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Research Topic: **Threshold Sensitive Scheme with Fuzzy based Clustering and Mobile Sink- An Energy Efficient Sensor Network Protocol**

Findings

Energy-efficient data transmission and communication is a critical research area in Wireless Sensor Networks (WSNs) as it directly influences the lifetime of the network. A common approach is to partition the WSN into clusters, with each cluster having a Cluster Head (CH) that aggregates and forwards data from its member nodes to the sink. However, as CHs perform additional tasks compared to member nodes, they experience faster energy depletion, creating what is widely known as the energy-hole problem. Addressing this problem is essential to enhance the stability and operational lifetime of WSNs.

To overcome this challenge, our research proposes a series of strategies based on mobile sink deployment, virtual grid formation, dynamic clustering, k-means optimization, and reinforcement-learning-driven aggregator selection. Collectively, these techniques aim to balance energy consumption, reduce control overhead, and improve data transmission efficiency in WSNs.

In the first phase, we present a clustering scheme with a mobile sink that reduces clustering cost and message exchanges. The network is divided into K virtual grid-based clusters of equal size, and a virtual backbone network is established by elected CHs. These CHs collect and transmit aggregated data to the mobile sink. As the sink moves along a predefined path inside the sensing field, only the backbone CHs update their routes to the sink's latest position, thus minimizing reconfiguration overhead. Additionally, a fuzzy inference system determines the update cycle length using three parameters: the CH's distance from the mobile sink, the average sensed data rate, and the residual energy of nodes. MATLAB simulations comparing our scheme with VGRSS and ODCM show significant improvements in terms of energy conservation, reduced control packet overhead, and extended network lifetime.

In the second phase, we address the limitations of conventional clustering algorithms, particularly the uneven distribution of CHs that causes imbalance in energy usage. To solve this, we propose a virtual grid and k-means-based clustering scheme with sink mobility integration. Traditional k-means algorithms initialize centroids randomly, often leading to imbalanced CH placement. In contrast, our method uses grid cell centroids as initial k-means centroids, ensuring balanced CH distribution across the entire sensing area. This bounded localization reduces communication cost, stabilizes the clustering process, and extends network lifetime. Extensive simulations against VGDR and GBK demonstrate superior performance of our approach in terms of energy consumption, cluster stability, and network scalability.

In the third phase, we focus on optimizing data aggregation, as CHs rapidly deplete their energy while aggregating and transmitting data. We propose a fuzzy reinforcement-learning (FRL) mechanism to select aggregator nodes in addition to CHs. After initial CH election and grid formation, an aggregator node is chosen in each cluster based on three key parameters: distance, neighborhood overlap (NOVER), and algebraic connectivity (AC). This dual-role structure of CHs and aggregator nodes, combined with the predefined mobile sink path, ensures efficient routing and data collection. The performance is evaluated using comprehensive metrics, including energy consumption, network lifetime, throughput, latency, end-to-end delay, packet loss ratio (PLR), and packet delivery ratio (PDR). Comparative analysis with GCFRS-RL, FR-EEDG, and TCBDGA shows that our FRL-based approach significantly outperforms these schemes, achieving better energy efficiency, lower delay, and higher delivery ratios.

Collectively, these three contributions create a comprehensive and adaptive framework that effectively addresses the key challenges of WSNs: limited energy, data redundancy, and dynamic topology caused by sink mobility. The combination of virtual grid-based clustering, k-means balanced CH selection, reinforcement learning-driven aggregator selection, and fuzzy logic-based update cycles ensures optimized energy utilization at each stage of network operation. Periodic CH rotation, balanced CH placement across grid cells, and intelligent aggregator selection further contribute to longer and more stable network lifetimes.

The proposed framework has been validated extensively through MATLAB simulations, demonstrating substantial improvements in energy conservation, control overhead reduction, throughput, and reliability compared to existing state-of-the-art algorithms. Its adaptability, scalability, and robustness make it highly suitable for real-world WSN applications, particularly in environments where node replacement or recharging is impractical, and prolonged network operation is essential.

Keywords: Virtual grid, Data aggregation, WSN, Energy efficiency, Mobile sink