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Node Status Information Maintenance Strategy in Centralized Cluster-based WSNs

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Abstract

Wireless sensor networks (WSNs) have been widely applied in various fields due to their good ability to manage a large number of sensor nodes in a self-organizing manner for continuous monitoring of various targets. Compared to distributed clustering protocols, centralized clustering protocols offer much higher task execution quality since the control center has the global information about the network. However, maintaining network status information in centralized clustering protocols is a tough challenge, and researchers have proposed various methods to reduce the cost of maintaining node status information. In this paper, we first introduce the classification of centralized network status information maintenance strategies, and then we illustrate the representative protocols for each category.

Keywords

Wireless Sensor Network; Network Status; Centralized Clustering; Maintenance Strategy.

1. Introduction

Wireless Sensor Networks (WSNs), as highly distributed network systems, have demonstrated immense potential in various fields such as environmental monitoring, smart homes, health care, and military reconnaissance [1-3]. These networks consist of a large number of autonomous sensor nodes that are responsible for collecting, processing, and transmitting data on environmental or physical phenomena. A sample WSN is illustrated in Figure 1. However, since sensor nodes are typically limited by battery power, maintaining the long-term stable operation of the network has become an urgent issue to address.

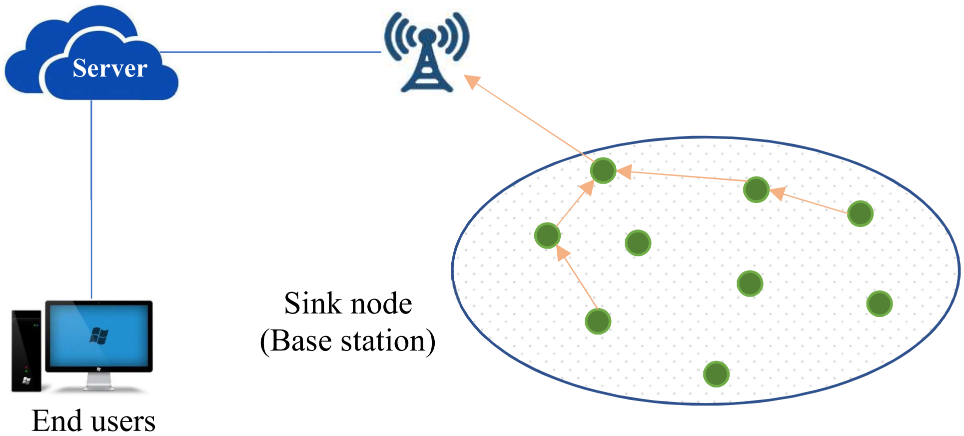

Figure 1. A sample wireless sensor network

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Among the various energy-saving technologies [4-6] in wireless sensor networks, centralized clustering protocols have emerged as one of the most popular and effective methods for energy conservation. Centralized clustering protocols organize the nodes in the network into multiple clusters, with each cluster having one or more cluster heads to manage the network effectively. The cluster heads coordinate communication and data fusion within the cluster, as well as interactions with the base station or other cluster heads. This approach not only helps to reduce unnecessary data transmission and lower energy consumption but also improves the efficiency of data transmission and the scalability of the network. Additionally, there exists a control center in such networks, which possesses the status information of the entire network and is responsible for executing energy-sensitive tasks in the network.

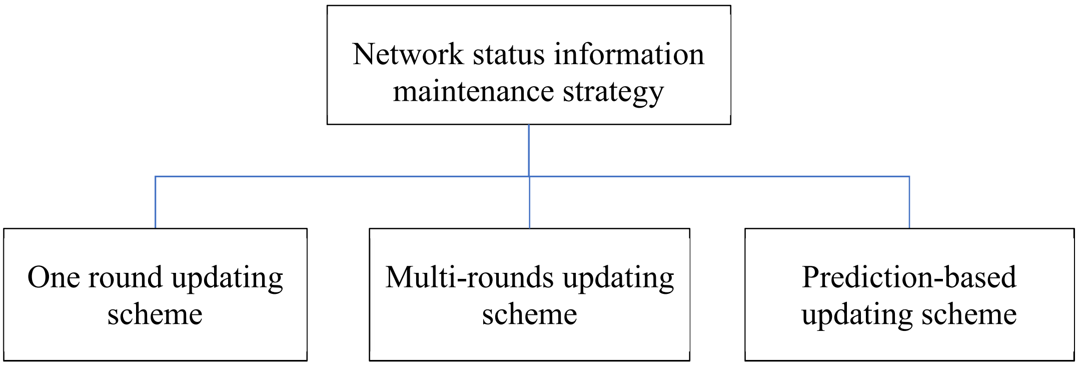

Figure 2. Classification of node status information maintenance strategies

To achieve high task execution efficiency for the centralized control center, it is essential that the maintenance of network status information is energy-efficient. In this paper, we will summarize the classification of node status information maintenance strategies, which is illustrated in Figure 2, in existing centralized clustering protocols, thereby providing guidance for the design of future centralized clustering protocols.

2. One Round Updating Scheme

The LEACH protocol [7] is one of the pioneering clustering protocols, which elects cluster heads through a randomized process. Each node becomes a cluster head based on a given probability, which is related to the node's remaining energy and the number of cluster heads already elected in the network. During the data transmission process, ordinary nodes send the collected data to the cluster head of their respective cluster. The cluster head is responsible for receiving and aggregating this data, and then transmitting the aggregated data to the base station. In order to improve the data transmission process and the selection of cluster heads in the network, the aruthors propose a new optimized LEACH-C protocol. In the above protocol, the base station is responsible for monitoring and managing the entire network, including the election of cluster heads and the routing of data. To obtain accurate information about the remaining energy of nodes, the base station receives energy update messages from every node at each round. During the cluster head election process, the energy level, location, and historical election records of nodes are taken into consideration to ensure balanced energy consumption. However, in order to maintain the quality of cluster head elections and data routing computations, the base station must receive energy update information from each node at every round, which can result in higher network maintenance costs.

In the BCDCP protocol [8], the base station is responsible for supervising and managing the election of cluster heads, ensuring that every node in the network has the opportunity to become a cluster head, thereby achieving energy consumption balance. Additionally, the base station may adjust the rules for cluster head election based on the energy levels, locations, and historical performance of the nodes.

In terms of data transmission, the base station is responsible for assigning priorities to data packets and monitoring the energy consumption within the network. It can adjust the priorities of data packets based on their importance and urgency, ensuring that critical data is given priority. To ensure the quality of tasks executed by the base station, each node reports its energy status to the base station at each round.

The protocol in [9] assumes the presence of a central sink (base station) that has global knowledge of the network, including the location, energy levels, and communication capabilities of all sensor nodes. This central control is responsible for managing the entire clustering process and optimizing the network's energy efficiency. The protocol dynamically elects cluster heads based on the optimization results from the GA. This adaptive election process aims to distribute the energy load evenly among the nodes, thereby preventing hotspots and extending the network's overall lifetime. Similar to the above protocols, every node in the network also updates its status information in the base station at each round.

3. Multiple Rounds Updating Scheme

Base on the Type-2 Fuzzy system [10], the base station selects the most appropriate nodes to act as cluster heads with consideration of their energy levels, distances, and other potential metrics such as communication capabilities or historical performance. Moreover, the base station utilizes an optimization model to determine the optimal cluster head election strategy and communication routes between nodes. This model takes into account minimizing the overall energy consumption of the network, maximizing the coverage area for data collection, or ensuring the reliability of data transmission. To maintain energy balance, the algorithm initiates a new cluster head election process when the energy consumption of a cluster head is nearing a certain threshold, or it may reassign tasks of data collection and transmission among nodes within the cluster. To save the costs of node energy information collection and cluster head re-selection, each cluster head in the network takes their roles for several rounds.

The author in [11] adopted a novel cluster head election mechanism that takes into account the residual energy of nodes and the distance between them and the base station. This election method aims to ensure an even distribution of energy consumption across the network, thereby preventing the formation of energy holes. To further optimize energy consumption, the protocol employs a centralized clustering algorithm to determine the best path for data transmission. This includes the use of multi-hop routing and avoiding data transmission through nodes with high energy consumption. Performance evaluation results show that compared to traditional routing protocols, this energy-aware routing protocol has significant improvements in terms of energy consumption, latency, and network lifetime. To reduce the overhead of maintaining node status information at the base station, nodes send their status information once every 5 rounds.

Researchers in [12] introduced a centralized cluster-based routing approach, which is executed by the base station, for WSNs that leverages the Grey Wolf Optimizer (GWO) to enhance energy efficiency. The procedure of the above proposed scheme is as follows: (1) Initialization: The algorithm begins by randomly generating a population of wolves, where each wolf represents a potential solution; (2) Fitness Evaluation: Each wolf's fitness is assessed, which represents the quality of their solution as a routing path. The fitness function considers factors such as energy consumption, latency, and reliability of the routing path; (3) Update α, β, and δ wolves: Based on the fitness evaluation, the current best wolf (α), the second best (β), and the third best (δ) are identified; (4) Search and Update: Other wolves update their positions based on the positions of the α, β, and δ wolves, simulating the pack's hunting behavior. This process involves mathematical calculations where wolves adjust their search direction and step size based on the positions of α, β, and δ, their current position, and random factors; (5) Repeat Steps (2)-(4) until obtain the optimal solusion: The algorithm iteratively updates the positions of the wolves, continually improving the solutions until the stopping criteria are met, such as reaching a predetermined number of iterations or when fitness improvements become negligible. To reduce the centralized network status information maintenance cost, the same clustering setting is often used for several rounds.

4. Prediction-based Updating Scheme

In most existing clustering protocols, clusters are formed without considering the positional distribution of query targets, and the procedures of cluster head selection and inter-cluster routing are performed in a distributed way, which is energy-consuming. To resovle the above issues, the researchers in [13] propsed LEDC protocol. In the raised protocol, the dynamic cluster is formed according to the user queries at each round, and after the data transmission is over, and the dynamic clusters are completed. The responsibilities of the base station inlude node clustering, cluster head selection and data routing among clusters. So as to minimize the centralized node status information maintenance overhead, the base station employs the node residual energy prediction method. Compared with the one round updating and multiple rounds updating schemes, the overhead of maintenance cost is greatly reduced, and the network scalability is also highly improved.

5. Conclusion

Nowadays, clustering protocols have become one of the most popular strategies to save energy in wireless sensor networks. Also, the centralized clustering protocols have better performance compared with their distributed counterpart. How to effective maintain the node status information in control center is a challenging task. In this paper, we classify the strategies of maintaining the node status information in the network, and also present the each calssical protocol in each calssification.

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