

WSN multi-hop routing algorithm based on non-uniform clustering

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ABSTRACT

In order to prolong network life, improve network throughput and reduce energy consumption within the network of WSN, a multi-hop routing algorithm for WSN based on non-uniform clustering is proposed in this paper. This protocol effectively alleviates the problem that in the multi-hop data transmission network, the cluster head close to the base station bears too many tasks, and the energy consumption is high, which leads to the premature death of the node. The cluster heads within the direct communication radius in the network will communicate directly with the base station, and the other cluster heads will select the neighbor cluster heads with the least communication cost as relay nodes for multi-hop transmission. Finally, the simulation results show that the protocol can effectively alleviate the premature aging phenomenon in the multi-hop network, and the energy consumption of the nodes in the system is balanced, which meets the design requirements of the wireless sensor network routing protocol.

Keywords: Wireless sensor network, low energy adaptive clustering hierarchy (LEACH) protocol, low energy consumption, clustering algorithm, multi-hop

1. INTRODUCTION

Wireless sensor node can monitor various environmental states such as temperature, humidity, brightness, pressure, noise, speed and direction of moving objects in real time¹. Different from traditional networks, the data that WSN needs to transmit basically does not involve intensive data such as voice, video, and images, so the demand for bandwidth is not high. But the areas that WSN needs to monitor, such as deserts, ponds, forests, etc., are hard-to-reach areas for humans. However, the nodes of WSNs are usually small in size, and the energy carried by the power supply is very limited², so our priority is to find an algorithm that can be implemented to effectively reduce battery power consumption³. In order to solve the energy problem faced by wireless sensor networks, the LEACH protocol, which has great research significance in the clustering protocol, is preferred in this paper. However, the LEACH protocol selects CH probabilistically according to the set threshold, so that the energy and position of the selected cluster heads are not necessarily optimal. LEACH itself has many shortcomings. Using the original protocol cannot maximize the energy utilization rate of the sensor, and cannot be directly put into the actual network. It needs to be improved.

In response to the above problems, many scholars have proposed a variety of methods to optimize LEACH from different angles. The EEUC algorithm⁴ adopts a non-uniform clustering method, but it needs to randomly select cluster heads periodically, and the selected cluster heads may not be optimal. The DEEC algorithm proposed in Reference⁵ adopts a single-hop transmission mode in the communication, so the cluster head has a heavy energy load and will die earlier than ordinary nodes⁶. The energy balance routing algorithm proposed in Reference⁷ does not consider the selection of the optimal path^{8,9}. Reference¹⁰ does not consider the residual energy of the cluster head in the non-uniform cluster head election process. The algorithm¹¹ adopts the ZigBee distributed address allocation strategy. The algorithm does not change the CH in real time with the relative distance between the surviving communication nodes in the network. The IMP-LEACH algorithm¹² only takes into account the residual energy factor^{13,14} when selecting the CH, and does not take into account the distance factor¹⁵.

Aiming at the problems existing in the current WSNs routing algorithm, this paper proposes an improved routing algorithm EEM-LEACH (An energy efficient multi-hop WSNs clustering optimization algorithm) based on LEACH and multi-hop routing protocol. The algorithm uses the weighting idea to improve the LEACH algorithm, so that the node generates a weight based on energy and density, and selects the cluster head through the probability threshold of this weight, and then generates the entire cluster. The weight comprehensively considers the network environment and its

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own state of the node. The more neighbor nodes where the node is located, the higher the percentage of members in the cluster, the greater the density, and the greater the probability of becoming the cluster head. At the same time, the greater the residual energy of the node, the greater the weight, and the greater the probability of becoming the cluster head node.

2. IMPROVED ALGORITHM EEM-LEACH

2.1 Cluster head selection process

The first stage is the establishment of clusters, which is randomly selected in the traditional LEACH protocol. In this way, if a sensor node has less remaining energy or is far away from the sink node, it will still be elected as the cluster head multiple times, and the node will increase energy consumption in a short time and lose its function prematurely. Different from the traditional idea, the algorithm in this paper does not adopt the strategy of randomly selecting cluster heads. During cluster head selection, the remaining energy of nodes in the network needs to be given priority. First, query the remaining energy $E(i)_{res}$ of each node. Then, the average residual energy of the network is estimated according to the network model. The average remaining energy E_{avg} is then calculated¹⁶.

$$E_{avg} = \frac{\sum_{i=1}^n E(i)_{res}}{n} \quad (1)$$

The following equation is the calculation equation of the threshold $T(n)$ after the adjustment of the EEM-LEACH algorithm

$$T(n) = \frac{p}{1 - p[(r+1) \bmod (1/p)]} \times \left(w_1 \times \frac{E(i)_{res}}{E_{avg}} + w_2 \times \frac{1}{\sum_{i=1}^n d_{(i,j)}^2 + d_{(i,BS)}^2} \right) \quad (2)$$

among them, $d_{(i,BS)}^2$ represents the square of the distance from the candidate CH i to the BS . $d_{(i,j)}^2$ is the square of the distance from the candidate CH i to the neighbor node j . w_1 and w_2 are the weighting coefficients used to adjust the influence of each item in the equation on the node threshold.

The prerequisite for a node to be elected as the CH is that the random number generated by $rand(1,1)$ is less than the threshold $T(n)$. The above process is repeated until all the cluster heads in the round are selected¹⁷. Equation (2) makes it easier to select the node that is closer to the neighbor node, closer to the base station, and higher residual energy as the cluster head.

The descriptive pseudocode of the specific CH selection process is as follows:

Algorithm 1: Cluster head selection strategy

Input: Network initialization conditions

Output: Whether the node is CH

for $i=0 : n$

 if the energy of the node $E(i) > 0$

 if the node has never been elected as CH in this cycle

$T = p / (1 - p[(r+1) \bmod (1/p)])$

$Q = \sum_{i=1}^n d_{(i,j)}^2 + d_{(i,BS)}^2$

 temp_rand = rand(1,1)

 if temp_rand < $T * (w_1 * (E(i)_{res} / E(i)_{avg}) + w_2 * (1/Q))$ and node to base station distance $d >$ the

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        communication radius R of the node
            the node is CH
        else
            the node is MN
        end if
    else
        the type of the node is a normal node
    end if
end if
end for

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2.2 Node clustering process

Each node stores a table of information about the cluster head node, including ID, status, remaining energy, node location information, and the number of neighbor nodes corresponding to the CH. Common nodes join the CH with the smallest $C(i)$, and the cost function $C(i)$ is

$$C(i) = w_{c1} \times \frac{d(i, CH)}{d_{\max}(i, BS)} + w_{c2} \times \frac{|N(CH)|}{n} + w_{c3} \times \frac{E_0}{E(CH)} \quad (3)$$

among them, $d(i, CH)$ is the distance between the normal node and CH, $d_{\max}(i, BS)$ is the maximum distance between the normal node and BS , and $|N(CH)|$ is the number of neighbor nodes joining the CH . E_0 represents the initial energy of the node, $E(CH)$ is the current remaining energy of the CH , and w_{c1} , w_{c2} and w_{c3} are the weighting coefficients. The goal of constructing the above function is to select the best cluster for nodes to join with the lowest energy consumption.

The normal node selects the CH that is closer to the node position, closer to the BS, less number of clustering nodes and more residual energy according to equation (3) to apply for joining, and complete the clustering process. This measure is conducive to reliable communication between nodes and energy balance within the cluster.

The descriptive pseudocode of the specific node clustering process is as follows:

Algorithm 2: Node clustering strategy

Input: Normal Nodes and CH

Output: Network clustering results

for $i=0 : n$

 if the node is a common node && the node's energy > 0

 calculate the $C(i)$ of all CH

 find the CH with the smallest $C(i)$

 if the distance d from the node to the CH is less than the communication radius R

 the node applies to join the cluster

 else if $d > R$

 the node selects the cluster head closest to itself to apply for clustering

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else
    the common node communicates directly with the base station.
end if
end if
end for

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2.3 Inter-cluster communication process

The cluster head node undertakes the functions of data reception and fusion and data packet forwarding of the cluster member nodes, so the energy saving and energy consumption balance of the cluster head node are the key research contents. When the distance is greater than the critical value of the communication radius, the energy consumption will change significantly even if the distance increases a little. The short-distance transmission energy consumption is proportional to the square of the distance, and the energy consumption will not have a great impact with the increase of the distance. Therefore, it is necessary to shorten the transmission distance as much as possible, and divide the long-distance transmission path into multiple shorter short-distance paths for sequential transmission. The EEM-LEACH algorithm adopts a multi-hop transmission method between clusters, in which the relay nodes in the transmission path are selected from the cluster head. Inter-cluster communication transmission rules are as follows (The communication radius is denoted by R):

- $d \leq R$: Nodes communicate directly with base stations.
- $d > R$: Common nodes transmit data to the CH of this cluster.
- $d > R$: The CH transmits the data to the relay node.

The CH selects the neighbor cluster head node with few cluster nodes, high residual energy, close to the BS and close to the CH as the relay node through the relay forwarding function $R(i, j)$. Therefore, it is necessary to select a node with a larger $R(i, j)$ value as the next forwarding cluster head.

The function $R(i, j)$ is expressed by the following equation:

$$R(i, j) = d_{ij} \times \frac{E(j)_{res}}{\sum_{j=1}^m E(j)_{res}} \times \frac{1/|N(j)|}{\sum_{j=1}^m 1/|N(j)|} \quad (4)$$

where d_{ij} in equation (4) is as follows:

$$d_{ij} = 1/\sqrt{d_{(i,j)}^2 + d_{(j,BS)}^2} \quad (5)$$

among them, j is the neighbor cluster head node. m is the number of nodes within the communication radius of i . $E(j)_{res}$ represents the remaining energy of j , and $|N(j)|$ is the number of cluster nodes of j .

- The relay node continues to select the transmission path according to the method in the above steps until the data is transmitted to the BS.

The descriptive pseudocode of the multi-hop transmission process between clusters of the algorithm is as follows:

Algorithm 3: Inter-cluster communication strategy

Input: Initialization conditions for the network

Output: network data transmission routing

for $i=0$ to the total number of nodes n

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if d < R
    nodes communicate directly with base stations
else
    if the node type is normal node
        nodes communicate with their cluster heads
    else
        select the former cluster head node with larger R(i,j) as the relay node
        transfer data to relay nodes
    end if
end if
end for

```

3. SIMULATION RESULTS AND ANALYSIS

This paper uses MATLAB to simulate the LEACH, DEEC, IMP-LEACH and EEM-LEACH algorithms in two different scenarios. The two scenarios are a small area of $100 \times 100 \text{ m}^2$ and a large area of $200 \times 200 \text{ m}^2$. The specific simulation parameter settings are shown in Table 1.

Table 1. The simulation parameters.

Parameter	Value
Network size	100 m *100m/200 m *200 m
Number of nodes	100
Probability of CH selection	0.1
Location of BS	(50, 50)/(100, 100)
Initial energy of normal node, E_0	0.2J
Packet size	4000bits
Control message size	32bits
Data transmission rate	5000 bps
Radio electronics energy, $E_{Tx} = E_{Rx}$	50 nJ/bit
Energy for data-aggregation, E_{DA}	5 nJ/bit
Radio amplifier energy, ϵ_{fs}	100 pJ/bit/m ²
Radio amplifier energy, ϵ_{mp}	0.0013 pJ/bit/m ⁴
W_1, W_2	0.6, 0.4
W_{c1}, W_{c2}, W_{c3}	0.5, 0.3, 0.2
Running rounds	1000

Figures 1 and 2 are the node distribution diagrams of 100 sensor nodes randomly deployed in $100 \times 100 \text{ m}^2$ and $200 \times 200 \text{ m}^2$ monitoring areas, respectively.

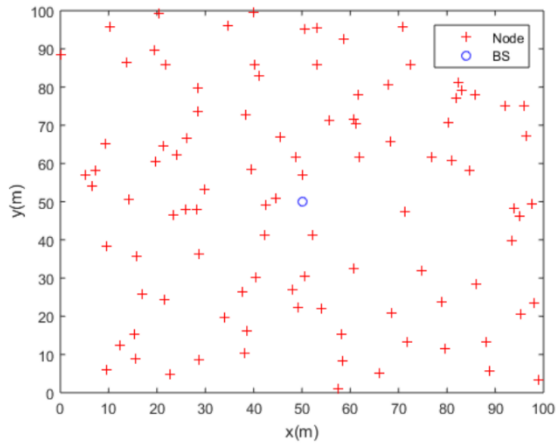


Figure 1. 100×100m² Node distribution.

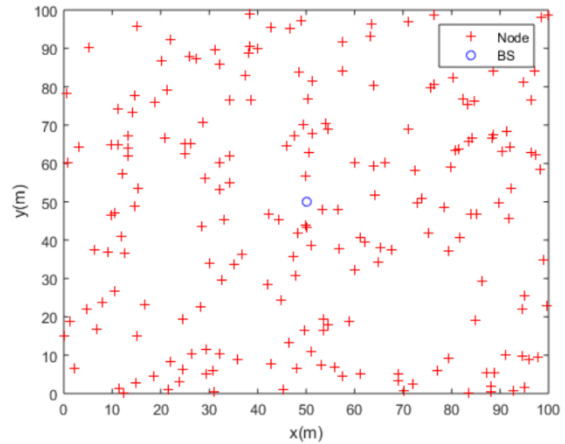


Figure 2. 200×200m² Node distribution.

3.1 Network lifecycle comparison

It can be seen from Figures 3 and 4 that as the number of sensor network data collection increases, the number of dead nodes increases, but the number of dead nodes in the EEM-LEACH algorithm is relatively lower than other algorithms under the monitoring area of 100×100 m² and 200×200 m², so the algorithm proposed in this paper fully considers the energy balance.

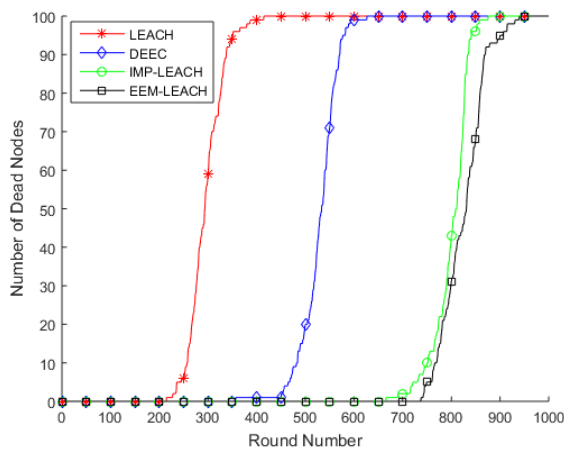


Figure 3. 100×100 m² Life cycle comparison.

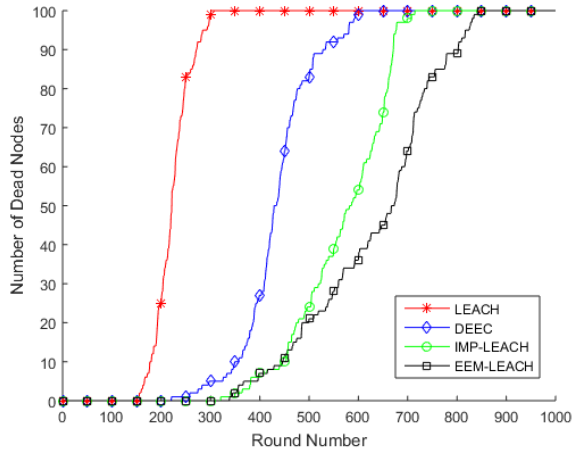


Figure 4. 200×200 m² Life cycle comparison.

3.2 Network residual energy comparison

The amount of energy remaining in the network determines how long a node can work. When the remaining energy is 0, the network loses its use value. From Figures 5 and 6, it can be concluded that with the increase of the number of sensor network data collection, the average residual energy of the four routing protocols gradually decreases, but the residual energy of the EEM-LEACH algorithm is relatively higher than other algorithms under the monitoring areas of 100×100 m² and 200×200 m².

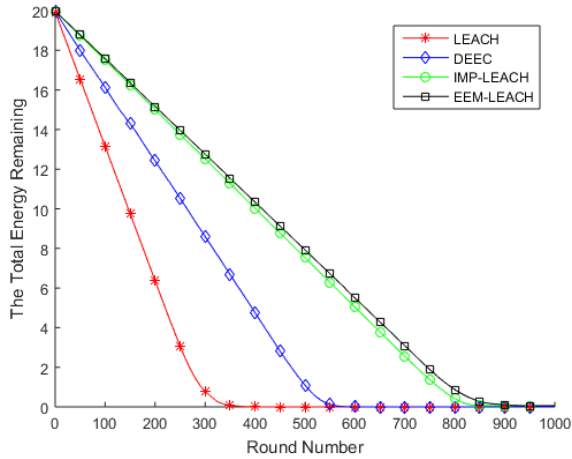


Figure 5. 100×100 m² residual energy contrast.

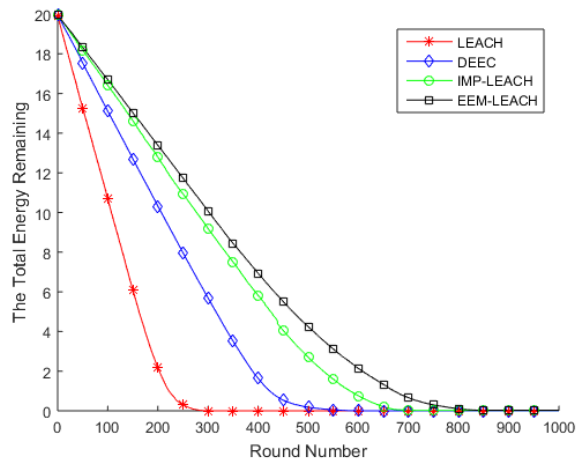


Figure 6. 200×200 m² residual energy contrast.

3.3 Network throughput comparison

From Figures 7 and 8, it can be concluded that with the increase of the number of sensor network data collection, the amount of data received by the base station of the EEM-LEACH algorithm is gradually larger than that of the other three algorithms. It can be seen that the strategy of determining the relay nodes between clusters according to the relay forwarding function is feasible.

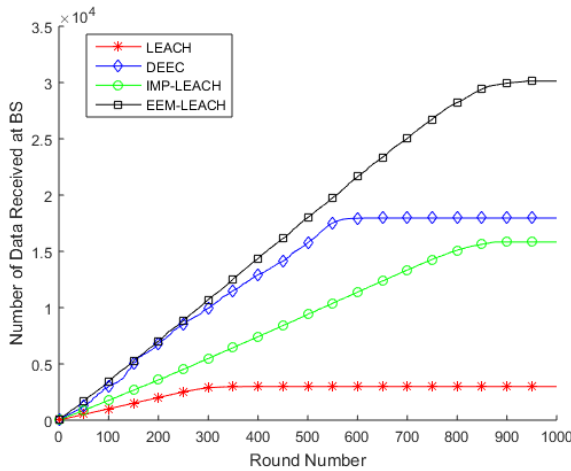


Figure 7. 100×100 m² throughput comparison.

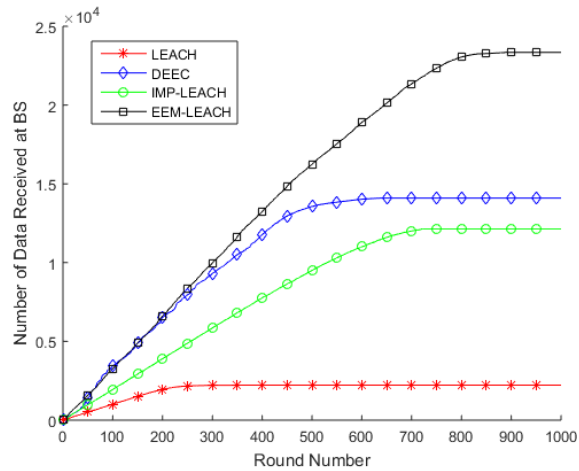


Figure 8. 200×200 m² throughput comparison.

4. CONCLUSION

Aiming at the problems of uneven cluster head selection and unbalanced energy consumption in traditional clustering algorithms, this paper proposes a multi-hop routing algorithm for WSN based on non-uniform clustering, EEM-LEACH. This algorithm applies a more reasonable cluster head selection mechanism and a more uniform clustering strategy. In this algorithm, the information transfer between each node and base station adopts the hybrid energy-saving matching mode of single-hop or multi-hop between clusters, which makes up for the deficiency of traditional single-hop routing algorithm. According to the “relay forwarding function election method”, the only best forwarding node is finally determined, and the link formed by several forwarding cluster heads becomes the inter-cluster transmission path of this “round”. Finally, the simulation results verify the effectiveness of the EEM-LEACH algorithm in improving the relevant operational indicators of WSN.

REFERENCES

- [1] Zhang, D. and Zhang, L., "Double cluster head selection algorithm for WSN dynamic trust based on k-means," *Journal of Nanjing University of Posts and Telecommunications*, 40(2):108-114(2020).
- [2] Qian, Z. H. and Wang, Y. J., "Overview of wireless sensor networks for Internet of things," *Journal of Electronics & Information Technology*, 35(1), 215-227(2013).
- [3] Yang, Z. Q. and Lv, W., "Research on wireless sensor network design for the Internet of Things," *Digital Communication World*, 03(1), 57-58(2018).
- [4] Li, C. F. and Chen, G. H., "A wireless sensor network routing protocol based on non-uniform clustering," *Chinese Journal of Computers*, 30(1), 27-36(2007).
- [5] Qing, L., Zhu, Q. X., Wang, M. W., "Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks," *Computer Communications*, 17(3), 481-489(2006).
- [6] Li, Q., Zhu, Q. and Wang, M., "Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks," *Computer Communications*, 29(12), 2230-2237(2006).
- [7] Li, L. Y., Jiang, X. L., Zhong, S. H., et al., "Energy balancing clustering algorithm for wireless sensor network," 2009 International Conference on Networks Security, Wireless Communications and Trusted Computing, Wuhan, 61-64(2009).
- [8] Yang, T., Bai, Y. L. and Jiang, X. H., "Wireless sensor network routing based on improved ant colony algorithm," *Journal of Inner Mongolia University*, 46(1), 92-96(2015).
- [9] Yu, Y., "Research and design of energy efficient routing protocol for heterogeneous wireless sensor networks," *China University of Mining and Technology*, 6, 72-141(2020).
- [10] Zhang, M. C., Xue, A. R. and Wang, W., "Non-uniform cluster routing algorithm based on minimum spanning tree," *Journal of Computer Applications*, 32(3), 787-790(2012).
- [11] Zhao, L., Lan, Z. G. and Xiong, Z. L., "Improved algorithm for selecting cluster heads in wireless sensor networks based on LEACH," *Journal of Electronic Measurement and Instrument*, 33(12), 86-93(2019).
- [12] Pan, H., Chen, J. P., Ding, K., et al., "A LEACH protocol optimization based on multi-hop and data volume-distance distribution," *Electronics Optics & Control*, 25(11), 89-92(2018).
- [13] Cui, Y. N., Wei, W. and Hu, Y. H., "Improved routing of LEACH based on particle swarm optimization in WSN," *Journal of the Chinese Academy of Electronic Sciences*, 14(11), 1169-1173(2019).
- [14] Zhang, X., "Research on the model and method of security technology fusion in wireless sensor network," *Beijing University of Technology*, 3, 65-131(2011).
- [15] Zheng, H. H., Bai, Y. X., Zhang, Y. Q., "Wireless sensor network routing protocol applied in mine roadway," *Microcomputer Applications*, 36(9), 15-17(2020).
- [16] Wang, Q., Liu, W., Wang, T., et al., "Reducing delay and maximizing lifetime for wireless sensor networks with dynamic traffic patterns," *IEEE Access*, (99), 1-1(2019).
- [17] Yu, X. W., Li, Y., Liu, Y., et al., "WSN clustering routing algorithm based on hybrid genetic tabu search," *Wireless Personal Communications*, 124, 3485-3506(2022).