Improved Energy Efficient Adaptive Clustering Routing Algorithm for WSN

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Abstract. Routing algorithm is the key to prolong the lifetime of the overall wireless sensor network. At present, clustering routing algorithm is more widely used in wireless sensor networks. But this way of transmitting information through the cluster can lead to uneven energy consumption in the network, which is known as the "hot zone" problem. However, the uneven clusters, the way of multi-hop transmission between clusters can solve this problem. According to the characteristics of routing in wireless sensor network, this paper analyzes the defects and disadvantages of the current routing algorithm. This paper proposes a series of improvement measures for the current uneven clustering routing algorithm. This paper proposes a new algorithm which has a longer network life and better stability compared with the existing routing algorithm through experimental results and analysis.

Keywords: Wireless sensor networks · Routing algorithm
Uneven clustering routing

1 Introduction

Wireless sensor network (WSN) [1] is a widely used distributed sensing network. WSN is able to connect a large number of wireless sensor nodes through wireless connection. It builds the network through self organization, which makes the WSN flexible and changeable. Therefore, WSNs are widely used in various fields, such as medical, commercial and military et al.

At present, the research on WSNs mainly focuses on localization, routing, storage and trustworthiness, but routing is the key to prolong the overall network lifetime. From the aspect of network topology, routing algorithms for WSNs are mainly divided into plane routing algorithm and clustering routing algorithm.

As matters stand, cluster routing is more widely used in WSNs. The nodes are divided into clusters and each cluster head is responsible for the collection and integration of data within the cluster. The information of one cluster will be transmitted to the sink node by the cluster head. It thus can effectively reduce the overall energy consumption of the network nodes. However, transmitting information through cluster heads can make the energy consumption of cluster head nodes too large which will lead to uneven energy consumption of the network, also known as the "hot zone" problem.

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Furthermore, multi-hop transmission between clusters, the uneven clusters, can improve this problem. In order to extend the overall network lifetime and increase the average energy of the whole network, an improved algorithm is designed in this paper when analyzes the defects and shortcomings of the current routing algorithm according to the characteristics of routing in wireless sensor network routing and make a series of improvement on the current uneven clustering routing algorithm.

There are several drawbacks in EEUC and BEERA algorithm and problems such as the energy consumption asymmetric of nodes. The routing algorithm is designed on the basis of the features of the problems which need to be resolved: this paper puts forward an Improved Energy-Efficient Adaptive Clustering Routing Algorithm, IEACRA.

The innovation of this paper is that the cluster head election considers more about the current network state, simultaneously, applying different competition radius calculation methods according to different state of network. So that the nodes within the scope can join the cluster and finally through the inter cluster multi-hop data transmission. Finally, we successfully balanced the energy load and prolonged the network life time.

The rest of the paper is organized as follows. Section 2 describes the related work for clustering routing in WSN. In Sect. 3, models used in the IEACRA algorithm of the WSNs are introduced. Section 4 explains the proposed improved energy-efficient adaptive clustering routing algorithm. In Sect. 5, simulation results are discussed and Sect. 6 concludes the major findings of the whole paper.

2 Related Work

In recent years, researchers have been pushing forward the research of clustering routing for wireless sensor networks. The most typical and the first hierarchical routing algorithm, i.e., LEACH (Low Energy Adaptive Clustering Hierarchy) [2], proposed by Heinzelman et al. The algorithm can balance the energy of nodes in the whole network by cluster head rotation, so that the lifetime of the whole network is extended by 15% compared with the static clustering routing algorithm.

EEUC [3] (Energy-Efficient Uneven Clustering) was proposed by the Li from Nanjing University, which selects cluster heads through competitions mainly based on the residual energy of nodes. Taking into account the node energy while reselecting the cluster head node and also setting the node density for the nodes, Wang proposed the NCHS-Leach [4] (Novel Cluster Head Selecting Leach) algorithm. LBMC [5] (Layer Based Multi-hop Clustering routing algorithm for wireless sensor networks) was proposed by Zhou et al. based on the communication cost as a benchmark for hierarchical network. Jiang et al. proposed DEBUC [6] (Distributed Energy-balanced Unequal Clustering Routing Protocol), which controls the competition radius based on the time cluster head competition algorithm and the residual energy of nodes.

Feng focus on the “hot zone” problem, through improving the LEACH algorithm and the optimal threshold competition radius to improve the energy of cluster head load balancing, proposed BEERA [7] (Balanced Energy Efficient Clustering Routing Algorithm). Li proposed UAUC [8] (uneven clustering routing algorithm). The algorithm through divided non equal partition of the network and according to the energy factor, distance factor and intensity factor in each region to select the appropriate cluster head node.

PEGASIS [9] proposed by Lindsey et al. on the basis of knowing the location information of each node, it organizes the network node into chains, then data fused on the chain and transmitted to the sink. Younis et al. have studied a hybrid clustering algorithm, HEED [10], which present the idea of backup cluster head.

DECAR [11] algorithm was proposed by Tarach and Amgoth of India, and it balances the load of the whole network by taking into account the coverage area of the cluster head. Martins et al. combine Dijkstra algorithm with BBE-C [12] routing algorithm to reduce the energy used in computing route, and develop a routing algorithm called MBBEC [13]. The ElhamRezaei team from Iran proposed the MMRCE [14] algorithm to select the optimal cluster head by adding residual energy and distance factors to further prolong network lifetime.

3 Analysis of the Problem

We make a description about the network model and the energy model before elaborating the core algorithm design of this paper.

3.1 Network Model

This paper uses a network model similar to paper [3]. In a square region A, N wireless sensor nodes are randomly distributed among them. The application scenario is a periodic WSN for data collection. The i sensor nodes are represented using s_i, and eventually the sensor nodes in the network are represented as:

$$S\{s_1, s_2, s_3, s_4, \ldots\ldots, s_N\},\ |S| = \mathrm{N}. \tag{1}$$

We assume that the WSN model has the following characteristics:

(1) The sink node of WSN is outside the WSN, and after the network is randomly arranged, the location of the sink node and all the sensor nodes is not changing.
(2) All sensor nodes have the same data processing capability and network communication function, and all nodes have the opportunity to become cluster head nodes, and each node has their unique ID.
(3) The communication power of the sensor nodes can be adjusted automatically, that is, the nodes can automatically adjust the transmit power of their signals according to the current communication distance, thus further reducing the energy consumption.
(4) The overall link is symmetric. If the transmitted power of the other node is known, then the node that receives the information can estimate the distance between them based on the strength of the signal received at this time.
(5) All nodes of the network are not installed with GPS modules, and could not know their detailed location through GPS.

3.2 Energy Model

The energy model is the same as the wireless communication energy consumption model used by the Leach algorithm. If the WSN node sends k bit data, the distance from the receiving data node is d, total energy consumption at this time is the sum of emission circuit consumption and power amplification losses, as follows:

$$E_{Tx}(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times d^2, d < d_0 \\ k \times E_{elec} + k \times \varepsilon_{mp} \times d^4, d \geq d_0 \end{cases} \tag{2}$$

Among them, $E_{Tx}(k,d)$ represents the overall energy consumption. k indicates the size of the data to be sent. d stands for the distances between the nodes. The E_{elec} represents the emission circuit consumption. In the free space model, the energy required for power amplification is ε_{fs}. In multipath fading model, the energy needed for power amplification is ε_{mp}. $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$ is a decision threshold that represents the transmission distance. When the transmission distance is less than it, the loss of power amplification calculation using the free space model. Otherwise, multipath fading model is adopted.

Thus, when the data received by the node is k bit, the total amount of energy consumed at this time is

$$E_{Rx}(k) = k \times E_{elec} \tag{3}$$

If the data is fused at the cluster head node, the energy consumption of the data fusion is also generated, and at this point the E_{Rx} is used to represent the energy consumed when fusing 1 bit data. At the same time, assuming that the data collected by nodes is more redundant, the cluster head nodes can fuse the data collected from the nodes in the cluster into fixed length packets, and finally send them to the sink node.

4 IEACRA Algorithm Design

When the network initializes, all sensor nodes need to receive a signal, whose transmission power is known, broadcast by sink node. Then the sensor node calculates the approximate distance between it and the sink node by the received RSSI signal strength.

Next, the IEACRA algorithm uses a recursive method with two stages in each round including the cluster formation phase and the data transfer phase. The cluster formation stage includes the election of cluster head nodes and the establishment of clusters, and the data transfer stage includes inter cluster routing and cluster head data transmission.

4.1 Cluster Formation Stage

At the beginning of the algorithm, cluster-headed elections are required. In the beginning of the network, the cluster head election is still random. Therefore, in this paper we refer to paper [15] to improve the threshold calculation formula for controlling cluster head election in LEACH [2].

$$T(n) = \begin{cases} \frac{p}{1-p\times[r\times mod(\frac{1}{p})]} \times \frac{E_{res}}{E_o}, & n \in G \\ 0, & n \notin G \end{cases} \tag{4}$$

Where $T(n)$ represents the threshold of the node at this point. p is the proportion of all nodes that need to be selected for cluster heads. r is the current number of rounds. E_{res} is the residual energy of the current node. E_o is the initial energy of the node.

But this way of calculating the threshold is too one-sided. The overall choice of thresholds should take into account the average energy of the current network. In this way, it is possible to increase the chances that the nodes with large remaining energy are selected as cluster heads. Therefore, the following threshold selection formulae are proposed.

$$T(n) = \begin{cases} \frac{p}{1-p\times[r\times mod(\frac{1}{p})]} \times \frac{E_{res}}{E_{avg}}, & n \in G, \frac{E_{res}}{E_{avg,}} \leq 0.7 \\ 1 & n \in G, \frac{E_{res}}{E_{avg}} > 0.7 \\ 0, & n \notin G \end{cases} \tag{5}$$

Among them, E_{avg} is the average node energy of the current network, taking into account the existence of residual energy is greater than the average energy. Therefore, when the value of $\frac{E_{res}}{E_{avg}}$ is greater than 0.7, the node becomes a candidate cluster head directly, thus ensuring that the nodes with large energy have the opportunity to become cluster heads. A large number of factors needs to be considered in choosing the threshold of the election cluster head, so there is no definite way to determine the threshold. A threshold range of 0.3–0.9 is tested in this paper. The selection of the ratio is the optimal value selected by many experiments.

After the candidate cluster heads are generated, the candidate cluster heads need to broadcast their competition messages to the nodes within their competition radius. The competition information includes the ID of the node, the competition radius, the distance between the sink node, and the current residual energy of the candidate cluster head. Previous studies have used a fixed radius calculation formula of competition in order to implement the uneven clustering, but in the initialization of the network should not rush to realize uneven clustering. We should let the nodes of the network consider the problem of energy consumption after the node becomes the cluster head. It means we need to select the cluster head, and then proceed to realize uneven clustering. Therefore, this paper refers to the paper [3] and paper [8] for the study of the radius of competition, and obtains the following formula for the calculation of the competition radius.

$$R_c = \begin{cases} \sqrt{4\frac{2\varepsilon_{mp}}{\pi\rho\varepsilon_{fs}}}, & r = 1 \\ \left(1 - c\frac{d_{max}-d(s_i,DS)}{d_{max}-d_{min}}\right)R_c^0, & r > 1 \end{cases} \tag{6}$$

Among them, R_c is the competition radius. ε_{mp} and ε_{fs} are radio signal propagation parameters used by cluster members and cluster heads for communication, and wireless model propagation parameters for cluster heads to communicate with sink nodes. ρ is the current network node density. d_{max} and d_{min} represent the maximum and minimum values of the distance between nodes in the network to the sink node, respectively. $d(s_i, DS)$ represents the distance from node s_i to the sink node. R_c^0 is the maximum value of the competition radius of cluster heads. c takes $\frac{1}{3}$.

When $r = 1$, the formula is derived from BEERA proposed by Jiang [8]. It has been found that the excellence of the formula adopted in this algorithm lies in the time of network initialization. That is because the energy of the nodes is the same in the start, however, as the network continues to process, the nodes will die and the energy varies. As a result, the decisive factor is the path from the node to the sink node. Therefore, when $r > 1$ is used, an algorithm based on the competition radius algorithm of EEUC [3], which focus on uneven clustering of WSNs, should be used. At the same time, the value of the important parameter c is also determined according to the analysis in this paper [3].

In order to verify the most appropriate use of time for different formulae, all cases are divided into three categories. These three different situations are the initial time of node, the initial stage of node operation, and the later stage of node operation. At the same time, each case is set with 9 different thresholds. Finally, after research and experimental verification, we can get the conclusion that it is appropriate only at the node initialization.

Figure 1 is the schematic diagram of network initialization, at which time the network belongs to even clustering stage.

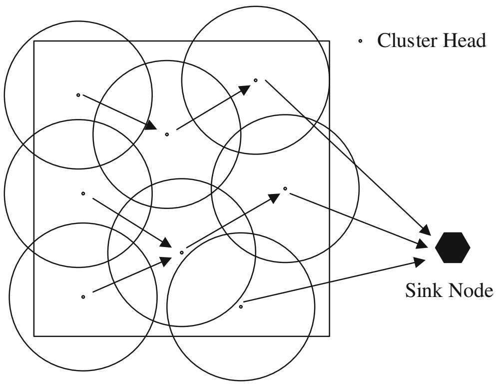

Fig. 1. Schematic diagram of cluster routing in network initialization

Then, with the continuous operation of the network, clustering routing starts from the original even clustering to the current uneven clustering. It is easy to see that the closer to the sink node, the smaller the candidate cluster head will be and the number of cluster heads will increase, thus alleviating the “hot zone” problem in WSNs. As shown in Fig. 2.

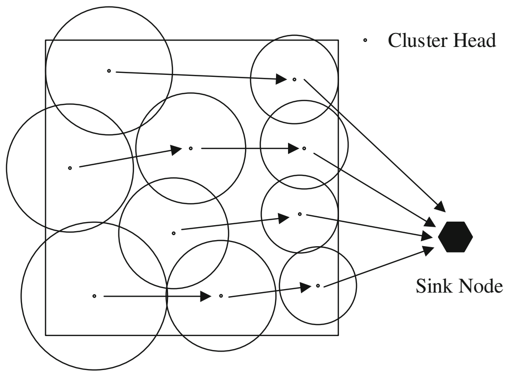

Fig. 2. Schematic diagram of uneven clustering routing in network operation

After all nodes have successfully broadcast their own campaign information, each cluster head begins to compete with other cluster heads. Among the candidate cluster heads in the same range of competition, the most remaining energy node can eventually become cluster heads. At the same time, successful candidates for the cluster head send a "succeed" information to other nodes within the radius, and the other candidate nodes will also send a "unsucceed" information. After that, each common node joins the nearest cluster according to the accepted message. At this point, each cluster is successfully created.

4.2 Data Transfer Stage

Each cluster head receives the data sent by the node in its own cluster, simultaneously, the data is fused which means that all the data is integrated into one packets. Each packet has the same size now.

At this point, the cluster head generates its own data transmission path by the minimum hop count. Each cluster head node initializes the direct hop value of 500. The initial hop value of the sink node is 0 and it sends hop information to all cluster heads within its communication range. The cluster head node that receives the hop information of the sink node can set its own number of hops to one, and simultaneously send its own hop count information as a sink node does. If the cluster head receives less hops than its own number of hops, it changes its own hop count to this new hop count plus 1 and adding into its own transmission path. And so on, until all cluster head nodes can transmit data to the sink node via multi hop mode.

When all paths have been established, the cluster head node transmits its integrated packets to the sink node through a multi-hop way.

Flow chart of IEACRA algorithm is given as follows (Fig. 3).

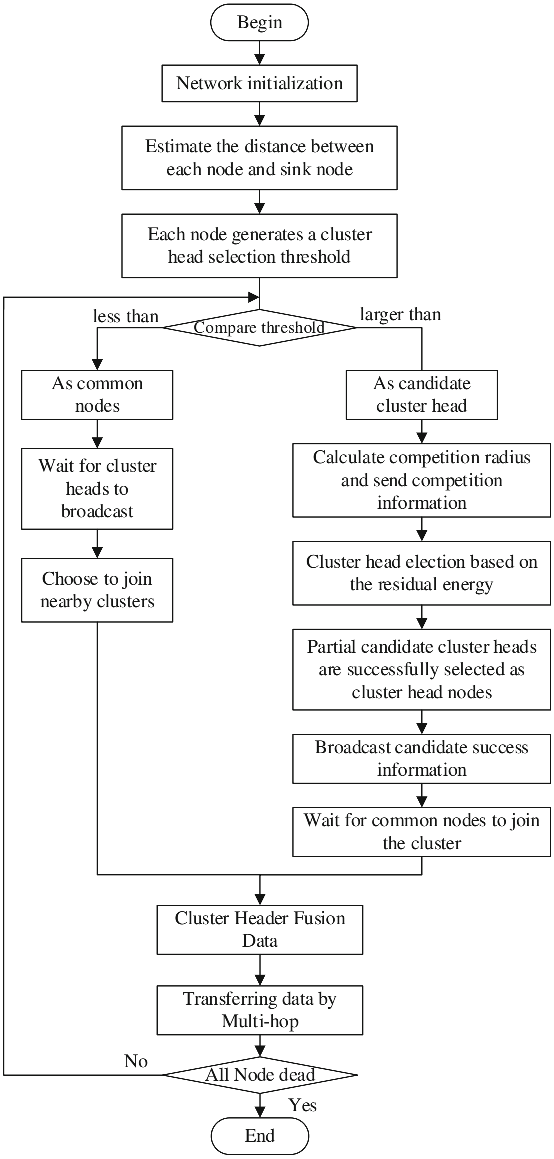

Fig. 3. Flow chart of IEACRA algorithm

5 Simulations and Analysis

This paper uses Matlab to build network models. The LEACH, EEUC, BEERA and IEACRA algorithms described in this paper are all simulated. The performance of the algorithm is compared from two aspects, the network lifetime and the network state.

5.1 Simulation Settings

For simulating the experimental environment, the nodes are randomly distributed in a region of (0,0) ~ (400,400). Meanwhile, each node has the same initial energy. Coordinate of sink node is (200,450). The number of node is 1600. The packet size is 4000 bit. The control packet size is 100 bit. The hop count size is 100 bit. All the parameters are set as Table 1.

Table 1. Simulation parameter setting

Parameter name	Parameter values
Area	(0,0) ~ (400,400)
Location of sink node	(200,450)
Node number	1600
Packet size	4000 bit
Control packet size	100 bit
Hop count size	100 bit
ε_{mp}	0.0013 pJ/bit/m^4
ε_{fs}	10 pJ/bit/m^2
E_{elec}	50 nJ/bit
E_0	0.3 J
d_0	87 m

5.2 Simulation Results and Analysis

Figure 4 shows how four different algorithms operate with the same parameter setting. It is easy to see that, as the number of rounds increases, the LEACH algorithm first begins to die, which is mainly due to the randomness of the cluster head election in LEACH algorithm. Next, the node of the EEUC algorithm dies. Although the death node of BEERA appeared slightly later than the EEUC algorithm, the BEERA is always in a state of instability due to the BEERA competition radius. The IEACRA algorithm in this paper is more stable, and also can effectively prolong the network lifetime.

Although BEERA improvements can extend a certain network lifetime, the average energy of the algorithm is poor. IEACRA algorithm can not only guarantee the overall life extension of the network, but also guarantee the average energy of nodes. The network state diagrams of both algorithms are shown in Fig. 5.

By comparing the two best selected algorithms, you can see that a small jump occurs around 430 round because the overall energy consumption of the BEERA is unstable. This is mainly due to a large number of node deaths, leaving only some nodes with great energy. It is obvious that the average energy of IEACRA algorithm is better than that of BEERA algorithm and the curve of which is also smoother.

The reason why the algorithm improves the network lifetime is the following two points. Firstly, as shown in formula (4), we propose a threshold selection method that

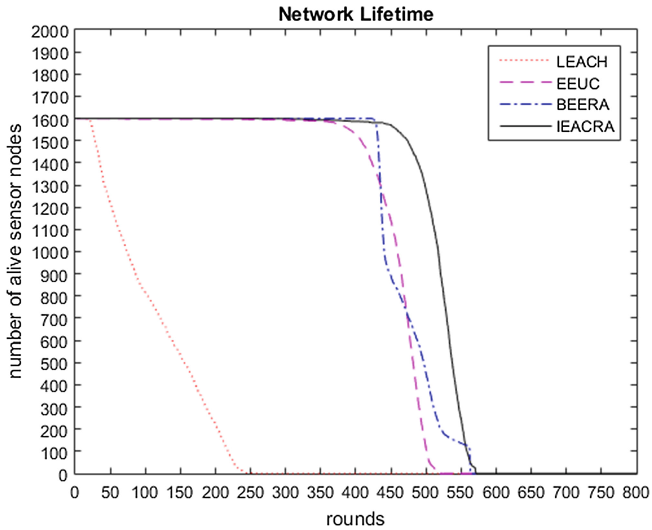

Fig. 4. Network lifetime comparison

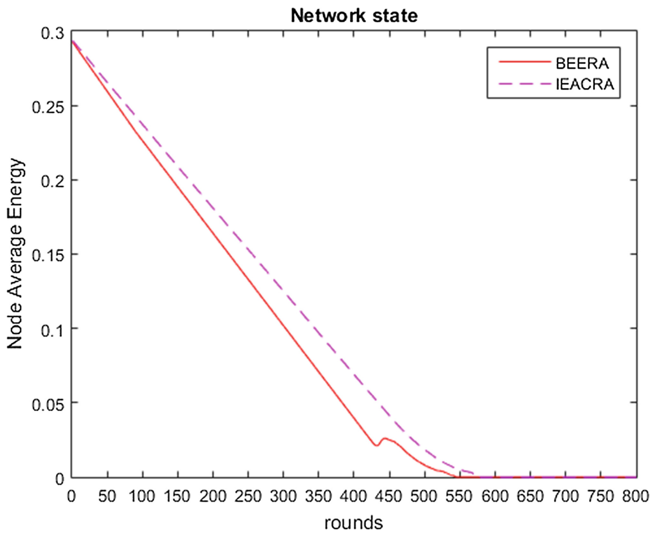

Fig. 5. Network state diagram

takes more into account the average energy of the current network. Secondly, as shown in formula (5), we modify the selection formula of competition radius according to different network states.

6 Conclusions

The algorithm proposed in this paper is used to solve the problem of the insufficiency of the current uneven clustering routing algorithm and the uneven energy consumption of WSN nodes. The innovation of this paper is that the cluster head election takes into account the current network state and can apply different competitive radius calculation method according to different state of network. So that the nodes in the range can join the cluster and finally transmit the data through the multi-hop mode. The simulation results show that compared with EEUC and BEERA algorithm, the IEACRA algorithm achieves the effective improvement of the "hot zone" problem, the energy load balancing and the extension of network life time.

Because of the experimental error, this paper had not been able to make a reasonable explanation for the value of threshold parameter selection. A further analysis of the threshold parameter values in the algorithm and comparison of network parameters and environments in more ways still need to be done. At the same time more excellent scheme can be considered in routing transmissions, thus further reducing the "hot zone" problem.

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