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Energy efficient clustering algorithm for maximizing lifetime of wireless sensor networks

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Abstract

The sensor nodes deployed in wireless sensor networks are extremely power constrained, so maximizing the lifetime of the entire networks is mainly considered in the design. An energy efficient clustering algorithm with optimum parameters is designed for reducing the energy consumption and prolonging the system lifetime. An analytical clustering model with one-hop distance and clustering angle is given. The optimum one-hop distance and clustering angle are formulated by minimizing the energy consumption between inter-cluster and intra-cluster. Furthermore, the continuous working mechanism of each cluster head which acts as the local control center and will not be replaced by the candidate cluster head until its continuous working times reach the optimum values is given, and the optimum continuous working times of each cluster head can be obtained through the optimum one-hop distance and the clustering angle. With the mechanism, the frequency of updating cluster head and the energy consumption for establishing new cluster head can be reduced. The simulation results demonstrate that the clustering algorithm can effectively reduce the energy consumption and increase the system lifetime.
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Keywords: Wireless sensor networks; Lifetime; Clustering algorithm; One-hop distance; Clustering angle

1. Introduction

The energy source of sensor nodes in wireless sensor networks (WSN) is usually powered by battery, which is undesirable, even impossible to be recharged or replaced. Therefore, improving the energy efficiency and maximizing the networking lifetime are the major challenges in sensor networks. In recent years, many algorithms mainly focus on the energy balance of the nodes to prolong the lifetime. LEACH (low-energy adaptive clustering hierarchy) algorithm [1], which is based on gradient cluster, plays a great role in reducing the energy consumption of the nodes and enhancing the network lifetime. However, the LEACH algorithm selects the cluster heads dynamically and frequently by round mechanism, which makes the cluster heads broadcast messages to all the general nodes in the establishment stage with additional energy consumption [2,3]. The authors in [4] extend LEACH's stochastic cluster head selection algorithm by a deterministic component which improves the lifetime compared with the LEACH algorithm. Unequal clustering size (UCS) clustering algorithm balances the energy dissipation through controlling the size of the cluster [5]; this scheme can prolong the network lifetime. In [6], the authors analyze the problem of prolonging the lifetime of a network by determining the optimal cluster size and propose a location aware hybrid transmission scheme that can further prolong the network lifetime. But with the number

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of dead nodes increasing, it is difficult to control the actual size of the clusters and maximize the system lifetime through controlling the distribution of clusters. Besides, if the algorithm strives to balance the energy consumption of every node, cluster heads will be selected dynamically and frequently, which results in additional energy consumption for the cluster head set-up. At the same time, some residual energy of general nodes cannot be used effectively because of receiving broadcast message frequently from the new cluster head. Furthermore, in actual application, WSN may contain hundreds or thousands of nodes, and as sensor nodes are random deployed in high density (up to 20 nodes/m^3) [7], it is difficult to realize the energy balance for all nodes.

Owing to the above problems, a new clustering algorithm based on the optimum parameters is given, which is adopted to prolong the network lifetime by reducing the energy consumption for inter-cluster and intra-cluster communication. All nodes are divided into static clusters with the optimum parameters. The sizes of the clusters closer to the base station (BS) are smaller than those farther away from the BS. The different sizes of the clusters assure that the cluster heads closer to the BS have enough energy to transmit the fused data which comes from other cluster heads farther away from the BS, which realizes the energy consumption balance in inter-cluster. In intra-cluster, a new mechanism where the current cluster head continuously acts as the local control center is adapted to reduce the frequency of updating cluster and the energy consumption for new cluster head set-up. With the clustering algorithm, the energy consumption for communication between the inter-cluster and the intra-cluster is reduced. The simulation results demonstrate that the system lifetime is obviously extended.

2. The algorithm model

2.1. The energy consumption model

In WSN, the main energy consumption of the active node is made up of three parts: message sending, message receiving and data processing [3,8]. The simplified energy consumption model for each part can be defined as

$$\begin{cases} P_T(k) = E_{elec} \times k + E_{amp} \times d^{\gamma} \times k \\ P_R(k) = E_{elec} \times k \\ P_{cpu}(k) = E_{cpu} \times k \end{cases} \tag{1}$$

where k is the length (bits) of packets, d is the transmission distance (m). The radio dissipates E_{elec} (nJ/bit) per bit to run the radio circuitry. E_{amp} (nJ/bit/m^2) is the power above E_{elec} needed by the transmitter for an acceptable E_b/N_0 at the receiver's demodulator. E_{cpu} (nJ/bit) is the energy dissipation for processing per bit. γ is the path loss exponent that is related to the transmission distance.

Based on Eq. (1), the energy consumption for the cluster head receiving and transmitting k bits packets can be

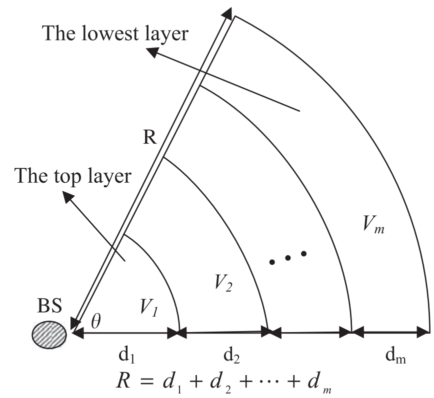

Fig. 1. Sketch map of clustering model.

defined as

$$\begin{aligned} P &= P_T(k) + P_{cpu}(k) + P_R(k) \\ &= k(2E_{elec} + E_{cpu} + E_{amp} \times d^{\gamma}) \end{aligned} \tag{2}$$

In Eq. (2), the energy consumption is in direct proportion to the length of data packets or message packets. If the message packets can be reduced, the energy consumption can be reduced. At the same time, the energy consumption is in direct proportion to d^2 when the transmission distance is less than a threshold. Otherwise, the energy consumption is in direct proportion to d^4 [3,9]. Thus, shortening the transmission distance can reduce the energy consumption.

2.2. The model of clustering algorithm

In clustering algorithm, cluster head acts as the local control center and is burdened with transmitting data from other cluster heads through multi-hop, thus the energy dissipation of the cluster head is much more than that of the general nodes [10,11]. Obviously, to maintain the connectivity of the entire network, it is very important that the cluster heads closer to the BS keep alive as long as possible for the inter-cluster communication. So the number of the nodes in the clusters closer to the BS ought to be smaller than those farther away from the BS [12].

Now, assume that n sensor nodes are deployed in a wedge V area with angle θ called the clustering angle, and the nodes are deployed with uniform density ρ (nodes/m^2). V is partitioned into m rings $V_1, V_2, \ldots, V_m$. Each ring denotes a cluster, and the center distance between the two adjacent rings is $d_1, d_2, \ldots, d_m$, and d_i $(1 \leqslant i \leqslant m)$ is a one-hop distance for inter-cluster communication. To describe in simple terms, the cluster closer to the BS is called the upper layer cluster and other is called the lower layer cluster. The sketch map of the model is shown in Fig. 1.

In Fig. 1, cluster C_1 is made of nodes located in ring V_1, and cluster C_2 is made of nodes located in ring V_2, and so forth. Let $n_1, n_2, \ldots, n_m$ denote the number of nodes

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