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An Energy-Efficient Clustering Protocol for IoT-Based Wireless Sensor Networks

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ABSTRACT

Wireless sensor networks are the sensing backbone of many Internet-of-Things deployments, but the limited battery of each node makes energy efficiency the foremost design concern, since replacing batteries in the field is often impractical. Clustering, in which nodes elect cluster heads to aggregate and relay data, is a proven way to conserve energy, and the method of selecting cluster heads strongly affects network lifetime. This paper proposes an energy-efficient clustering protocol for IoT-based wireless sensor networks that selects cluster heads using both residual energy and distance to the base station, rotating the role to balance the load. The protocol was evaluated by simulation against the well-known LEACH and HEED protocols, with network lifetime as the principal measure. The proposed protocol extended the network lifetime substantially, delaying the death of the first node and keeping nodes alive for far more rounds than the baselines. The results show that energy- and distance-aware cluster-head selection markedly improves the longevity of wireless sensor networks, supporting more sustainable Internet-of-Things deployments.

KEYWORDS: *wireless sensor networks, energy efficiency, clustering protocol, Internet of Things, network lifetime, cluster head*

INTRODUCTION

Many Internet-of-Things systems rely on wireless sensor networks to gather data from the physical environment, from agriculture and industry to environmental monitoring. The sensor nodes are typically battery-powered and deployed where recharging is difficult, so the energy

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each node expends determines how long the network can operate (1). Prolonging network lifetime is therefore the central challenge in designing such networks (2).

Communication consumes most of a node's energy, and clustering reduces this cost by grouping nodes around elected cluster heads that aggregate data and communicate with the base station on the cluster's behalf. The choice of which nodes become cluster heads, and how often the role rotates, has a strong influence on how evenly energy is consumed and hence on lifetime (3). Poor selection drains some nodes prematurely, fragmenting the network.

This paper proposes a clustering protocol that selects cluster heads using both their residual energy and their distance to the base station, rotating the role to spread the burden. The protocol is evaluated by simulation against the established LEACH and HEED protocols, with network lifetime as the key metric (4).

LITERATURE REVIEW

Energy-efficient clustering has been studied intensively since the introduction of the LEACH protocol, which rotates cluster-head roles randomly. Subsequent protocols have refined the selection criteria to account for residual energy, node density, and distance, seeking to extend lifetime further (5).

Clustering Protocols for Sensor Networks

LEACH selects cluster heads probabilistically without regard to remaining energy, which can cause low-energy nodes to be chosen and fail early. Protocols such as HEED incorporate residual energy into the selection, and others add distance or density information; studies report that energy-aware selection consistently outperforms purely random rotation in terms of network lifetime (6).

- Communication dominates the energy consumption of sensor nodes.
- Random cluster-head selection can drain low-energy nodes prematurely.
- Energy-aware selection extends network lifetime over random rotation.
- Distance to the base station affects the cost of cluster-head communication.

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Even so, many protocols consider residual energy or distance alone, and direct comparison of a combined energy-and-distance criterion against both LEACH and HEED under the same conditions is less common (7).

RESEARCH GAP

Although energy-efficient clustering is well studied, protocols often base cluster-head selection on a single factor, and the benefit of jointly considering residual energy and distance to the base station is not always quantified against multiple established baselines. Reporting first-node-death and full-lifetime metrics together is also uncommon (8).

This study addresses the gap by proposing a combined energy-and-distance selection criterion and comparing it against LEACH and HEED on the same simulated network, reporting first-node death, half-node, and full-lifetime measures.

OBJECTIVES

- To design a clustering protocol using residual energy and distance for cluster-head selection.
- To rotate the cluster-head role to balance energy consumption across nodes.
- To evaluate the protocol by simulation against LEACH and HEED.
- To measure network lifetime through first-node-death and node-survival metrics.

METHODOLOGY

The protocol was evaluated in a simulated wireless sensor network in which nodes were distributed over a square field with a central base station. Each round comprised cluster formation followed by data transmission, and the simulation ran until the nodes were exhausted.

Network Model and Parameters

The simulation parameters are summarised in Table 1. Nodes began with equal energy and consumed energy according to a standard radio model for transmitting, receiving, and

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aggregating data. The base station was placed at the centre of the field, and performance was measured by the number of nodes remaining alive over successive rounds.

Table 1: Simulation parameters

Parameter	Value
Number of nodes	100
Network area	200 m × 200 m
Initial energy	0.5 J per node
Base station	Centre of the field
Packet size	4000 bits
Cluster-head selection	Energy- and distance-aware

Proposed Clustering Protocol

In each round, the protocol computed a selection score for every node that increased with its residual energy and decreased with its distance to the base station, so that nodes with more energy and better positions were preferred as cluster heads. The role rotated as energy was consumed, preventing any node from being repeatedly burdened, and non-head nodes joined the nearest cluster head to minimise their transmission cost.

RESULTS AND FINDINGS

The proposed protocol kept nodes alive for considerably longer than the baselines. The number of alive nodes over successive rounds for the three protocols is shown in Figure 2. The first-node-death, half-node, and full-lifetime rounds for each protocol are summarised in Table 2.

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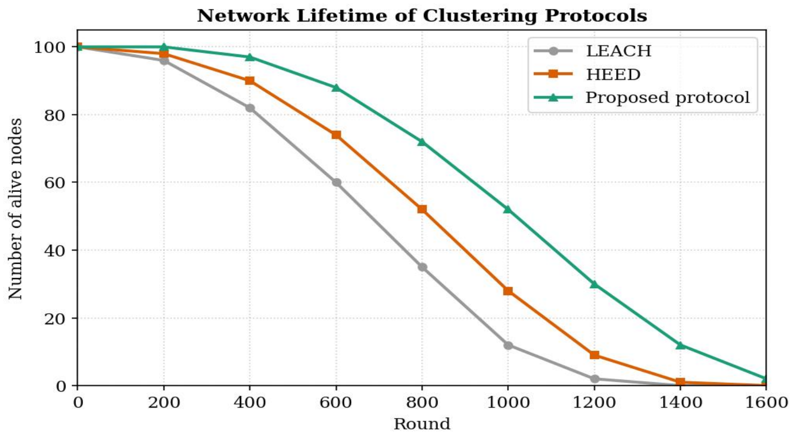

Figure 2: Number of alive nodes over rounds for the clustering protocols

As shown in Figure 2, the proposed protocol sustained a higher number of alive nodes across the simulation and the decline began later than for LEACH and HEED. As reported in Table 2, the first node death was delayed to round 690, compared with 410 for LEACH and 520 for HEED, and the network remained partially operational for substantially more rounds. These gains stem from preferentially selecting well-positioned, high-energy nodes as cluster heads and rotating the role to balance the load.

Table 2: Network lifetime comparison

Protocol	**First node death (round)**	**Half nodes alive (round)**	**Network lifetime (round)**
LEACH	410	720	1180
HEED	520	880	1340
Proposed	690	1120	1580

DISCUSSION

The improvement in lifetime confirms that the criterion used to select cluster heads is decisive for energy efficiency. By favouring nodes with more residual energy, the protocol avoided draining weak nodes, and by favouring nodes closer to the base station it reduced the energy spent on the costly cluster-head-to-base-station link. Rotating the role then prevented

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the same nodes from bearing the burden repeatedly, which is the weakness that random selection in LEACH does not address (9).

The delayed first-node death is particularly valuable, because the loss of the first nodes often marks the onset of coverage gaps in the monitored area. The protocol's reliance on knowing residual energy and position is a modest assumption in most deployments, where nodes can estimate both. Extending the approach to mobile nodes and to multi-hop communication between cluster heads and the base station are natural directions for further improvement (10).

LIMITATIONS

- The evaluation assumed static nodes and did not consider node mobility.
- Single-hop communication between cluster heads and the base station was assumed.
- Real radio effects such as interference and packet loss were idealised in the model.

FUTURE SCOPE

- Extending the protocol to networks with mobile sensor nodes.
- Introducing multi-hop communication among cluster heads to reduce long-range transmission.
- Incorporating realistic channel and interference models into the evaluation.
- Combining the protocol with energy harvesting to further prolong operation.

CONCLUSION

This paper proposed an energy-efficient clustering protocol for IoT-based wireless sensor networks that selects cluster heads using both residual energy and distance to the base station and rotates the role to balance energy consumption. In simulation, the protocol extended network lifetime well beyond the LEACH and HEED baselines, delaying the first node death to round 690 and keeping nodes alive far longer. The results show that energy- and distance-aware cluster-head selection markedly improves the longevity of wireless sensor networks for sustainable Internet-of-Things deployments.

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