# An Improved Unequal Clustering Routing Protocol for Wireless Sensor Networks

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***Abstract*** —When the data are transmitted from cluster heads to sink node via multi-hop communication, the energy hole may be arisen. In order to solve the problem, an improved unequal clustering routing protocol is proposed. During the stage of the cluster heads selection, the cluster head selection time of each node is calculated by the protocol based on such factors as the residual energy of the node, the average residual energy of neighbor nodes, and the average distance between the neighbor nodes. The protocol selects the cluster nodes by timing mode, and those unselected nodes will be joined into the nearest cluster to complete the clustering process, thereby the networks are divided into multiple clusters with different sizes. During the stage of routing establishment between clusters, the protocol builds up the minimum spanning tree based optimal transmission path according to such factors as the residual energy of cluster heads, and the distance between cluster heads. During the stage of data transmission, the ordinary nodes of a cluster send the data to cluster head by single hop, and cluster heads send the data to Sink node through the nodes of the tree by multi-hop. The simulation shows that the routing protocol can efficiently balance and reduce the energy consumption, then prolong the service time of the wireless sensor networks.

***Index Terms***—wireless sensor networks, energy balance, uneven clustering, minimum spanning tree

## I. Introduction

Wireless sensor networks are composed of a large number of sensor nodes and one or more Sink nodes, in which sensor nodes collect data and upload to the Sink node. The power of these sensor nodes is supplied by batteries, but the energy of batteries is limited and cannot be replenished. So how to reduce the energy consumption of sensors and provide energy-saving algorithm in the network layer is a research hotspot on Wireless Sensor Networks (WSN) [1], [2].

Studies have shown that the sensors are firstly divided into several clusters and the data from sensors are transmitted to the Sink node by the cluster heads through multi-hop, which is helpful for saving energy [3]. But after passing through multi- hop, the cluster heads are closer to the Sink node, thus the energy consumption will be much bigger for forwarding the data of other cluster head. Thus the "energy hole" will be formed slowly in the wireless sensor networks, then the data of other sensor nodes will not be able to upload data to the Sink node, thus will waste the energy and shorten the network life cycle.

To solve the problem of "energy hole", many researchers have put forward different cluster head selection way and multi-hop routing algorithm. EEUC [4] and DEBUC [5] algorithms put forward unequal clustering way, which the clusters near the Sink node are smaller and the nodes in the cluster are fewer. The uneven clustering way can reduce energy consumption within the clusters and save energy for forwarding data, which can effectively balance energy consumption and prolong the network life cycle. But the two algorithms select cluster heads based on probability and threshold, so the optimum of the selected clusters can’t be ensured. EBUCA[6] algorithm also put forward uneven clustering way, and set the threshold for the selection of cluster head based on density and residual energy of nodes, which achieved the goal of balancing the energy consumption.

In addition, in terms of the choice of multi-hop routing, the literature [7] adopted optimized ant colony algorithm to select route, but did not consider link quality on route choice. Literature [8] and literature [9] used minimum spanning tree algorithm to select route, but they only considered the residual energy of cluster head or the distance between cluster head and the Sink node when constructing spanning tree.

In order to solve the above problems, this paper proposes an improved unequal clustering routing protocol for wireless sensor networks. In the protocol each node constructs the competition time of cluster head according to the residual energy of nodes, average energy of neighbor nodes and average distance between neighbor nodes at the election stage of cluster head. The nodes with short competition time will get better chance to become the cluster head. After the completion of cluster head selection, a minimum spanning tree will be constructed. The minimum spanning tree uses the residual energy of cluster head as well as the distance between two cluster heads as parameters, and uses the Sink node as root node. The single-hop method is adopted for the data transmission among the clusters, and the communication between cluster heads and the Sink node use the route of the minimum spanning tree by

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multi-hop. The protocol can balance the energy consumption of each node very well and prolong the service time of the wireless sensor networks.

## II. Relevance Model

### A. Network Model

①Nodes can't be moved anymore and energy cannot be added after the nodes being deployed, moreover the location of Sink node is fixed. The WSN has only one Sink node and energy is not limited. ② Nodes can calculate the distance between the nodes according to the received signal strength and can freely adjust the transmission power. ③The sensor nodes have the same initial energy, and have the same communications as well as data handling capabilities. ④All the sensor nodes are within the communication zone of the Sink node. ⑤Each node has the unique ID identifier.

### B. Energy Model

Because the energy consumption of communication in wireless sensor networks is far more than other energy consumption [10], the paper only considers the energy consumption of communication and uses the same first-order energy consumption of wireless communication model as literature [11] to make analysis and simulation. The energy consumption formula of the model is following:

$$E_{Tx}(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times d^2, d < d_0 \\ k \times E_{elec} + k \times \varepsilon_{mp} \times d^4, d \geq d_0 \end{cases} \quad (1)$$

$$E_{Rx}(k) = k \times E_{elec} \quad (2)$$

In the formula, $E_{Tx}(k,d)$ refers to the energy consumption in sending data of $k$ bits, $E_{Rx}(k)$ refers to the energy consumption in receiving data of $k$ bits, $E_{elec}$ refers to the energy consumption of circuit in sending or receiving data of each bit, $d$ refers to the transmission distance, and $d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}}$ . If $d < d_0$, the energy consumption is adopted by free space model. If $d \geq d_0$, the energy consumption is adopted by multipath attenuation model. $\varepsilon_{fs}$ refers to the energy consumption in sending data of each bit in free space mode, and $\varepsilon_{mp}$ refers to the energy consumption in sending data of each bit in multipath attenuation model.

From formula (1) and (2), it can be known that the energy consumption of node is mainly decided by the data sizes $k$ and the transmission distance $d$ .This paper only considers the influence of transmission distance, and the energy consumption can be effectively reduced by optimizing the cluster head selection and reducing the transmission distance as far as possible.

## III. An Improved Unequal Clustering Routing Protocol

Like the LEACH protocol, this protocol also uses "round" way, each round is divided into the cluster establishment stage and data transmission stage. During the stage of the cluster establishment, a cluster head selection considers the residual energy of the node, the average residual energy of neighbor nodes and the average distance between neighbor nodes, and uses time sequence method to select. During the stage of data transmission, the protocol considers the residual energy of cluster head and the distance between two cluster heads to build up the optimal transmission path based on minimum spanning tree.

### A. The Formation of Clusters

In the protocol, each node has a table to store information of neighbor nodes as shown in Table I. In Table I, the state of node has three values: cluster head, ordinary node and candidate node of cluster head.

TABLE I: CONTENT OF NEIGHBOR TABLE

| Node identify | state | residual energy | Distance to the node |
|---|---|---|---|
| ID | state | $e$ | $d$ |

Node regards all other nodes within radius ( $r/2$ ) of the node as its neighbor nodes and the value of is calculated by the following formula (3).

$$r = \left(1 - c\frac{d_{\max} - d(i,DS)}{d_{\max} - d_{\min}}\right)R_c^0 \quad (3)$$

In the formula, $R_c^0$ refers to the max maximum radius which is defined beforehand, $d_{\max}$ refers to the maximum distance from the node to Sink node, $d_{\min}$ refers to the minimum distance from the node to Sink node, the value of $c$ is the parameter in the range 0～1 to control the value range, $d(i,DS)$ is the distance from the node to Sink node.

In the protocol, the duration which node gets neighbor nodes information is set to $T_1$, and the competition time of cluster head is set to $T_2$.

At the Beginning phase, Sink node broadcasts the PAR_MSG message in the whole network. Each sensor node calculates the distance between the node to the Sink node according to the received message strength, and then calculate the radius ( $r$ ) of the node according to the formula (3).

At the beginning of each round, each node gets the information of neighbor node according to the preplanned duration ( $T_1$ ). Each sensor node broadcasts the Comp_MSG message with radius of $r/2$ .The Comp_MSG message includes the identify, residual energy, and the distance $d$ between the node and neighbor node. The distance $d$ can be calculated according to the received message strength from neighbor node. The information is stored in neighbor node table.

When the time $T_1$ is arrived, the neighbor node tables are updated completely. Each node calculates the number ($m$) of neighbor nodes, average residual energy ($E_{avg}$) of neighbor nodes, average distance ($d_{avg}$) from neighbor nodes to the node. The value of $E_{avg}$ and $d_{avg}$ are calculated by the following formula (4) and (5).

$$E_{avg} = (\sum_{i=1}^{m} e_i)/m \tag{4}$$

$$d_{avg} = (\sum_{i=1}^{m} d_i)/m \tag{5}$$

Each node calculates the competition time ($t$) of cluster head by the following formula (6).

$$t = \alpha \times T_2 \times \frac{E_{avg}}{e_i} \times \frac{d_{avg}}{d_{avg} + \beta} \tag{6}$$

In the formula (6), $\alpha$ is a random real number between [0.9, 1], $e_i$ refers to residual energy of node, and $\beta$ refers to regulatory factor of distance.

As can be seen from formula (6), the competition time ($t$) is determined by $\frac{E_{avg}}{e_i}$ and $\frac{d_{avg}}{d_{avg}+\beta}$. $\frac{E_{avg}}{e_i}$ as the main parameter can better handle the problem of energy heterogeneous. $\frac{d_{avg}}{d_{avg}+\beta}$ as auxiliary parameter can better reduce the energy consume of data communication in the cluster.

Then the protocol enters into the period of the cluster head selection. If a node has not received the SUC_MSG message from neighbor nodes before the competition time ($t$) arrived, the node broadcasts the SUC_MSG message in the radius ($r$) to announce the election success of cluster head. If a node receives the SUC_MSG message from neighbor nodes before the competition time ($t$) arrived, the node broadcasts the FAI_MSG message to announce selection failure of cluster head and the selection of cluster head has to be given up.

When the time ($T_2$) is arrived, the selection of cluster head has been completed, then the protocol enters into the period ($T_3$) that ordinary nodes join to the cluster. Each ordinary node sends JOIN_MSG message to nearest cluster head in the neighbor table, requests to join the cluster and deletes the nodes which are not in the same cluster from the neighbor table.

When the time ($T_3$) is arrived, the cluster process has been completed. The algorithm of cluster is shown in algorithm 1.

Algorithm 1. The Formation of Clusters

For every node in the network

```
Broadcast Comp_MSG(ID,e)
On receiving a Comp_MSG(ID,e)
update table NT[]
when T1 is arrived
calculate the Eavg and davg
calculate the time t
while(the time T2 is not arrived)
  if(currentTime<t)
    if(a SUC_MSG is arrived from NT[i])
          Broadcast FAI_MSG(ID)
          NT[i],state=head
         state=plain
              endif
  else
        if(state=cand)
            broadcast SUC_MSG(ID)
           state=head
        endif
   endif
 endif
endwhile
while(the time T3 is not arrived)
  if(state==head)
       receive JOIN_MSG(ID) from table NT[]
       update table NT[]
  else
      send JOIN_MSG(ID) to nearest cluster head
      update table NT[]
  endif
endwhile
```

In the above algorithm, the whole network is divided into unequal clusters. The cluster is nearer to the Sink node, and the smaller with the cluster, the better to benefit energy balance. The competition time considers the residual energy, average residual energy and average distance and can guarantee that the integrated performance of cluster head is best.

### *B. Building up Routing Tree between Clusters*

After clustering, each cluster head broadcasts the CLU_MSG (ID, e) message with radius of $r$, receives the message from other cluster head, and calculates the distance between clusters.

The cluster heads use minimum spanning tree to communicate with Sink node by multi-hop. The Sink node is the tree root of the minimum spanning tree. At first, each cluster head is abstracted to a point, adjacent cluster heads are linked by edge, and the wireless sensor networks is constructed to a weight connected grid graph. The protocol let G=(V,E) be the weight connected grid graph with point set V and edge set E . The point set V includes all cluster heads and Sink node.

The weight of edge between cluster head $i$ and cluster head $j$ takes into account the distance and residual energy. The formula of weight is shown as the following.

$$w_{ij} = \rho \times \frac{d_{ij}}{e_i} + (1-\rho) \times \frac{d_{ij}}{e_j} \tag{7}$$

In the formula (7), $w_{ij}$ refers to the weight, $d_{ij}$ refers to the distance between cluster heads, $e_i$ refers to the residual energy of cluster head $i$, $e_j$ refers to the residual energy of cluster head $j$, and $\rho$ refers to variable parameter. If two cluster heads cannot receive information each other, the weight of edge between the two cluster heads is set as infinity. As can be seen from

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formula (7), the weight is determined by $\frac{d_{ij}}{e_i}$ and $\frac{d_{ij}}{e_j}$. If the residual energy is lower and the distance is farther between two cluster heads, the value of $w_{ij}$ is bigger, the probability which the cluster head is selected as data forwarding is smaller, low energy cluster head can reduce energy consumption of communication, so the protocol can efficiently prolong the wireless sensor networks survival period and balance the whole network energy.

According to the distance $d(i,DS)$ from cluster head to Sink node and the distance $d_{ij}$ between adjacent cluster heads, the route from cluster head to Sink node use Prim algorithm to construct minimum spanning tree. The algorithm is shown in algorithm 2. In the algorithm 2, U is the point set of the tree; TE is the edge set of the tree. The cluster head in the set C can direct communicate with Sink node.

Algorithm 2. Building Routing Tree between Clusters

For every cluster head in the network.

*1: if(d(i,DS)/ei < h) //h is a constant value*
*2: add the node i to C*
*3: endif*
*4: add cluster heads in Set C and Sink node to U*
*5: add the edges between cluster heads in Set C and Sink node to TE*
*6: while(U!=V)*
*7: pick the edge with the lowest weight $w_{uv}$ (u ∈ U, v ∈ V-U),*
*8: add the edge to TE and add v to U*
*9: endwhile*

When the algorithm 2 completes, the spanning tree T=(U,TE) is the minimum spanning tree of connected graph G. According to minimum spanning tree T, Each cluster head adjusts its transmission power which can reach the one-hop neighbor cluster heads, so can reduce energy consumption.

### C. Data Communication

When the election of cluster head and cluster head routing tree building are completed, the protocol enters into the period of data communication. Ordinary nodes send data to the cluster head by TDMA mode within the cluster. Then the cluster head sends data to Sink node by multi-hop according to the minimum spanning tree.

### D. Algorithm Analysis

Supposes the number of nodes is N and the number of cluster heads is M in the WSN.

**Property 1:** The message complexity of the algorithm is $O(N)$.

The number of PAR_MSG message is one, the number of Comp_MSG message is N; the number of SUC_MSG message is M; the number of FAI_MSG message is N-M; the number of JOIN_MSG is N-M; the number of CLU_MSG message is N-M; so the total number of message is

$$1+N+M+(N-M)+(N-M)+(N-M)=1+4\times N-2\times M.$$

So the message complexity of the algorithm is $O(N)$.

**Property 2:** The time complexity of the algorithm is $O(N^2)$.

In the formation of clusters, the time complexity is $O(N)$ when each node calculates the distance between the node and Sink node. The time complexity is $O(N^2)$ when each node calculates the distance between the node and neighbor node. The time complexity is $O(N)$ when each node calculates the average residual energy of neighbor nodes, average distance between neighbor nodes to the node. The time complexity is $O(N^2)$ in the period of the election of cluster head. In the period of building routing tree between clusters, mainly the cluster heads participate in the operation and $N >> M$, so the time complexity of the whole algorithm is $O(N^2)$.

## IV. Simulation Experiment

In the paper, we choose OPNET to carry out the simulation experiment, and compare with EEUC protocol and EBUCA protocol. In the experiment, the number of sensor nodes is 100, these sensor nodes are randomly distributed in the rectangular area of 100m×100m, and the Sink node is located in the center of the rectangular area. The simulation parameters are: $E_{elec}$ =50nJ/bit, $\varepsilon_{mp}$ =0.0013pJ/(bit · m4) , $\varepsilon_{fs}$ =10pJ/(bit · m2) , $E_{elec}$ =0.5J. The packet size is 600bits. In order to compare, this experiment takes $c$ =0.5, $\rho$ =0.5, and the energy consumption of data fusion is ignored. Figure 1 shows the number change of the total survival nodes with the rounds. Figure 2 shows the change of the total residual energy with the rounds.

Simulation result from figure 1 shows that the failure time of the paper lags behind EEUC and EBUCA protocol, both for the first node and the last node. In the paper, cluster head selection which is considered residual energy, average residual energy of neighbor nodes and average distance from neighbor nodes to the node is better for balancing energy consumption and prolonging the network service time.

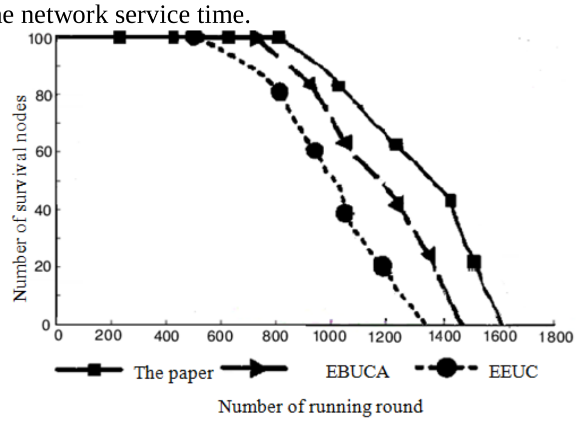


Fig. 1. Number comparison of survival nodes

Simulation result from Fig. 2 shows that the energy consumption resulted from the paper is slower than

EEUC and EBUCA protocol, and the longer the time is, the more obvious the effect is. The network service time resulted from the paper is longer than EEUC and EBUCA protocol.

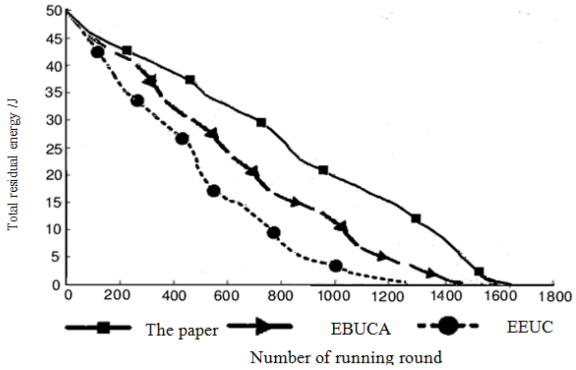


Fig. 2. Comparison of total residual energy

## V. Conclusion

In this paper, we used the idea of unequal clustering to calculate the radius of nodes, and have put forward an improved unequal clustering routing protocol for wireless sensor networks. In the protocol, each node calculates the competition time of cluster head according to the residual energy of nodes, average energy of neighbor nodes and average distance between neighbor nodes, and cluster heads are selected by time sequence method. Regarding the data communication between cluster heads and Sink node, a minimum spanning tree is constructed according with the residual energy of cluster heads and the distance between two cluster heads, and an optimal data transmission path has been selected to transmit data by multi-hop. The Simulation results show that the protocol of the people can efficiently balance and reduce the energy consumption, and prolong the service time of the wireless sensor networks.

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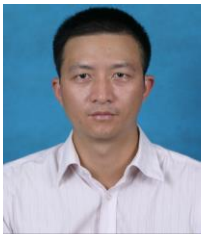

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