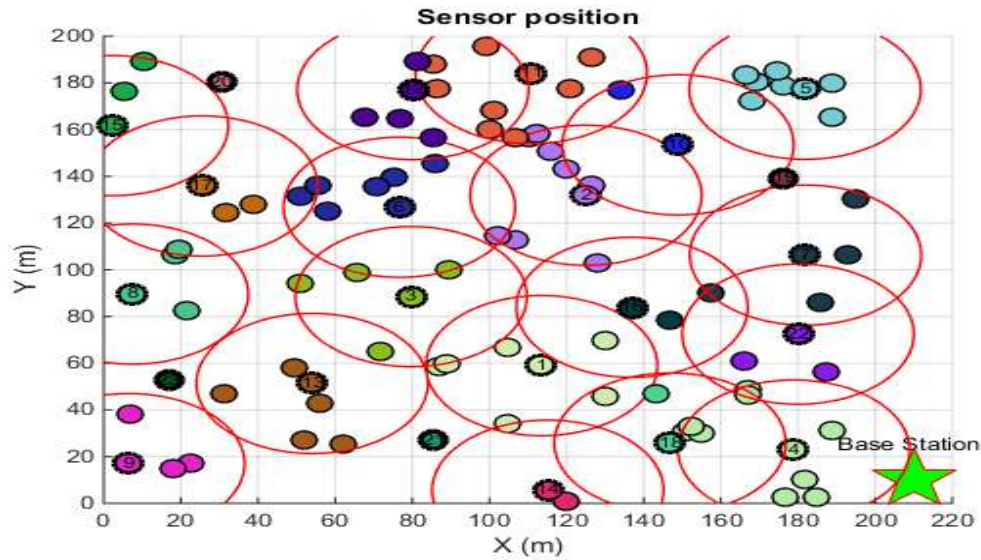


Figure 4. All cluster and cluster heads

The network is divided into clusters. Each cluster contains a cluster head and ordinary sensor nodes. Member nodes transmit sensed information to their cluster heads, which forward aggregated information toward the base station. The proposed method dynamically modifies the cluster-head selection probability to improve energy distribution.

3.3 Particle Swarm Optimization

PSO searches for improved candidate configurations by maintaining a population of particles. Each particle represents a candidate solution and is evaluated using a fitness function. Local-best and global-best solutions guide velocity and position updates. The implementation in the paper includes fitness calculation, local-best and global-best selection, velocity updating, and position updating.

3.4 Shortest-Path Routing

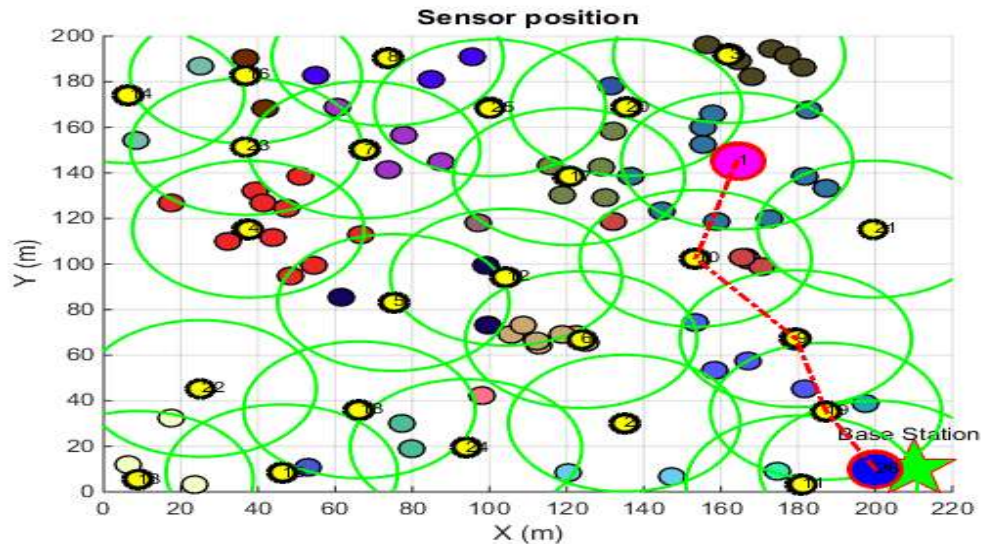


Figure 5. First routing in cluster-head sensor

After cluster formation, communication between cluster heads and the base station is optimized using shortest-path routing. The paper applies Dijkstra's algorithm to determine shortest paths. The routing stage is intended to reduce unnecessary communication distance and therefore reduce transmission energy.

4. Experimental Setup

The proposed method was implemented using MATLAB 2017a. The reported experiment uses 100 randomly distributed sensor nodes within a predefined network area. Cluster formation and cluster-head selection are performed before routing information toward the base station.

The main performance indicators are total energy consumption, throughput, packet delivery ratio, and overall network lifetime.

5. Results and Discussion

5.1 Total Energy Consumption

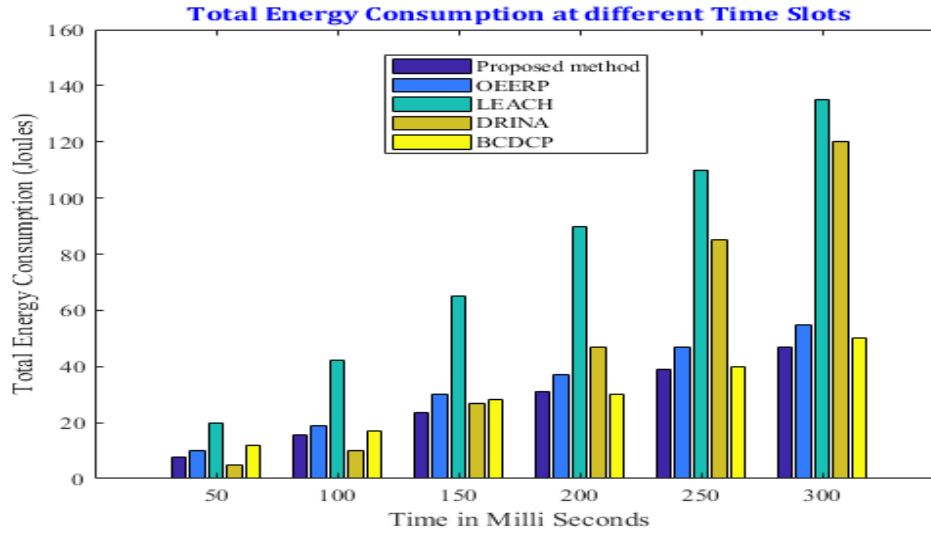


Figure 6. Total energy consumption at different time slots

The paper reports that the proposed method produced the lowest total energy consumption in the corresponding comparison. This result is attributed to the optimized cluster-head selection and shortest-path routing.

5.2 Throughput

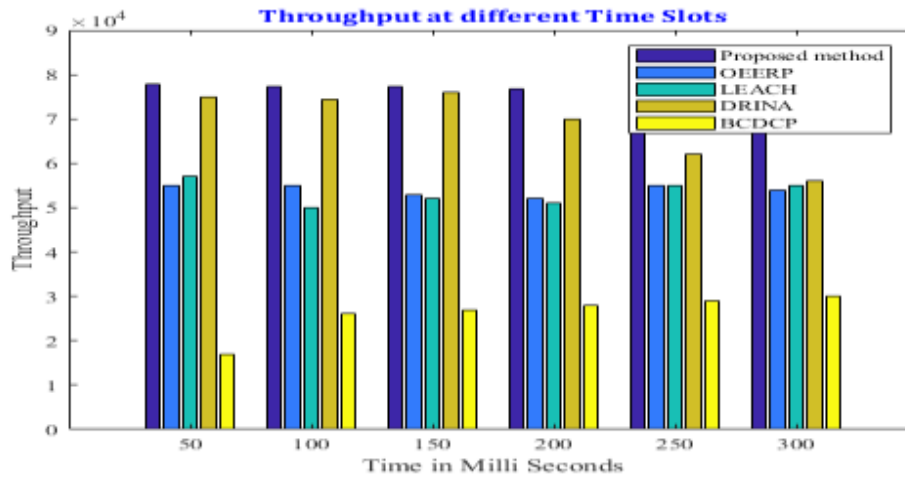


Figure 7. Throughput at different time slots

The reported experimental results indicate that the proposed method achieved the highest throughput among the compared methods, while BCDCP produced the lowest value in the reported comparison.

5.3 Packet Delivery Ratio

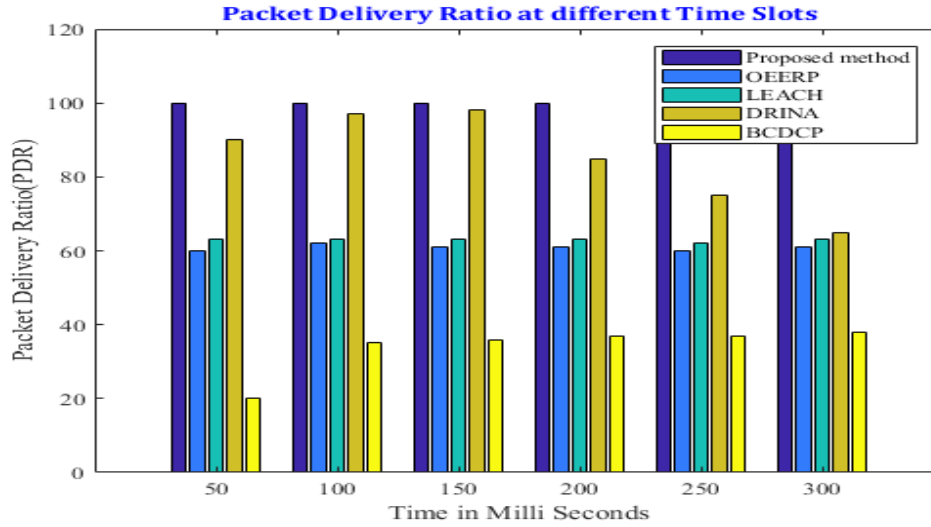


Figure 8. Packet delivery ratio at different time slots

The reported results indicate that the proposed method achieved the maximum packet delivery ratio among the compared methods. This indicates improved delivery performance under the tested simulation conditions.

5.4 Network Lifetime

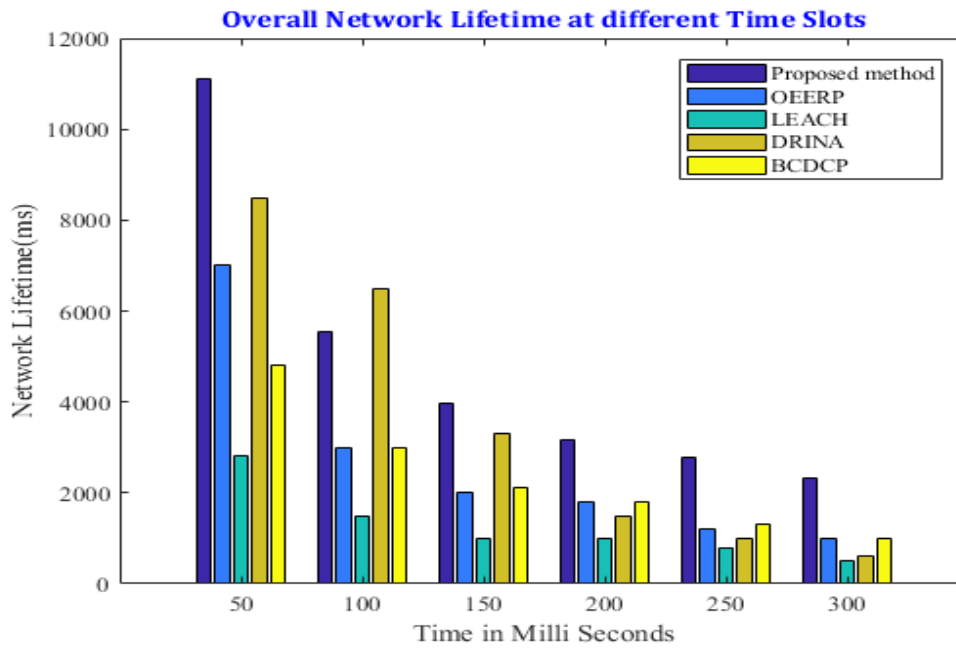


Figure 9. Overall network lifetime at different time slots

The paper reports that the proposed method achieved a higher overall network lifetime than the other compared methods. Because energy depletion is a major cause of network degradation, lower energy consumption contributes to maintaining network operation for a longer period.

5.5 Effect of Network Parameters

This paper discussion identifies network size, communication radius, sensing period, and routing strategy as factors affecting energy consumption. Increasing the number of nodes and communication distance can increase

energy expenditure. Longer sensing intervals can allow nodes to conserve energy, while shorter intervals can increase processing and transmission activity. The routing strategy also affects energy consumption because longer communication paths generally require more transmission energy.

6. Comparison with LEACH

LEACH uses probabilistic cluster-head selection. Its random selection mechanism can result in an uneven distribution of energy consumption. The proposed method addresses this issue by dynamically modifying the cluster-head selection probability using PSO. Under the experimental conditions reported in the paper, the proposed method showed lower energy consumption and longer network lifetime than the compared approaches, including LEACH.

7. Limitations

The reported evaluation is simulation-based and was implemented in MATLAB rather than through a physical WSN deployment. The experimental configuration also uses a specific network size and predefined simulation conditions.

Future evaluation should report numerical values for all performance indicators, repeat simulations to quantify variability, examine sensitivity to PSO parameters, and test different network sizes, node densities, base-station locations, and energy configurations.

8. Conclusion

This paper presented a PSO-based approach for energy-efficient clustering and routing in wireless sensor networks. The proposed method dynamically modifies cluster-head selection probability and combines optimized clustering with shortest-path routing. The reported simulation results indicate reduced total energy consumption, increased throughput, improved packet delivery ratio, and extended network lifetime compared with the evaluated approaches. The findings support further investigation of optimization-based cluster-head selection for energy-constrained WSNs.

Future work should investigate larger and heterogeneous networks, different base-station locations, dynamic deployment conditions, multi-objective optimization, and experimental validation using real sensor platforms.

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