A Novel Cluster Algorithm for Wireless Sensor Networks Based on Edge Centrality and Reference Nodes

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Abstract — The **Low Energy Clustering Hierarchy routing protocol, often termed LEACH, does not apply to large-scale networks where energy consumption is uneven. We propose a cluster-head selection algorithm based on edge-Centrality,- often called 'between-ness' but here the more correct English word Centrality will be used throughout. First the whole network is divided into several clusters by edge Centrality. At each cluster, a node which has the largest residual energy is selected as the reference node. A cluster head can be rotated periodically according to the distances between 'base station and node' and between 'reference node and node within cluster'. The algorithm forms a reasonable and stable cluster structure based on the structure of the network itself. Then a cluster head is selected at each cluster. The algorithm takes as factors node energy and location in selecting cluster heads so that the energy consumption of the whole network is relatively balanced. Matlab simulation shows the new algorithm extends the life cycle of the network by 20% compared to LEACH protocol.**

Keywords - Wireless Sensor Network; reference node; clustering algorithms on reference node; Centrality; network life cycle.

I. INTRODUCTION

Wireless sensor network (WSN) is a new network system of information acquisition and data processing which integrates sensor, communication and computer technologies and currently has been applied in many fields [1]. Wireless sensor networks is rated to be the top one of ten new emerging technologies for future human life by an America's magazine named " Technology Review ", and they believe that it is another technique which will exert a significant influence on human society following the Internet. Sensor nodes are usually limited energy and energy supplement successor is not realistic, so the design of energy-efficient routing protocol is extremely important to extend the network life cycle. Compared to the planar routing protocols, clustering routing protocol has a greater advantage and has become a hot topic of concern in recent years [2].

Low-energy adaptive clustering hierarchy (LEACH) was the first proposed clustering routing protocol, whose basic idea runs through the majority of the later development of clustering algorithm [3]. The algorithm's basic idea is: each node randomly but circularly selects cluster head node by a certain probability in order to make the whole network energy load evenly distributed to each node, thus effectively reducing the network energy consumption and improving overall network lifetime. The algorithm is really simple and easy to implement, but it also has its disadvantages.

(1) Energy factor is not considered in the selection of cluster head nodes that may result in node with lower energy elected as cluster head node.

(2) The position of the cluster head is random, which may lead to uneven distribution of cluster heads.

(3) The cluster heads communicate with the base station directly so that transmission energy consumption of cluster head which far away from the base station is too large.

Literature [4] made improvement on the basis of LEACH algorithm: only when the remaining energy of nodes exceeds the average residual energy of the network, it can be selected as the cluster head node. Literature [5] proposed a minimum ID clustering algorithm, and the method is very simple to implement. However, nodes need to exchange ID when clustered, which brings great energy cost and the distribution of selected cluster heads are not uniform. A centralized clustering algorithm (LEACH-C) was put forward in literature [6], in which, the base station selects cluster head according to the energy and position information transmitted by nodes at the end of each round. Though it solves the problem of uneven distribution of cluster head, it wastes a lot of energy to transmit information of energy and position in each round. Both literature [7] and [8] assumed the nodes distribute uniformly in the whole network, however, the sensor nodes are not uniformly distributed in many practical cases. The HEED algorithm proposed in literature [9] bases on the energy of main parameter and time parameter within the cluster communication cost while selecting the cluster head, thus, it produces faster clustering, evenly distributed cluster heads and more reasonable network topology. However, it has a large cluster communication overhead. The EEDC algorithm presented by literature [10] put forward a new strategy based on the intra-cluster communication, but has little consideration on the stage of cluster head data forwarding. Literature [11] proposes a competition based non-uniform clustering algorithm (EEUC) that presents a partial node to compete for cluster head. But the competition for head in each round would result in large

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waste of energy if too many nodes participate in such competition. Paper [12] proposed a DEEC algorithm with good clustering effect. However, the direct communication between cluster head and the sink node results in great energy consumption of cluster heads that affects the survival of the entire network.

Many scholars combined with the "small world" theory and designed some WSN routing protocol algorithms with better performance, which mainly focus on the method of cluster formation and inter-cluster communication. The RLOC algorithm presented by literature [13] utilizes the small world phenomenon to optimize topology of the wireless sensor network based on random distribution of nodes. In this method, some excess edges are selectively removed until the network is divided into a plurality of disconnected subnets to exhibit distinct cluster structure and finally complete the subdivision of the clusters. SWST algorithm is divided into sensor network construction and maintenance proposed by Literature [14]. In the formation process, all super-nodes formed a super-node ring on the basis of NW small world network model and a cluster has only one super node, while ordinary nodes join in the nearest cluster. Literature [15] judges by the characteristics of complex small-world network model, combines the algorithm RLOC, makes comprehensive comparison of the node residual energy, the distance from the sink node and the adjacent node degree, and finally chooses the most suitable cluster head node.

Aiming at the deficiency of these algorithms, the paper takes the balanced and reduced energy consumption of network nodes and the prolonged network lifetime as its starting point in order to research the clustering routing technology in wireless sensor networks. Through the comparison and analysis of typical clustering routing protocol, we based on the existing algorithms and combined with the characteristics of complex networks to propose a clustering routing algorithm based on edge Centrality and reference node.

II. ALGORITHMS

The basic idea of clustering algorithm on basis of the reference node and edge Centrality is to use the concept of edge Centrality in complex network theory to optimize the topology of wireless sensor network so that the network topology can be much clearer and cluster structure can be more apparent. Once formed, clusters will no longer change, which, to a certain extent, reduces energy consumption during each round of clustering and stabilizes the cluster head number. In the cluster head rotation selection, each cluster shall select cluster head independently. Combined with the energy and distance, after the end of each round, the node with the most residual energy will be taken as a reference node, while the node can become a cluster head only when it is nearer to the reference node and nearest to the sink node. Rotation could be done while the energy of cluster head node is less than the average inter-cluster energy in order to reduce the energy consumption of each cluster head rotation.

$$K = \frac{B\max}{(\sum_{i=1}^{m} B_i - B\max)/(m-1)} \tag{1}$$

The multi-hop algorithm is often applied in the inter-cluster communication, where the cluster head farther away from the base station transmits the information to the node that locates nearer to the base station within its coverage and owns large energy so that the energy consumption of network can be balanced.

A. *The Formation of Clusters*

In the network, the edge Centrality of an edge is defined as the number of the shortest paths which pass through all sides of this edge. According to the definition of the edge Centrality, it can be summed that the edge Centrality of an edge is calculated as follows:

Where, Bij is the edge Centrality of connection side of node i and j ; Pijk is the number of the shortest path starting from the node k (going through ij) and arriving at other nodes in the network.

$$B_{ij} = \sum_{k=1}^{n} P_{ijk} \tag{2}$$

Where ,Bmax is the maximum number of edge Centrality in the network; m is the number of edge in the network; Bi is the edge Centrality of edge i.

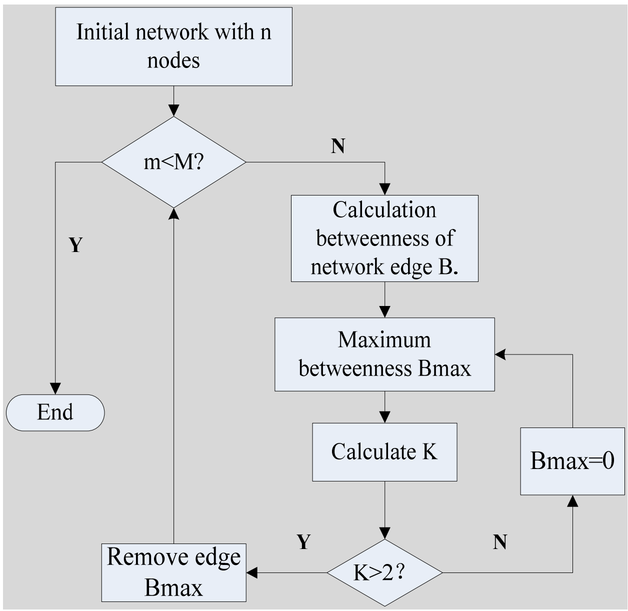

Figure 1. Cluster formation flowchart.

The greater the edge Centrality is, the more intensive two sub-networks connected by this edge will be. If you remove the edge with maximum edge Centrality, you can get two dense sub-networks. So, we can split a large network into a number of small dense networks. Then the edge Centrality of each side in the network is calculated to find the maximum edge Centrality Bmax; if the value of K is less than 2, the side with the maximum edge Centrality should not be removed and let Bmax = 0, otherwise, we shall remove this edge until the number of side in the network m <M (M is the set value).The cluster formation flowchart as shown in Fig.1.

B. Cluster Head Rotation

In the initial period all nodes have the same energy and transmission radius. For the first time, we shall randomly select nodes with optimal number of cluster head to act as a cluster head, which will be responsible for collecting the data transmitted from respective cluster members and sending the data to aggregation nodes through the cluster head. Since the cluster head node consumes more energy, therefore, after working for a period of time, imbalance of energy distribution will appear in the nodes. When there is a need to rotate, the cluster head is dynamically rotated in the cluster to reduce the energy consumption of the periodic rotation of cluster head. After the end of each round, the next cluster head rotation begins when the energy of cluster head is lower than the average energy of nodes in this cluster. The nodes with most residual energy in last rotation should be selected as the reference node of cluster head in this rotation; namely, the cluster head of this rotation should be the node that is closest to the reference node and close to the sink node. All subsequent steps follow this to circulate. Therefore, before the death of node, the number of cluster head remains unchanged in the wireless sensor networks in each rotation. Each cluster head broadcast uniformly intensified information to their surrounding, and then the ordinary node receives this message, judges the strength of signal to join in the cluster with most intensified signal (now the communication distance is the shortest and finally broadcast information to the cluster head for participation. After the cluster head receives information from the common node for participation, it will establish the TDMA time schedule. According to this schedule, the nodes in cluster will communicate with cluster head within their respective time slots. The cluster head selection flowchart as shown in Fig.2.

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$

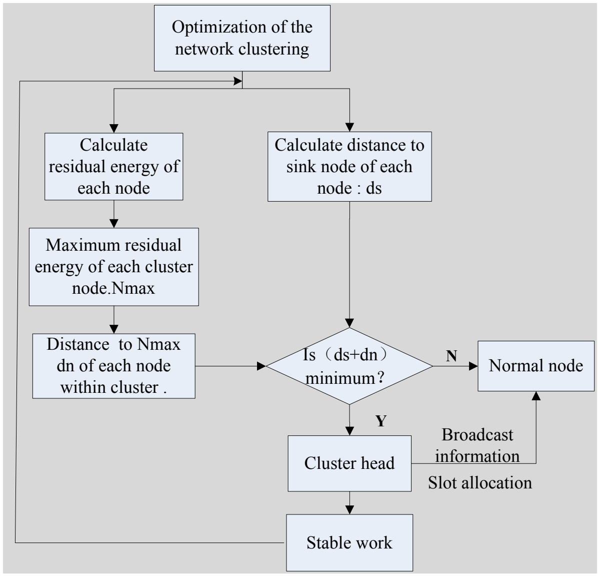

Figure 2. Cluster head selection flowchart.

III. ASSUMPTIONS OF RELATED MODELS

C. Network Model Assumptions

Several sensor nodes are randomly distributed in a square area with side length being a. We make following assumptions about sensor networks:

(1) The locations of sensor nodes and only sink node do not change once deployed.

(2) All sensor nodes have the same initial energy and transmission radius, have a unique ID number and possess the ability of data fusion.

(3) Satisfy the symmetry of the signal transmission, i.e. energy consumption is the same to transmit the same data between nodes A and node B.

(4) Node locations can be obtained by positioning algorithm, GPS or other methods.

(5) All nodes have the same capabilities of computing and data processing.

This paper uses the energy model in literature [1], where node's energy is mainly consumed to transmit and receive data. When a node transmits k-bit data and transfer distance is d, the energy consumption is:

$$= \begin{cases} kE_{\mathrm{elec}} + \varepsilon_{\mathrm{f}} kd^2, d < d_0 \\ kE_{\mathrm{elec}} + \varepsilon_{\mathrm{mp}} kd^4, d > d_0 \end{cases} \quad (3)$$

$$E_{Rx}(k,d) = kE_{\mathrm{elec}} \quad (4)$$

$$d_0 = \sqrt{\frac{\varepsilon_f}{\varepsilon_{mp}}} \quad (5)$$

In which, $E_{Tx}(k,d)$ is the energy consumption of transmitting node, $E_{Rx}(k,d)$ is the energy consumption of receive node; $E_{Tx\text{-}elec}(k)$ is the energy consumption of transmitting circuit to transmit k bit data, $E_{Tx-amp}(k,d)$ is the energy consumption of the power amplifier to transmit k bit data in a transmit distance of d; E_{elec} is the energy consumption of transmitting one bit data for the receiving and transmitting circuits, ε_f is the free space propagation constant, ε_{mp} is the multi-path fading transmission, d_0 is a constant, saying threshold value of transmission distance. If the transmission distance is less than the threshold, loss of the power amplifier shall use the free space model, otherwise use the multi-path fading model.

IV. SIMULATION AND ANALYSIS

D. *Simulation Parameters*

In this paper, the network life cycle is defined as the duration from that network starts to run until all nodes of the entire network are died. If the energy of node is exhausted, the node is considered dead. In order to prove the validity of this algorithm, we used the classic Matlab software simulation tools to conduct simulation comparison and analysis of the proposed algorithm and LEACH protocol under the same conditions. The relevant parameters settings are shown in table 1.

TABLE 1. SIMULATION PARAMETERS

Parameters	Parameter values	Parameters	Parameter values
Region	100×100m	Initial energy	0.5J
Nodes number	100	E_{DA}	5nJ/bit
Location of sink node	（50,50）	ε_f	1×10^{-11}
Packet size	4000	ε_{mp}	1×10^{-15}
Control packet size	100	Distance threshold	87.7m

E. *Analysis of Simulation*

From the Fig.3, compared to LEACH algorithm, the proposed algorithm prolongs the network life cycle, namely, the first death node has been delayed for about 200 rounds, which proves the better stability of proposed algorithm.

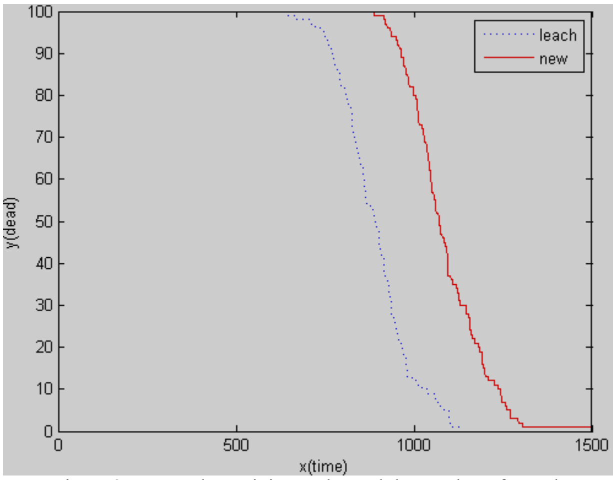

Figure 3. Network surviving nodes and the number of rounds

In LEACH algorithm, the division of clusters and the cluster head selection are implemented in each round, which makes the most node energy used in the cluster formation stage and results in more energy consumption. After completion of the clustering using algorithm in this paper, the structure of the cluster no longer changes, reducing the energy consumption of clustering in each round. At the same time, cluster head to be replaced only when needed, to avoid frequent rotation and unnecessary energy consumption and keep nodes work for a longer time. From the Fig.4, the algorithm proposed in this paper makes the energy consumption of network more balanced. In LEACH algorithm, the division of clusters occurring in each round results in excessive and faster energy consumption in nodes. By comparison, the proposed algorithm sets reference node and accepts the distance between reference node and node and the distance between node and sink node as the reference factor of selecting cluster heads, so that excessive energy consumption can be avoided in nodes with farthest distance from base station or with lower energy. However, the algorithm needs to wholly consider the energy and location information of nodes which consumes a small amount of energy. At the same time, cluster head to be replaced only when needed can avoid frequent rotation and unnecessary energy consumption, enable most energy in node used in communication, prolong the network life cycle, transmit more data packets and provide more data information to managers.

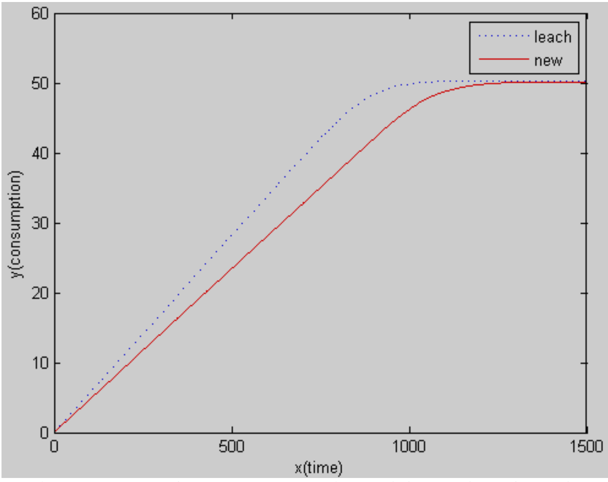

Figure 4. Network energy consumption and the number of rounds.

V. CONCLUSION

The paper proposed a WSN clustering algorithm based on the edge Centrality and reference node compared with LEACH algorithm. First of all, on the basis of the structure of network, it depends on the algorithm to form a reasonable and stable cluster structure, and then selects cluster head in each cluster according to the algorithm. Considering the energy and location factors of node in choosing cluster head makes the energy consumption in whole network to be relatively balanced. The result of simulation test shows that this algorithm can effectively prolong the network lifetime compared with the LEACH algorithm. How to better conduct cluster classification, make the node clustering and structure more reasonable, further prolong the network life cycle and balance the energy consumption of network, These will be the focus of further research.

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