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Energy efficient data collection through hybrid unequal clustering for wireless sensor networks ☆

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ABSTRACT

The existing clustering algorithms are either static or dynamic depending on the frequency of clustering. In static clustering, clusters are formed once, which reduces the clustering overhead but leads to early energy drain of a few nodes in the network. The network lifetime can be improved by dynamic clustering in which clusters are reformed after every round, which increases the clustering overhead. To optimize the parameters, including clustering overhead, network lifetime, energy hole, FND (first node dies) and LND (last node dies) in WSN, a hybrid unequal clustering with layering protocol (HUCL) is proposed. The HUCL is a hybrid of static and dynamic clustering approaches. In HUCL, the network is divided into layers and clusters of various sizes. The cluster heads are selected based on available energy, the distance to the sink and the number of neighbors. Once the cluster is formed, the same structure is maintained for a few rounds. The data are forwarded to the sink through a multi-hop layer-based communication with an in-network data compression algorithm. In comparison with the existing protocols, the HUCL balances energy and achieves a good distribution of clusters, extends the lifetime of the network and avoid the energy hole problem.

1. Introduction

Wireless sensor networks (WSNs) are highly distributed networks of small, lightweight, battery-embedded sensor nodes. WSNs are becoming increasingly attractive for numerous application areas, such as military reconnaissance, disaster management, security surveillance, habitat monitoring, health care and industrial automation [1]. Data collection from these networks may be periodic, query based or event based. In periodic data gathering, the sensor nodes sense the environment and transmit the sensed value to the sink at regular intervals; the routing strategy plays an important role in prolonging the network lifetime in these applications. The widely suggested routing techniques are distributed among different classes, including flat, hierarchical and location-based techniques. Many energy efficient solutions have been developed in each category of routing protocols. An approach that is likely to succeed is the use of a hierarchical structure [2].

Hierarchical organization of sensor networks leads to three different types of routing protocols based on how they communicate data to the sink, which are the cluster-based approach, chain-based approach and tree-based approach.

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Applications that cover large sensor fields and need frequent data gathering should support data aggregation as a prime candidate for improving the lifetime of the network. Cluster-based configuration has achieved this with minimum overhead. In clustering schemes, sensor nodes are grouped into clusters, a node is selected as the cluster head (CH) and the other nodes are called cluster members (CMs) [3]. Each node in the cluster collects local data from the environment periodically and sends it to its cluster head. After receiving the data from all CMs, the CH aggregates them and transmits to the sink via direct single hop communication or through a multi-hop routing path. The existing clustering algorithms can be static or dynamic depending on the frequency of clustering. In dynamic algorithms, at each round, a new cluster head is elected and the clustering boundary is reconstructed, which increases the clustering overhead. In static algorithms, the cluster is formed once, which reduces the clustering overhead, but the cluster head is overloaded, decreasing the network lifetime.

In this work, a proposal for a hybrid unequal clustering with layering protocol (HUCL) is presented. The HUCL is a hybrid of static and dynamic clustering approaches. In HUCL, the network is divided into layers and precise numbers of cluster heads are selected depending on the nodes residual energy, number of neighbors and centrality among neighbors. Different sizes of clusters are formed locally depending on the distance from the sink.

The author's contribution in this paper: Each round of data transmission is divided into major slots, and each major slot is divided into several mini-slots. 1. In each mini-slot, the CMs sense the environment and send the data to the CH; the CH aggregates and transmits the data to the sink through a multi-hop transmission chain. 2. In every major slot, the current CH selects a node as the new CH within the same cluster boundary depending on the energy. The current CH informs the new CH about its predecessor and successor in the data transmission path. 3. In each round, the clusters are reformed to avoid early drain of some nodes. 4. An in-network data compression algorithm is used to enhance the lifetime of the network. Thus, the proposed approach reduces the clustering overhead and improves the network lifetime.

The rest of the paper is organized as follows. Section 2 presents an overview of clustering in WSN. Section 3 presents earlier works on uneven clustering and compression. Section 4 explores the detailed description of the proposed HUCL algorithm. Section 5 analyses several properties of the HUCL. Section 6 gives the simulation results, and Section 7 concludes the work.

2. Clustering overview

In clustering, the sensor nodes in a WSN are divided into different virtual groups according to a set of rules. Under a cluster structure, sensor nodes may be assigned different functions, such as CH or CM [4]. A cluster head normally serves as a manager for its cluster and provides intra-cluster transmission schedules, collects the data from its members, performs data aggregation/fusion and forwards the aggregated data to the sink. The characteristics and advantages of clustering algorithms were discussed in previous articles [1,2,4–6]. In earlier studies [7,8,10], CH uses single hop communication to transfer the data to sink, but to increase the network lifetime, multi-hop communication has been used in recent years. However, the previous studies suffer from an important problem called the "hot spot" problem. The papers [10–18] address this issue with uneven size clusters. To minimize the clustering overhead of dynamic clustering, the papers [19–22] use a static clustering approach. However, in the static approach, the CHs should have higher power than its members; otherwise, the CH may drain quickly.

3. Related works

In recent years, many algorithms have been proposed in the area of energy-efficient clustering and routing for WSNs. The authors of [7] proposed a clustering protocol called LEACH for periodic data-gathering applications. LEACH is a dynamic, two phase protocol. CHs are distributed in the setup phase, and the CH directly transmits data to the sink in the steady phase. An energy-aware variant of LEACH is proposed in [8]; here the nodes with higher energy are more likely to become CHs. HEED [9] introduces cluster radius to define the transmission power used for intra-cluster broadcasting. The tentative cluster heads are elected based on residual energy, and final heads are selected according to the intra-cluster communication cost. HEED achieves fairly uniform distribution of cluster heads across the network. In EECS [10], unequal size clusters are formed based on the distance from the sink. EECS uses a cluster head competitive algorithm without message exchange iterations. Because it uses single hop inter-cluster communication, clusters farther from the sink have smaller sizes; thus, some energy is preserved for data transmission to the sink.

Soro and Heinzelman [11] examined an unequal clustering model for balancing the energy consumption of CHs in multi-hop sensor networks. They focused on a heterogeneous network where high power cluster heads were deployed at pre-computed locations. In this case, it was easy to control the actual sizes of the clusters. EEUC [12] is a distributed, unequal clustering algorithm that elects tentative cluster heads based on the residual energy of the nodes. The tentative cluster head has a competition radius determined based on the distance from sink. The tentative cluster heads competing to become the final cluster head. The algorithm forms more clusters near the sink. The inter-cluster communication is a multi-hop model; each CH selects another CH in the upward direction to transmit the data to the BS. In [13], Chen extended EEUC to mitigate the hot spot problem and introduced a novel unequal clustering protocol called UCR. The selection and rotation of CHs are based on residual energy. The model increases the network lifetime by decreasing the number of nodes in clusters with higher relay loads near the sink. In [14], the authors addressed the "isolation point" and the hot spot problems. Each node collects its neighbor information for computing the average energy and assigns the waiting time for each node based on residual energy. After the waiting time expires, the node itself assumed as the CH and sends the CH announcement message