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Improving Energy Efficiency of Clustering-based WSNs with Efficient Energy Load Balancing Schemes

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Abstract

With the rapid development of wireless communication technology and the increasing demand for smart cities, wireless sensor networks (WSNs) have been widely used in all aspects of our lives and work. Since the energy resources of each sensor node in a wireless sensor network are often limited and it is also difficult to replace the power unit of these sensors, it is very important to save and balance the energy of each node in the sensor network. In wireless sensor networks, clustering protocols have been proven as one of the most effective methods to save energy. In clustering-based wireless sensor networks, nodes are divided into two categories: cluster heads and cluster member nodes. Cluster heads take more responsibilities compared to other nodes, and thus, cluster heads are prone to die earlier. In order to save as well as balance the energy among different nodes, researchers have proposed various energy load balancing schemes. In this paper, we first describe the classification of energy balancing schemes and then discuss how these schemes achieve energy saving as well as energy consumption balancing among nodes.

Keywords

Wireless Sensor Network; Energy Consumption; Balancing Scheme; Clustering Protocol.

1. Introduction

With rapid construction of smart cities [1,2,3] around the world, wireless sensor networks (WSNs) have become widely used to monitor the environment, traffic, and infrastructure so as to gather data for analysis. WSNs usually consist of a large number of small sensor nodes, and each sensor node has limited sensing ability, computing storage and communication capability. During the runtime of a wireless sensor network, when a sensor node generates data, its data is transmitted to the base station through the relay of other sensor nodes, and finally reaches the right cloud server. A sample WSN is shown in Figure 1. When the energy of a sensor node is exhausted, it is difficult to replace the battery with a new one in many cases, and then, the end-users will not be able to detect the monitoring area where the node is located, therefore, we hope that the energy consumption of the nodes in WSN is as low as possible and also balanced.

In order to reduce the energy consumption of nodes in wireless sensor networks, researchers have proposed various methods such as energy-aware routing [4,5], data compression [6,7], spatio-temporal correlation [8,9,10] techniques, etc., among them, clustering protocols have become one of the most popular and effective methods to save energy. In clustering protocols, the nodes in the entire WSN are partitioned into a number of clusters based on their different locations. In each cluster, one node is selected as cluster head, and other nodes are labeled as cluster members. During monitoring

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data transmission, the cluster head collects monitoring data from other nodes in its cluster and calculates the best route, and then, it send the data to the base station. Since the workload of cluster heads is much higher than other nodes, the cluster heads are more prone to early death. In order to make the wireless sensor network have long lifetime, the energy load balancing scheme between the cluster head and other nodes has to be designed.

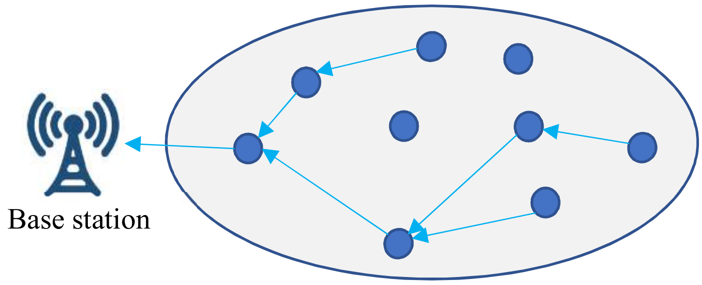

Figure 1. A sample of wireless sensor network

In this paper, we focus on the techniques used to balance the energy consumption of cluster heads with other nodes in clustering protocols. Section 2 classifies the energy load balancing schemes into two categories: round-based global clustering and combining global clustering with CH-rotation. Then, we illustrate the representative protocols in the above two categories in Section 3. Finally, we conclude the paper in Section 4.

2. Classification of Energy Load Balancing Schemes

The function of wireless sensor networks is to collect data from the monitoring area and transmit it to the end users, however, clustering protocols make the energy load among nodes unbalanced, which leads to the premature death of some nodes in the network. In order to balance the energy load balance among nodes, researchers have proposed different approaches which can be classified into two categories: global clustering and combining global clustering with CH-rotation, which is illustrated in Figure 2.

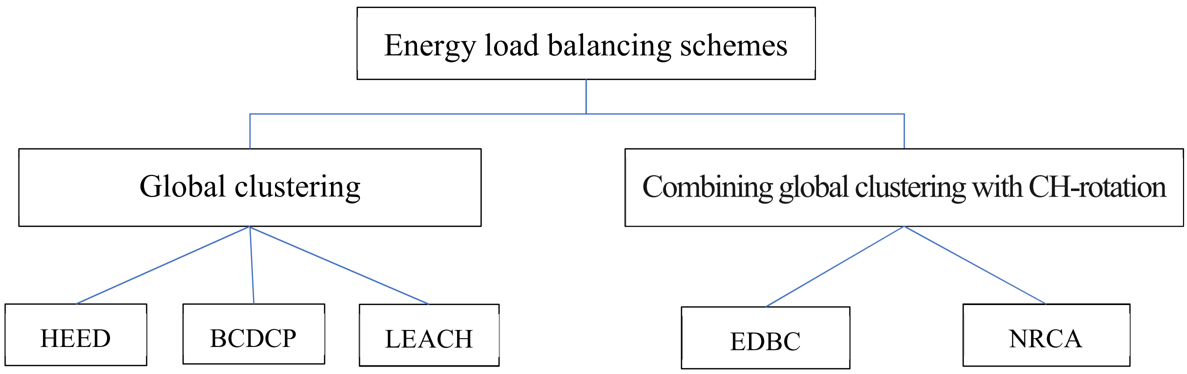

Figure 2. Classification of energy load balancing schemes in clustering-based WSNs

3. Global Clustering Scheme

Global clustering has been widely used to balance nodes' energy in WSNs. LEACH [11] is one of pioneering clustering protocols, in such network, each node has an equal opportunity to become a cluster head. Nodes communicate with neighboring nodes to determine if any of them have already become cluster heads and decide whether to become a cluster head based on a certain probability. This round-robin mechanism ensures that all nodes have a chance to become cluster heads, thereby

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distributing the energy consumption. LEACH protocol achieves energy consumption balance by dynamically adjusting the probability of being a cluster head. After each round, the cluster heads broadcast their remaining energy information to the other nodes. Other nodes adjust their probability of becoming a cluster head in the next round based on the energy information of the cluster heads. Nodes with more residual energy have a higher probability of becoming cluster heads, thus achieving energy consumption balance.

Compared to LEACH, in HEED [12] protocol, each node calculates a relative energy value based on its own energy level and the energy levels of its neighboring nodes. This relative energy value represents the node's energy ranking in the entire network. Nodes broadcast their relative energy values to other nodes, enabling each node to obtain its energy level in the network. Using the relative energy value, each node can calculate a probability indicating the likelihood of becoming a cluster head. The probability of a node choosing to become a cluster head is proportional to its relative energy value, with nodes having higher energy levels having a higher probability of becoming cluster heads. This mechanism encourages nodes with low energy levels to become ordinary nodes, while nodes with more remaining energy are more likely to become cluster heads. Through this probability-based selection mechanism, energy distribution is balanced throughout the network. To further balance energy consumption, HEED protocol mandates that cluster heads must switch after a certain time interval. Cluster heads broadcast their energy information to other nodes, and based on this information, other nodes recalculate their probability of becoming cluster heads. This ensures that nodes with higher energy levels have a higher probability of becoming cluster heads, thus achieving energy consumption balance.

In BCDCP [13], the base station (BS) is responsible for selecting the cluster heads. The cluster heads are responsible for aggregating data from other nodes and transmitting it to the base station. The BS selects nodes with higher energy levels and closer proximity to the BS as cluster heads based on factors such as node energy and the distance between this node and the BS. This increases the probability of nodes with higher energy levels becoming cluster heads. Furthermore, the BCDCP protocol introduces a mechanism for dynamically adjusting the cluster heads. After each round, the BS broadcasts the energy information of the current cluster heads to all nodes. Nodes calculate their probability of becoming a cluster head based on the received energy information. Nodes with higher energy levels have a higher probability of becoming a cluster head. This increases the likelihood of nodes with higher energy levels becoming cluster heads, thereby achieving energy consumption balance.

4. Combining Global Clustering with CH-Rotation

Considering that the global clustering mechanism is costly, in order to significantly reduce the cost of the energy balancing process among nodes, researchers have proposed a new approach that integrates global clustering with local cluster head rotation. In this approach, the role of the cluster head is rotated only among the nodes within the local area, such as in the local cluster. When certain conditions are met, the global clustering is initiated, thereby achieving energy balance among the nodes in the entire network.

In EDBC [14], nodes communicate with neighboring nodes to obtain information about energy levels and distances. Then, based on their own energy level and distance to the base station, nodes calculate an energy metric. After that, nodes broadcast the energy metric to the surrounding nodes, allowing each node to know its energy level relative to other nodes. Based on the energy metric, nodes calculate a probability indicating the likelihood of becoming a cluster head. Nodes with higher energy levels have a higher probability of becoming a cluster head. Through this probability-based selection mechanism, energy distribution is balanced throughout the network, thereby prolonging the network's lifetime.

In NRCA [15] protocol, each node calculates its residual capacity by measuring its energy level and transmission load. The node broadcasts its residual capacity information to neighboring nodes. Next, the nodes select a node with higher residual capacity as the cluster head based on the received residual capacity information. To achieve energy balance, the NRCA protocol introduces a rotation mechanism. After each round, the cluster head broadcasts its own residual capacity information to other nodes. Other nodes recalculate their residual capacity based on the received information and select a node with higher residual capacity as the new cluster head. Through this mechanism, nodes with higher energy consumption have the opportunity to become cluster member nodes, while nodes with lower energy consumption have the chance to become new cluster heads, achieving energy balance. The NRCA protocol effectively balances energy consumption and prolongs the overall network lifetime. When the energy levels of all nodes in the current cluster are lower than a predefined threshold, the global clustering will be initiated.

5. Conclusion

With rapid construction of smart city, wireless sensor networks have been widely used to collect various information in cities. In clustering protocols for wireless sensor networks, the energy consumption of cluster heads is much higher compared to other nodes. In order to ensure that all nodes in the network have the same lifetime, it is necessary to design mechanisms for energy load balance among nodes. In this paper, we categorized clustering protocols into different categories based on the methods of energy consumption balance among nodes, and also introduce the basic working principle of each representative clustering protocol.

Acknowledgments

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