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An Advanced Cluster-Based Routing Protocol for Wireless Sensor Networks with Nonuniform Node Distribution

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Abstract

Because of the non uniform node distribution, the energy spending among nodes are more imbalanced in cluster-based wireless sensor networks. Based on this problem, in this paper, a cluster-based routing protocol for wireless sensor networks with non uniform node distribution is proposed, which includes an energy-aware clustering algorithm EADC and a cluster-based routing algorithm. EADC uses competition range to make clusters of even sizes. At the same time, the routing algorithm increases forwarding tasks of the nodes in barely covered areas by forcing cluster heads to choose nodes with higher energy and fewer member nodes as their next hops, and finally, achieves load balance among cluster heads. Theoretical analysis and simulation results show that our protocol can balance the energy spending among nodes and increase the network lifetime considerably.

Keywords: *EADC, Network Lifetime, Cluster based routing protocol and Energy spending.*

1. Introduction

A wireless sensor network consists of thousands of low-cost, low-power and battery-powered sensor nodes. As sensor nodes have limited and non-rechargeable energy resources, energy is a very scarce resource and has to be managed carefully in order to extend the lifetime of the sensor networks. In recent years, researchers have done a lot of studies and proved that clustering is an effective scheme in increasing the scalability and lifetime of wireless sensor networks [1–4]. In clustering schemes, there are two kinds of nodes in one cluster, one cluster head (CH) and several cluster members (CMs). Cluster members assemble data from the environment periodically and send the data to cluster heads. Cluster heads aggregate the data from their cluster members, and send the aggregated data to the base station (BS). There are two kinds of communications between cluster heads and the BS, single-hop communication and multi-hop communication. In multi-hop communication clustering algorithms, the energy consumption of cluster heads consists of the energy for receiving, aggregating and sending the data from their cluster members (intra-cluster energy consumption) and the energy for forwarding data for their neighbor cluster heads (inter-cluster energy consumption).

In clustering networks, the imbalanced energy consumption among nodes is the key factor affecting the network lifetime. In order to balance the energy consumption among nodes, clustering algorithms for networks with uniform node distribution tend to construct uniformly distributed cluster heads, so that the clusters have the approximate number of members and coverage areas. Thus, the intra-cluster energy consumption of cluster heads is approximate and the energy consumption of cluster heads can be balanced. For cluster members, the maximum communicate distances of cluster members are approximate, because of the uniform cluster sizes. Thus, the energy consumption of cluster members can be balanced too. Therefore, the uniformly distributed cluster head set can balance the energy consumption among nodes and finally prolong the network lifetime. In networks with nonuniform node distribution, the mechanisms used to balance the energy consumption and prolong the network lifetime are not always effective. The uniformly distributed cluster heads enable the clusters have the uniform cluster sizes, so that the energy consumption among cluster members can be balanced. However, the imbalanced

energy consumption still exists among cluster heads due to the nonuniform node distribution.

In this paper, we propose a cluster-based routing protocol for wireless sensor networks with nonuniform node distribution whose cores are an energy-aware clustering algorithm EADC and a cluster-based routing algorithm. EADC constructs clusters of even sizes using competition range in order to balance the energy consumption among cluster members. To solve the imbalanced energy consumption among cluster heads caused by the nonuniform node distribution, a cluster-based routing algorithm is proposed, which balance the energy consumption among cluster heads by adjusting the intra-cluster and inter-cluster energy consumption of cluster heads. Therefore, it can achieve the balance of energy consumption among nodes and prolong the network lifetime. The rest of the paper is organized as follows. Section 2 covers the related works in this area. Section 3 discusses about the cluster based routing protocol. Section 4 presents Energy- Aware Clustering Algorithm EADC in detail. Section 5 analyzes the simulations of the protocol. Finally, Section 6 concludes this paper

2. Related Works

LEACH [1] is a typical clustering protocol proposed for periodical data gathering applications in wireless sensor networks. In LEACH, each node independently elects itself as a cluster head with a probability. Cluster heads receive and aggregate data from cluster members and send the aggregated data to the BS by single-hop communication. In order to balance the energy consumption, the role of cluster head is periodically rotated among the nodes. LEACH protocol is simple and does not require a large communication overhead. However, the performance in heterogeneous networks is not very well, because it elects cluster heads without considering the residual energy of nodes. To solve this problem, researchers improved LEACH and proposed some new algorithms [5–7]. EADEEG [8] is a novel distributed clustering algorithm. It elects cluster heads based on the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself, which can achieve a good cluster heads distribution and prolong the network lifetime. The authors in [9] analyzed EADEEG and proposed BPEC, a distributed energy saving clustering algorithm. BPEC elects cluster heads by the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself as its primary probability and the node's degree as its subsidiary probability. It is proved that BPEC can avoid the "isolate points" problem in EADEEG and keep all the cluster heads connected.

The above several algorithms only have one layer of the cluster head. Therefore they are called single-level clustering algorithms.

In order to further save energy in the network [10], literatures [11–13] adopted multi-level clustering strategy, and propose three multi-level clustering algorithms.

All the algorithms mentioned above are all based on the assumption that all the nodes are uniformly distributed in the networks. In networks with nonuniform node distribution, considering the network coverage problem, [14] proposed some good cluster head election techniques. However, this paper focused on coverage preservation, while the energy consumption balance and network lifetime on the back burner. Considering the node distribution, the authors in [15] proposed a hierarchical architecture of sensor network with cluster formation and cluster head selection algorithm. The authors used various parameter metrics related to node density and indicate the deployment density variation of nodes by the edge of link lengths standard deviations.

In [16], Yu et al. proposed an energy-aware distributed unequal clustering protocol (EADUC) in multi-hop heterogenous wireless sensor networks to "energy hole" problem

3. Cluster – based routing protocol

This protocol contains an energy-aware clustering algorithm EADC and a cluster-based routing algorithm. In order to elect cluster heads with higher energy, the parameter of cluster head competition in EADC is based on the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself. Moreover, cluster heads broadcast head messages using the same competition range to construct clusters of even sizes. Thus, the energy consumption among cluster members can be balanced well. However, the even cluster size also makes the energy consumption among cluster heads imbalanced, due to nonuniform distribution of nodes. Cluster heads in dense areas have more members nodes, so they have high intra-cluster energy consumption. For this, we propose an inter-cluster energy-efficient multi-hop routing protocol, in which cluster heads select the neighbor cluster head with higher residual energy and a smaller number of cluster members as the next hop to balance the energy consumption among cluster heads.

4. Energy- Aware Clustering Algorithm EADC

The algorithm is divided into three phases: information collection phase, whose duration is T1; cluster head competition phase, whose duration is T2; cluster formation phase, whose duration is T3. It is explained in the tables 1, 2 and 3.

Table 1: Information Collection Phase

```
begin (information collection algorithm)
    state ← Candidate
    Broadcast Node_Msg
    while (T1 has not expired) do
        Receive Node_Msg
        Update neighborhood table NT[]
    end
    ti ← broadcast delay time for competing a cluster head
end
```

Table 2: Cluster Head Competition Phase

```
begin (cluster head competition algorithm)
    while (T2 has not expired) do
        if CurrentTime < ti do
            if receive a Head_Msg from a neighbor NT[j] do
                state ← Plain
                NT[j].state ← Head
            else
                Continue
            end
        else if state = Candidate do
            state ← Head
            Broadcast Head_Msg
        end
    end
end
```

Table 3: Cluster Formation Phase

```
begin (cluster formation algorithm)
    while (T3 has not expired) do
        if state = Plain&& has not sent Join_Msg do
            Send Join_Msg to the nearest cluster head
        else if state = Head do
            Receive Join_Msg from its neighbor Plain nodes
        end
    end
    if state = Head do
        Broadcast Schedule_Msg
    end
end
```

5. Simulations

The simulation were performed in NS-2, every simulation result shown in the paper is the average of 250 independent experiments unless otherwise specified. Where each experiment is done in different scenarios and two scenarios are chosen to be shown as follows:

Scenario 1 200 nodes are randomly deployed over a 200 m×200 m field.
Scenario 2 200 nodes are non-uniformly deployed over a 200 m×200 m field.

Since EADUC does not take into account the non uniform node distribution, the advantage of the uneven clustering is not in evidence. Furthermore, EADC overcomes the imbalance energy spending problem by introducing a cluster-based inter cluster routing protocol. Therefore, EADC outperforms EADUC in scenario 2. Here, we can draw the conclusion that EADC can solve the nonuniform distribution and heterogeneity of nodes well, and prolong the network lifetime significantly. The network lifetime output with two scenarios is plotted in Fig.1

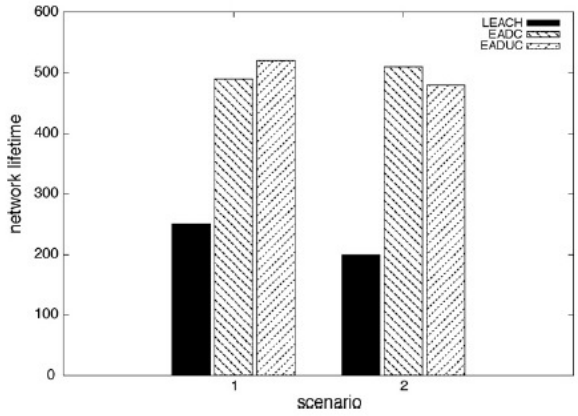

Fig. 1 Network Lifetime

6. Conclusion

In this paper, we propose a cluster-based routing protocol for wireless sensor networks with nonuniform node distribution which contains an energy-aware clustering algorithm and a cluster-based routing algorithm. The clustering algorithm balances the energy spending among cluster members by making equal clusters. Certainly, the energy spending among cluster heads is imbalance due to the nonuniform node distribution. Therefore, we propose a cluster-based inter-cluster routing algorithm to balance the energy spending among cluster heads by adjusting intra-

cluster energy spending and inter-cluster energy spending. Each cluster head chooses a cluster head with higher residual energy and fewer cluster members as its next hop. The imbalanced energy spending caused by nonuniform node distribution is solved by increasing forwarding task of the cluster heads in sparse areas. By using the above mechanisms, our protocol can take advantage of the nonuniform distribution and heterogeneity of nodes well, and prolong the network lifetime considerably.

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