An Energy-efficient Routing Protocol Based on DPC-MND Clustering in WSNs

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Abstract. Energy Efficiency has become a primary issue in wireless sensor networks (WSNs). Due to the non-uniform distribution and difficulty in supplementing energy of nodes in large-scale WSNs, the design of energy-efficient routing protocols for wireless sensor networks has become a challenge nowadays. It has been already proved that one of the essential approaches to improve WSNs performance is clustering, routing, and data aggregation. However, the main problem dealt with the selection of optimal CH that reduces energy consumption. Till now, more research works have been processing on solving this issue by considering different constraints. Under this scenario, this paper proposes An Energy-efficient Routing Protocol DMBERP(DPC-MND based energy-efficient routing protocol)Based on DPC-MND(Density Peaks Clustering based on Mutual Neighborhood Degrees). This protocol uses an improved DPC-MND clustering algorithm to cluster the nodes in WSNs. Then, in each cluster, two cluster heads are elected according to the residual energy of the node and the distance to the base station. The primary cluster head is responsible for routing and forwarding, and the secondary cluster head is responsible for data collection in the cluster. Finally, a dynamic multi-hop routing between clusters is designed according to the energy, distance and other factors. The experimental results show that the routing protocol proposed in this paper achieves better performance in balancing node energy consumption and prolonging network lifetime.

Keywords: Wireless sensor network · Routing algorithm · multi-hop · Clustering · Density Peaks Clustering based on Mutual Neighborhood Degrees(DPC-MND)

1 Introduction

WSNs is a distributed sensor network [10], composed of a large number of stationary or moving sensors in a self-organizing and multi-hop manner. These sensors cooperatively sense, collect, process and transmit the information of the perceived objects in the geographical area covered by the network, and finally send the information to the owner of the network. Wireless sensor networks are widely

B. Li et al. (Eds.): APWeb-WAIM 2022, LNCS 13421, pp. 199–206, 2023.
https://doi.org/10.1007/978-3-031-25158-0_16

used and have the application scenarios such as intrusion detection, weather monitoring, security and tactical reconnaissance [2]. At present, the main research works are concentrated on the routing algorithms about the energy consumption, security, QOS, etc. [7,12], which derives a series of technologies which includes low-energy routing protocols, data aggregation technologies, energy harvesting technology and secure routing technology, etc. [1].

Due to the continuous expansion of the application, most of the researches [9,13] have a certain degree of inappropriate content. The wireless sensor routing protocol mentioned in this article is the core technology of WSN, which is also the basic guarantee for information collection and transmission, closely related to the performance of the entire network. In large-scale wireless sensor networks, the distribution of sensor nodes is generally uneven. Under the circumstance of huge number of sensor nodes and huge size of network area, uneven energy consumption or even broken network structure may be happened, which definitely brings great challenges to the design of routing protocols for large-scale wireless sensor networks.

2 Related Work

Aiming at solving the problem of energy consumption in WSN, Heinzelman.W.R et al. proposed the classic LEACH [5] protocol. Each node randomly generates a 0-1 decimal. If it is less than the threshold T(n), it will immediately be elected as the cluster head, and other nodes choose a cluster head closest to join the cluster; in recent years, Li Jianzhou and others proposed the EBCRP [6] protocol on the basis of the LEACH, which adds the consideration of distance when electing the cluster head, so that the cluster head probability function changes continuously with distance. In [11] , the authors used K means clustering method as Cluster Head selection algorithm is used over LEACH as base protocol. Initially distance as a parameter is used and later distance plus residual energy of node is chosen. The later proves to be 4 times efficient.

In order to further optimize the clustering routing protocol of WSN, this paper proposes an energy-efficient routing protocol DMBERP based on DPC-MND [14] clustering algorithm. The protocol in this paper is optimized from three aspects:

(1) A dynamic factor related to the distance between the node and the base station is added on the basis of the original clustering algorithm of taking the peak density, the closer to the base station, the more density peak nodes are selected, so that the energy holes near the base station is appropriately avoided.
(2) Since the energy consumption of nodes is mainly in the transmission of data, a large amount of redundant data will shorten the life cycle of wireless sensor networks. Based on the idea of dual cluster heads in the literature [3], this paper distributes the energy consumed by data fusion and data transmission on two nodes, and optimizes the cluster head election to a certain extent.

(3) The multi-hop transmission method is adopted between clusters considering the idea of routing optimization int the literature [4,8], and three factors including distance, direction, and remaining energy are comprehensively considered in the selection of next-hop. This method avoids the influence that the sensor nodes far from the sink node consume more energy due to the long transmission distance in single-hop routing.

3 The Description of DMBERP Protocol

The DMBERP protocol runs in rounds, and each round mainly includes four stages: cluster establishment, cluster head election, inter-cluster routing establishment and stable data transmission. Clustering in each round will affect the overall efficiency for the reason of large resource consumption. Therefore, clusters are established every ten rounds in DMBERP protocol.

3.1 Cluster Establishment Phase

(1)**Introduction to Main Definitions**

Local density ρ: The local density of each sensor node x_i is the relative density in its local range, and its local density ρ_i is defined as follows:

$$\rho_i = \frac{\sum_{j=knn(i)} \sum_{v=knn(j)} d_{vj}^2}{2 \cdot k \cdot \sum_{j=knn(i)} d_{ij}^2} \tag{1}$$

Relative distance δ: The relative distance δ_i between a sensor node x_i and other nodes refers to the distance of the node whose local density is greater than itself and closest to itself. Its definition is as follows:

$$\delta_i = \max_{i \neq j} (\delta_j) \tag{2}$$

$$\delta_i = \min_{j:\rho_j > \rho_i} (d_{ij}) \tag{3}$$

Decision value γ: The decision value is to judge whether the node can be used as an indicator of the density peak. The closer to the base station, the higher the decision value and the more the clusters. Its definition is as follows:

$$\gamma_i = \frac{\rho_i \cdot \delta_i}{d_{toSink}} \tag{4}$$

Decision value ω: Proximity ω_{ij} is defined by the distance index between sensors. The further between the two nodes, the lower the similarity and the smaller the proximity. The definition is as follows:

$$\omega_{ij} = \begin{cases} e^{-\frac{d_{ij}^2}{\theta^2}}, & j \in knn(i) \\ 0, & \text{others} \end{cases} \tag{5}$$

Relative proximity deg**:** The above-mentioned proximity only considers the global information of the node, and local information needs to be considered to achieve the effect, so the relative proximity is defined as follows:

$$deg_{i \to j} = \frac{1}{k+1} \sum_{v \in [knn(i), i]} \omega_{vj}, \quad i \neq j \tag{6}$$

Mutual proximity A**:** Combining the relative proximity of two nodes, it is defined as follows:

$$A_{i,j} = deg_{i \to j} \cdot deg_{j \to i} \tag{7}$$

(2) **Algorithm Flow**

Input: sensor node set $Nodes$, neighboring number k, estimated number of clusters M

Output: clustering results C

a) Calculate the Euclidean distance between nodes, and obtain the local density ρ of each node and the relative distance δ between it and other nodes according to formula (7)(8)(9);
b) Calculate the decision value γ of each node, arrange them in descending order, and select the largest M peak nodes as the final cluster center set C_n;
c) Calculate the mutual proximity from other nodes not included in C_n to all nodes in C_n, select the peak node with the largest mutual proximity for each node, and join the cluster;
d) Repeat step c) until all nodes are clustered, and the cluster establishment is now completed.

3.2 Cluster Head Election Phase

The main cluster head election factor algorithm:

$$\lambda_{\mathrm{maj}CH} = \mu \frac{E_{res}}{\overline{E_{res}}} + \nu \left(1 - \frac{d_{toSink}}{\overline{d_{toSink}}}\right) + \gamma \left(1 - \frac{d_{toOthers}}{\overline{d_{toOthers}}}\right) \tag{8}$$

In this paper, $\mu = 0.5$, $\nu = 0.25$, $\gamma = 0.25$; E_{res} is the current remaining energy of the candidate node, $\overline{E_{res}}$ is the average value of the remaining energy of the candidate nodes; d_{toSink} is the distance from the candidate node to the base station, $\overline{d_{toSink}}$ is the average value of the distances from the candidate nodes to the base station; $d_{toOthers}$ is the sum of the distances between the centers of the point sets of other clusters, $\overline{d_{toOthers}}$ is the average of the sum of the distances between the candidate nodes and the center of other clusters; the cluster center $C = \sum_{i=1} x_i / n$, belongs to the point set of the cluster. Secondary cluster head election factor algorithm:

$$\lambda_{\mathrm{sec}CH} = \mu \frac{E_{res}}{\overline{E_{res}}} + \nu \left(1 - \frac{d_{toNodes}}{\overline{d_{toNodes}}}\right) \tag{9}$$

In this experiment, $\mu = 0.5$, $\nu = 0.5$; $d_{toNodes}$ is the sum of the distances from the candidate nodes to other nodes in the cluster, and $\overline{d_{toNodes}}$ is the average of the sum of the distances from the candidate nodes to other nodes in the cluster.

3.3 Inter-cluster Routing Establishment Phase

In the process of data transmission between clusters, the multi-hop is adopted between cluster heads, and the data is finally transmitted to the base station. Combining the three factors of energy, distance and direction to select the next hop cluster head will help reduce the number of relay hops and communication conflicts. The calculation formula of the relay node metric coefficient α is as follows:

$$\alpha = \frac{E \cdot \cos\theta}{D} \tag{10}$$

Among them, θ is the above-mentioned angle; $E = \frac{E_{res}}{E_{all}}$, E_{all} is the remaining energy of the entire network. When the remaining energy of the entire network is less, the next hop considers the higher proportion of the remaining energy; $D = e^{(d-d_0)/100}$, where d is the distance from the cluster head to the next hop cluster head, and d_0 is a threshold. When the transmission distance is greater than d_0, the energy consumption increases exponentially, that is, when the distance of the next hop cluster head exceeds d_0, the metric coefficient is lower. The following figure is a schematic diagram of the multi-hop transmission path of the cluster heads:

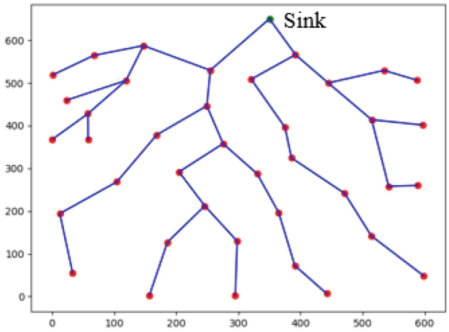

Fig. 1. Schematic diagram of nodes path.

4 Simulation and Performance Analysis

The experimental environment is as follows: the area of network is 600 * 600 and the number of sensor nodes is 1000. The energy consumption performance of DMBERP is analyzed through specific experiments, and the entire wireless sensor network is simulated through Python. The comparison experiments use the classic routing protocol LEACH, the EBCRP routing protocol proposed in recent years, the KBECRA routing protocol and the routing protocol based on DBSCAN clustering.

In this experiment, the maximum number of running rounds is set to 2000. It is determined that when the number of alive nodes is less than 20%, the network structure is severely damaged and cannot operate normally. Simulation experiment of the initialization parameters are shown in Table 1:

Table 1. Simulation Parameter

Parameter	Value
Number of sensor nodes	1000
Network size(m^2)	600*600
Base station location(sink x, sink y)	(300,650)
Initial energy of sensor node$E_0(J)$	0.5
Energy dissipation: receiving $E_{ele}(nJ/bit)$	50
Energy dissipation: free space model $E_{fs}(pJ/bit/m^2)$	10
Energy dissipation: multi-path fading model $E_{mp}(pJ/bit/m^4)$	0.0013
Energy dissipation: aggregation $E_{\mathrm{DA}}(J/bit/message)$	5
Data fusion ratio ar	0.6
Control message length $CPL(bits)$	200
Data message length $DPL(bits)$	4000

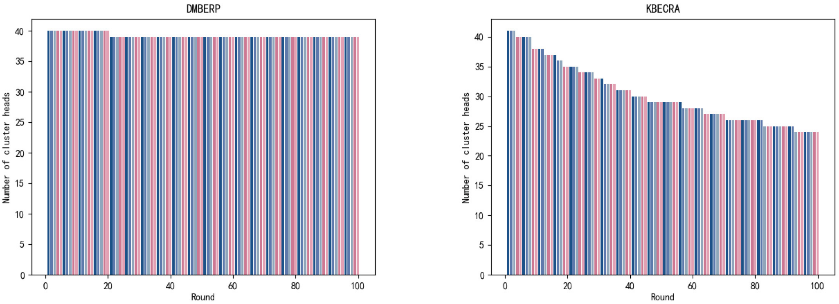

Fig. 2. Cluster adjustment

In this paper, the DPC-MND clustering algorithm requires two parameters to be set manually: the number of neighboring nodes and the number of clusters. Through experiments, it is concluded that when the number of neighboring nodes k is 10 and the number of clusters is 4% of the total number of points, the experiment effect behaves the best.

The number of cluster heads is an important indicator for evaluating the protocol. As can be seen from Fig. 2, the number of the cluster heads in the DMBERP proposed in this paper is stably distributed at the optimal value with good clustering effect and slow energy consumption, so the number of cluster heads does not show a downward trend at the beginning like the KBECRA. Therefore, the DMBERP protocol has high reliability.

We randomly select ten rounds from the experiment and record the average energy consumption of the cluster heads in each protocol and compare them. Figure 3 shows that the energy consumption of cluster heads in the EBCRP and the DMBERP is small and close, the DMBERP consumption is lower than the EBCRP. These two protocols have stable energy consumption and small fluctuation, indicating that the algorithm is stable and effectively balance the energy consumption.

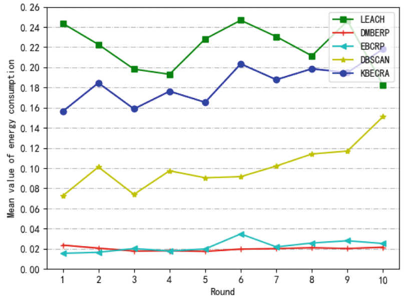

Fig. 3. Mean value of energy cost

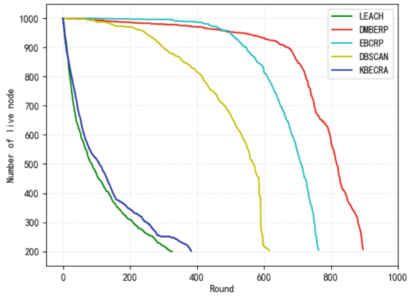

Fig. 4. Nodes lifetime.

Figure 4 shows the survival of sensor nodes in large-scale WSN. It can be seen that the network lifetime of the DMBERP algorithm based on the WSNs node is generally higher than that of the network under other comparison protocols.

5 Conclusion

Aiming at the problem of energy consumption in the process of data transmission, this paper proposed a routing protocol the DMBERP based on density for clustering wireless sensor network nodes improving and optimizing cluster head elections, inter-cluster routing, etc. Experimental results show that DMBERP can improve the energy utilization efficiency of the entire network, and effectively extends the survival period of the entire wireless sensor network. In the future, we will try to figure out the performance of the method in terms of network security.

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