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Energy-Saving Algorithm and Simulation of Wireless Sensor Networks Based on Clustering Routing Protocol

WEI HE
School of Electronic and Engineering, Xi'an University of Posts and Telecommunications, Xi'an 710121, China
e-mail: hewei@xupt.edu.cn

ABSTRACT An efficient and energy-saving algorithm, K-means and FAH (KAF), has been proposed to solve the problems of node energy constraints, short network cycle and low throughput in current wireless sensor networks. Network clustering is obtained by optimizing K-means clustering. Based on FAHP (Fuzzy Analytic Hierarchy Process) method, the cluster head selection is optimized considering the factors of node energy, distance from base station and energy efficiency of nodes. Based on the factors of transmission distance, energy and hop number, multi-hop routing is constructed to effectively reduce the energy consumption of nodes in data transmission. The simulation results show that compared with other protocols, KAF algorithm has obvious advantages in reducing node energy consumption, prolonging network life cycle and increasing network throughput. And under different routing protocol, the performances of the algorithm are verified. By adjusting the size of the candidate node set selection area, the reliability of data transmission of the long-distance node is increased, and the energy consumption load of the near-distance node is reduced. At the same time, the use of opportunistic transmission strategies increases the reliability of data transmission. The simulation results show that the proposed protocol can effectively reduce the energy consumption of nodes and prolong the network life cycle.

INDEX TERMS Wireless sensor networks, K-means clustering, multi-hop routing, energy-saving.

I. INTRODUCTION

In the applications of WSN (Wireless Sensor Network), once the sensor nodes have been deployed in the monitoring area, it is often difficult to perform subsequent maintenance [1]–[4]. These nodes are self-organized into a network system by mutual coordination, and the data collected from the monitoring area is transmitted to the base station [5], [6].

In general, a WSN will have many sensor nodes, and adjacent nodes can communicate with each other [7]. The data collected by each node usually needs to be transmitted to the base station through multiple intermediate nodes in a multi-hop forwarding manner. WSN is an energy-constrained network [8], [9]. Network node data requires the participation of a routing protocol for efficient transmission. Meanwhile, a routing protocol needs to be selected. This is one of the hot spots for WSN research [10]. Here, the WSN routing protocol can be regarded as a method of data transmission path to implement searching from the data source node to the target node [11]. There are two main methods of implementation [12]–[15]: one is to establish a suitable data transmission link, and the other is to correctly transmit datagram along the established data link. In the traditional Ad hoc network, the primary purpose of routing protocol design is to utilize the limited bandwidth resources of the network [16]. Therefore, a path with a small communication delay is usually found between the two kinds nodes to balance network traffic, avoid channel congestion, and improve network utilization [17], [18]. However, unlike traditional Ad hoc networks, the inherent characteristics of WSN make the design of their routing protocols more challenging [7], [19], [20]. First, the WSN resources are limited, including the energy of the node, data processing and storage capacity, bandwidth of the wireless channel, etc., so the routing protocol designed for WSN must operate in a different way. Secondly, the allocation of nodes in the WSN in the surveillance area is irregular, and considering the economic cost of the sensor nodes, most nodes will not be assisted by the Global Positioning

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System (GPS). Therefore, sensor nodes are not familiar with the location information of their place, and the accuracy of specific location-related information is also greatly limited. The extra cost required to maintain the global network topology information is very expensive, so the traditional IP-based routing protocol is not suitable for application to the WSN. When designing the WSN routing protocol, first, the problem of node energy limitation needs to be considered, secondly, each sensor node can only use the node topology information in the adjacent area to select the appropriate data forwarding path, finally, WSN has strong application relevance, and the data collected by nodes usually has strong similarity and needs to be processed by data fusion. Therefore, in addition to being used for normal data forwarding, the WSN routing protocol is also used to ensure efficient use of node energy. This will bring the energy consumption between the nodes to a balanced state, which will eventually make the network use longer.

Some scholars and researchers have proposed a classic low-power adaptive clustering hierarchical protocol LEACH protocol [21], [22]. For the first time, the LEACH protocol proposed the concept of "polling" in the routing field [23]. The idea of dynamic clustering became the basic idea of hierarchical routing [24]. In recent years, through in-depth research on the LEACH cluster idea, relevant researchers have proposed some new routing protocols [25].

In this paper, based on K-means and fuzzy comprehensive evaluation method-KAF (K-means and FAHP) algorithm, the clustering structure is optimized according to the improved K-means clustering model. Considering the distance between nodes, energy, load capacity and other factors, the multi-hop routing mode during data transmission is optimized, the transmission energy consumption is reduced and the network has a longer usage time. We first use the Fuzzy Hierarchical Comprehensive Assessment to get the information to provide the evidence for the optimizing routing protocol, and then, the KAF algorithm is used to optimize the routing protocol.

In large-scale "many-to-one" WSN, this paper uses the broadcast characteristics of opportunistic routing to increase the data transmission success rate for the unreliable data transmission of remote nodes. Due to the heavy load of the near-end node data transmission, when the candidate set is selected, the communication cost is reduced by selecting the direction and angle constraints of the candidate set, and the heterogeneous candidate node set is selected according to the geographical location information of the node, thereby reducing the energy consumption difference of the nodes in different regions. Finally, the effects of the proposed protocol on equalizing energy consumption and network lifetime are verified by simulation experiments.

The rest of this paper is organized as follows. Section 2 introduces the relevant methods, Section 3 studies WSN multi-hop clustering routing protocol for the energy acquisition, Section 4 is the simulation experiment results and discussion, and Section 5 summarizes the full text.

II. METHOD

A. CHARACTERISTICS OF THE METHOD

The characteristics of the network model used in the algorithm are as follows [26]: (1) The nodes are randomly deployed within the monitoring environment. (2) The positions of the nodes and base stations are fixed and not movable. (3) The receiver node calculates the distance between the two according to the transmit power of the sender node. (4) The sensor nodes are of the same type and have the capability of data fusion, and can communicate with each other and have unique numbers.

B. PARTITION OF CLUSTERS

In the beginning, the clustering of nodes was based on the K-means algorithm [27]. However, in this case, the final result of the cluster is prone to produce a local optimal solution, which we do not want to see. To this end, we introduce an optimization algorithm, namely ant colony clustering algorithm. However, K-means clustering will allocate nodes nearby, and the energy consumed by the network will vary with the distance of transmission. Farther away, it will add extra energy. In order not to overload the energy head, the effect of residual energy is considered. The node cluster can be optimized by the weight function (Formula 1).

$$f(i,j) = \omega \frac{E_i}{d\left(i, CH_j\right)} + (1-\omega)\frac{E_{CH_j}}{d\left(CH_j, BS\right)} \tag{1}$$

C. CLUSTER HEAD COMPETITION

When we select, the fuzzy hierarchical comprehensive evaluation method is adopted, and the cluster head is selected. The main steps are as follows.

1) Judge matrix A based on 9 scale method.

2) Calculate the product of the elements of each row in $n \times n$ matrix A (Formula 2).

$$M_i = \prod_{j=1}^{n} a_{ij} \tag{2}$$

3) The nth root of M_i is calculated to obtain a new vector B (Formula 3).

$$B_i = \sqrt[n]{M_i} \tag{3}$$

4) Normalize vector B to get vector G (Formula 4).

$$G = \{g_1, g_2, \ldots, g_n, \}, \quad g_i = B_i / \sum_{i=1}^{n} B_i \tag{4}$$

5) Calculate the product of matrix A and vector G to get the weight vector W.

6) Calculate the maximum eigenvalue (Formula 5).

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{w_i}{ng_i} \tag{5}$$

7) Verify maximum eigenvalue consistency (Formula 6).

$$CR = \frac{CT}{RI} = \frac{\lambda_{\max} - n}{RI \times (n-1)} \tag{6}$$

where RI is the average random consistency indicator, and the table can be used to obtain specific values. n is the order of the matrix A.

8) If the calculated CR value is less than 0.1, indicating that the finally obtained weight vector W is acceptable.

9) Determining the set of factors formed by the evaluation indicators of the nodes in the cluster U = (u1, u2, u3, ..., un).

10) Determine the evaluation object, that is, all nodes in the cluster that may be selected as CH. According to step (8), determine the | uij | value of node i at the evaluation index j.

11) Determine the evaluation matrix R = | rij | (Formula 7).

$$r_{ij} = C\left(u_{ij}\right) = \frac{u_{ij} - u_{\min}}{u_{\max} - u_{\min}} \quad (7)$$

In the formula, u_{max} and u_{min} are the maximum and minimum values of all evaluation objects at the evaluation index j.

12) The weight of the evaluation index obtained by the analytic hierarchy process. Calculate W × R to obtain the evaluation result vector B of each object, and normalize the operation of B to obtain the probability.

D. DATA FORWARDING

In terms of forwarding node data, the KAF algorithm needs to adopt a multi-hop routing method [25]. All CH and base stations (BS) form a connected undirected graph. In the undirected graph, there are one or more transmission paths between CH and the optimal path can be judged by the following criteria: 1) The energy consumed by this path. 2) The number of hops that the path passes to the base station.

Finally, use the weight function (Formula 8) to evaluate whether the path is optimal.

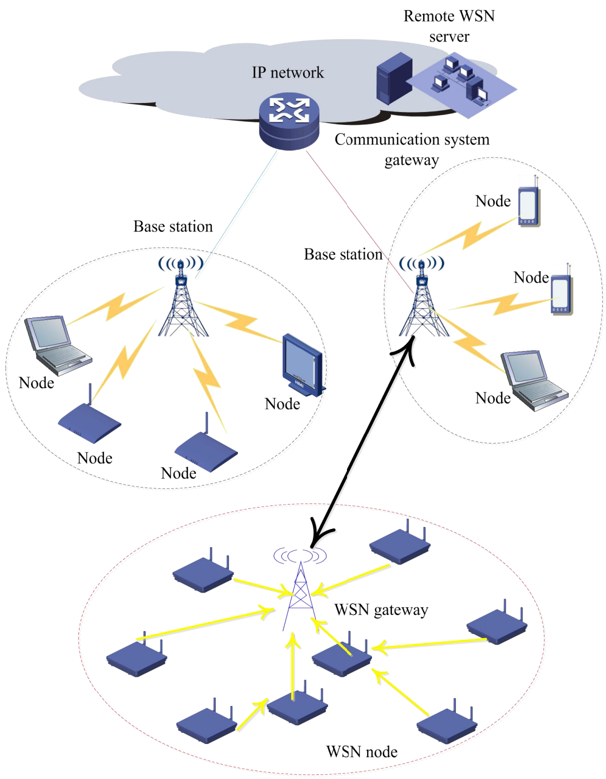
$$Max(fp) = \frac{\alpha}{E_c} + \beta \times E_{t\_E} + \frac{\gamma}{hop\_mum} \quad (8)$$

One of the paths to transmit data is selected, the fitness value of the path is calculated according to Formula 8, and the optimal path for data forwarding is selected.

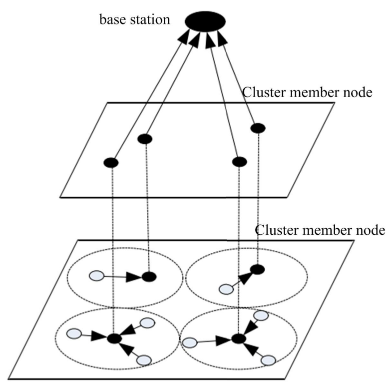
III. RESEARCH ON WSN MULTI-HOP CLUSTERING ROUTING PROTOCOL FOR ENERGY ACQUISITION

A. SYSTEM MODEL AND PROBLEM DESCRIPTION

As shown in Figure 1(a), if you need to allocate many sensor nodes in a large area of surveillance, only one base station is obviously not enough. In order to efficiently collect data from these nodes, multiple nodes are often required. If it is a circular monitoring area with a relatively small area, only one base station is needed, as shown in Figure 1(b), at which time the sensor node can independently collect and transmit data. In this chapter, it is assumed that this subnet is composed of chargeable sensor nodes, and the clustering routing problem in this subnet will be solved. Assuming that the area of the circular monitoring area corresponding to the subnet, the monitoring area can be divided into concentric annular units of equal size, and the area of each unit is a. In order to achieve efficient data transmission, cluster head nodes located in different units adopt multi-hop mode. The cluster head node in the i-th unit selects a cluster head node from the i-1th unit before forwarding the data, and uses this node as its own routing node.



(a) Network deployment scenario of WSN



(b) Network model

FIGURE 1. The Network deployment scenario and network model of WSN.

Energy consumption of nodes when transmitting L-bit sensing data is calculated as Formula 9 and 10.

$$E_{tx} = \begin{cases} l \times E_{ele} + l \times \varepsilon_{fs} \times d^2, & d \le d_0 \\ l \times E_{ele} + l \times \varepsilon_{ms} \times d^4, & d > d_0 \end{cases} \quad (9)$$

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{ms}}} \quad (10)$$

d is the physical distance between the nodes (Formula 12).

$$E_r = l \times E_{ele} \tag{11}$$

$$d_{ij} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{12}$$

where (x_1, y_1) and (x_2, y_2) are the coordinates of the two nodes.

In a clustered routing protocol, all cluster head nodes in the network form a backbone network, which is responsible for transmitting data collected by all nodes to the base station. Compared with the common member nodes in the cluster, the cluster head node has more data processing and transmission tasks, and the energy consumption rate is faster. It is necessary to adopt a reasonable mechanism to periodically select the cluster heads. When the cluster head node in the network is selected, the other common nodes adopt different strategies to select the appropriate cluster head node to join the cluster, thereby dividing the entire network into multiple clusters. The larger the size of a cluster, the heavier the data burden of the cluster head node and the higher the energy consumption rate. It is requisite to reasonably control the cluster size and balance the energy consumption between the cluster head nodes. It is the core technology of WSN based on clustering structure routing protocol research.

B. ENERGY CONSTRAINT AND ENERGY BALANCE

The characteristics of the wireless sensor network determine the more stringent requirements for the energy model. The traditional wireless network does not require high energy. The energy model can reflect the energy of the wireless sensor network as long as it reflects the approximate behavior of the network. It must be able to accurately describe the energy consumption. Energy consumption should not only consider the length of the packet, but also the energy consumed by data aggregation.

$$Ecm_i \le T_i P_e \quad (i = 1, 2, \cdots m) \tag{13}$$

$$Ech_i \le n_i T_i P_e - (n_i - 1) Ecm_i \quad (i = 1, 2, \cdots m) \tag{14}$$

where Ecm_i denotes the average energy consumption required for ordinary nodes; Ech_i denotes the average energy consumption required for cluster head nodes in unit i to receive data from cluster members, to fuse data and to forward fused data to routing nodes or base stations; p_e denotes the charging rate of nodes; T_i denotes the transmission cycle; n_i denotes the average energy consumption of each node in unit i.

$$Ecm_i = q(E_{ele} + \varepsilon_{fs} r_i^2) \tag{15}$$

$$\begin{aligned} Ech_i &= \frac{\rho(m-i)\,(s/m)\,aq}{c_i}(2E_{ele} + \varepsilon_{fs} d_i^2) + (n_i - 1) q E_{ele} \\ &= n_i q (1/a - 1) E_{DA} + n_i a q (E_{ele} + \varepsilon_{fs} d_i^2) \end{aligned} \tag{16}$$

where q denotes the length of data packets sent by nodes in each cycle; r_i is the average distance; ρ is the node distribution density; m is the unit number; m is the unit number; S is the area of monitoring area.

The design of the sensor node has been moving towards micro-low power consumption, and the node energy is limited, which results in the data transmission power of the node is limited, the transmission distance can not be too far, and the long-distance data transmission due to the propagation characteristics of the wireless channel will reduce the energy efficiency of the node, so the single-hop clustering routing protocol is only applicable to small-scale networks.

C. DESIGN OF MULTI-HOP ENERGY NEUTRAL CLUSTERING ROUTING PROTOCOL BASED ON FAHP METHOD

Because ordinary nodes consume less energy in a round than the harvested energy, after a certain round (energy accumulation cycle), the energy accumulated by nodes will reach a certain threshold, and then will be eligible for election cluster head. For any node, its n_i-round serves as cluster head once, so the energy accumulation period is n_i. According to formula (14), formula (15) and formula (16), ETh_i is:

$$ETh_i = Ech_i = n_i TP_e - (n_i - 1) Ecm_i \tag{17}$$

In the WSN clustering routing protocol, a clustered structure is used to divide a large-scale network system into multiple smaller networks. The clustering structure reduces the size of the node routing table, so that a single node only needs to store the local network topology information of the cluster in which it is located. Compared to a planar routing topology, a cluster-based network topology is easier to manage. The communication module of the sensor node consumes far less energy in the sleep state than in the idle and transceiver states. The node sleep mechanism is introduced in the clustering routing protocol to ensure that the communication module is in a sleep state for most of the time, and the communication module is started only when data needs to be sent.

Correspondingly, the limited channel resources can be allocated to each cluster in an orthogonal manner, and the cluster head nodes corresponding to the respective clusters independently allocate channel resources to their member nodes independently, thereby reducing the possibility of signal collision between clusters and improving the possibility. For any node j in unit i, the corresponding threshold $Th_{i,j}$ is:

$$Th_{i,j} = \begin{cases} \dfrac{p_i}{1 - p_i(r \bmod \frac{1}{p_i})} & j \in G \\ 0 & otherwise \end{cases} \tag{18}$$

The wireless sensor node is powered by the same power source as the power supply, and cannot be recharged after deployment. Therefore, improving energy efficiency is a primary requirement for an excellent network topology. In the network topology control, the amount of data transmitted is reduced to reduce the power loss. Then, the energy consumption between the nodes is balanced.

Wireless sensor networks are usually large in scale. Since all nodes are randomly deployed, the density is high in the monitoring area, which causes serious interference to the mutual communication between the nodes. Interference can cause the target node between nodes to receive data effectively and cause data to be retransmitted. By reducing the transmit power of the sensor node, interference can be mitigated, power consumption can be saved, and after the interference is reduced, the throughput of the network can be improved.

The wireless communication link is easily affected by the environment, which requires the introduction of a reply mechanism during the data transmission process, and the receiver needs to respond to the sender after receiving the data. The inter-node communication link must have symmetry to ensure that both the sender and the receiver can respond to the data information sent by the other party.

Because the same amount of power consumption of all nodes cannot be achieved, there must be a sequence of node deaths. When the nodes in the network die, the communication link is unstable, or new nodes join, the network topology will occur. It requires the network topology generated by the algorithm of the topology control part to be scalable.

In addition to the above points, the topology is also affected by factors such as the sparsity of the nodes and the degree of nodes. When the node degree of a node in the network is high, it means that there are many neighboring nodes around the node. At this time, the data interaction amount is larger and more complicated, and the network energy consumption is fast. On the contrary, all node degrees are maintained in a reasonable range, which will facilitate data forwarding between nodes in the network and reduce the complexity of the routing protocol. Different application scenarios have different emphasis on the above objectives, and the reasonable weights are given to the above research objectives in combination with actual needs, so that the most suitable topology control algorithm can be studied.

IV. RESULTS AND DISCUSSION

A. EXPERIMENTAL ENVIRONMENT CONFIGURATION

The section starts from two aspects:

(1) Comparing different algorithms under the same routing protocol;

(2) Verifying the reliability of the algorithm under different routing protocols.

The simulation experiment of KAF algorithm was carried out by MATLAB platform (CPU: core i5-9700, 520Gb hard disk), and the experimental results were compared with K-means-based routing (KMR) [10], LEACH and K-means (LEACH-K) [11], K-means and particle swarm optimization (KPSO) [12], energy efficient algorithm based K-means (KEE) [13]. The experimental simulation environment randomly distributes 100 sensing nodes in the 100 m × 90 m region, and the aggregation nodes are located at (49 m, 49 m).

TABLE 1. Parameter settings.

parameter	value
Datagram length(bits)	900
E_{elec} (nJ/bit)	49
E_{Tx} (nJ/bit)	49
E_{Rx} (nJ/bit)	49
ε_{fs} (pJ/bit/m^2)	8
E_{DA} (nJ/bit/message)	6
Node Distribution Density ρ (node/100m^2)	2
Data Fusion Ratio a	0.18
Energy acquisition rate p_e (J/h)	0.49

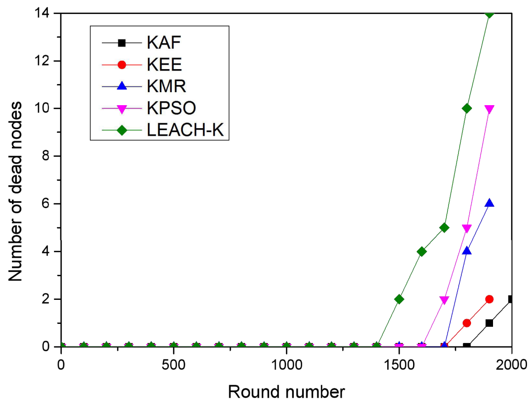


FIGURE 2. Change in the number of dead nodes.

B. EXPERIMENTAL RESULTS COMPARED WITH OTHER ALGORITHMS

Figure 2 shows the trend of the dead nodes of each algorithm as the number of iterations increases. When it is less than 1400 times, no node death occurs in each calculation method. When it is more than 1500 times, the LEACH-K algorithm begins to die. When it is greater than 1600, the KPSO algorithm begins to die. When it is greater than 1700, the KEE and KMR algorithms begin to die. When it is more than 1800, the KAF algorithm begins to die. In the same time, the nodes in LEACH-K die more. The KAF algorithm optimizes the K-means clustering structure and cluster head generation mechanism. The death time of the first node is the latest, which effectively extends the life cycle of the node.

The residual energy of the node is shown in Figure 3. As the round number increases, the remaining energy will decrease. And, this change is linear. When the number of times is reduced, the value of the KPSO algorithm is the smallest.

Figure 4 shows the trend of number of packets transmitted per round for different algorithms. The number of packets received per round using the KEE algorithm is 95. When it reaches 1700 rounds, the number of received packets drops. The number of packets received per round using the LEACH-K, KPSO, and KMR algorithms is 96. When it reaches 1400, 1600, and 1700, the number of packets received

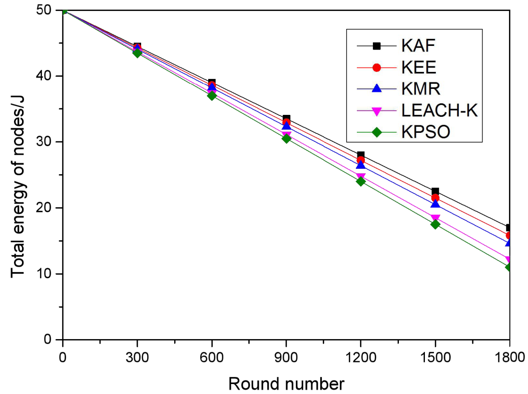


FIGURE 3. **Total energy change of the node.**

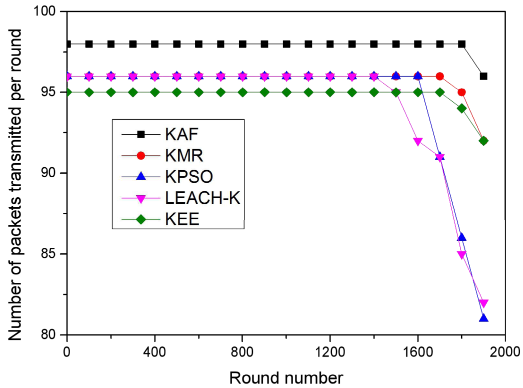


FIGURE 4. **Number of packets transmitted per round.**

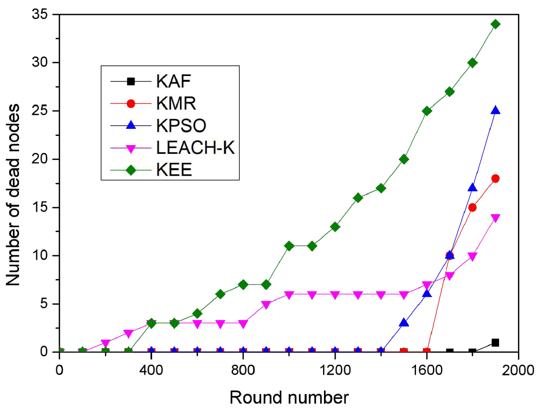


FIGURE 5. **Death node changes at the situation of base station far from the monitoring environment.**

by the LEACH-K, KPSO, and KMR algorithms decreases. The number of packets received per round using the KAF algorithm is 98. When the number of rounds reaches 1800, the received data packet drops. This shows that the KAF algorithm has the maximum number of packets transmitted per round.

Figures 5 and 6 show the trends in the total energy of the dead node and the network when the base station is far

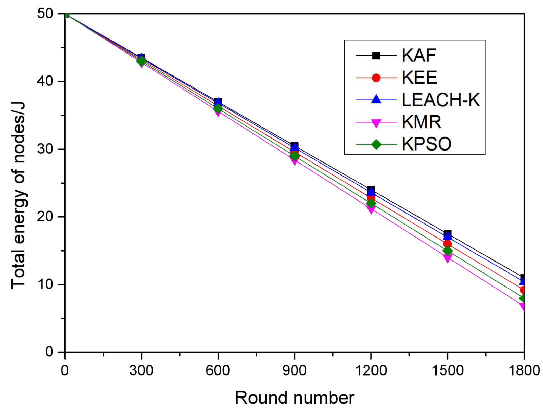


FIGURE 6. **Grid total energy change at the situation of base station far from the monitoring environment.**

from the monitoring environment. It shows that the energy consumption of the node becomes relatively more balanced. This index is optimized because the energy threshold is introduced to determine whether the network needs to perform the routing clustering algorithm globally for cluster head election and whether to perform the election of a new cluster head in the local election. The elections in the global and clusters is saved, thereby saving cluster energy costs.

C. EXPERIMENTAL RESULTS UNDER DIFFERENT rOUTING PROTOCOL

In this section, 500 rounds of data transmission will be simulated. It is assumed that before each round of data transmission, the cluster head node first estimates the required energy according to the number of member nodes in the cluster and the distance between the destination nodes, and then checks whether the remaining energy is sufficient. If the cluster head node does not have enough energy to transfer data, the data will be discarded and the cluster will fail. In addition, in the P-119 protocol, each cluster head node has a dedicated data forwarding node (Relay Node, RN), so if the forwarding node does not have enough energy to forward data, this also means that the cluster is invalid. In evaluating the performance of the MENC protocol, the following four metrics were used: Average Cluster Failure Times per Round (ACFTR), Average Network Throughput per Round (ANTR), Average Network Throughout Second (ANTS) and Average Energy Consumption per Round (AECR). In this paper, ANTR is defined as the average number of data packets successfully received by each base station, and ANTS is defined as the average number of data packets successfully received by the base station per second.

Figure 7 shows the comparison of the per round ACFTR of MENC, ENC, EP-LEACH and P-119 protocols when the data transmission cycle changes. It can be seen from the graph that the ACFTR of the MENC protocol are less than those of the other three protocols, which is attributed to the energy neutral constraints adopted in the MENC protocol to ensure that the nodes are eligible to be selected as cluster heads

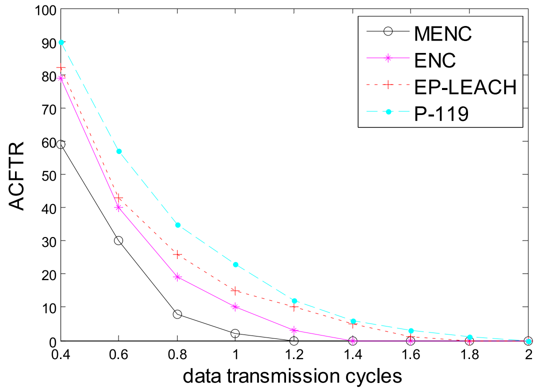


FIGURE 7. The comparison of ACFTR for different data transmission cycles.

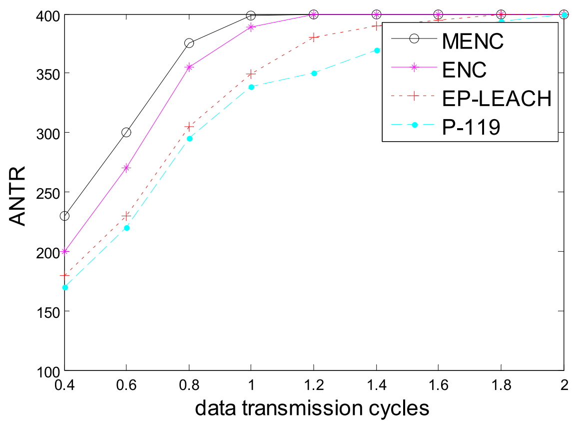


FIGURE 8. The comparison of ANTR for different data transmission cycles.

only when enough energy is harvested from the environment, and the number of members of the corresponding cluster of each cluster head node is controlled within the expected range. Cluster head clustering mechanism is adopted in ENC protocol, which allows multiple nodes in the cluster to act as cluster heads to share the amount of data in the cluster, so the ACFTR of ENC protocol is smaller than that of EP-LEACH and P-119 protocol.

In the ENC protocol, a node with less residual energy can be selected as a member of the cluster head cluster, which increases the possibility of cluster failure, so the ACFTR of the protocol is larger than the ACFTR of the MENC protocol. As the data transmission period increases, the ACFTR of the EP-LEACH protocol is first greater than the P-119 protocol and then less than the P-119 protocol. This is because each cluster head node in the P-119 protocol has a dedicated data forwarding node. Data fusion and forwarding in the cluster are performed by the cluster head node and the forwarding node, respectively.

Figure 8 shows the comparison of the average throughput ANTR of MENC, ENC, EP-LEACH and P-119 protocols per round when the data transmission cycle changes. Figure 8 shows that as the data transfer period increases, the four protocols of the ANTR increase to a maximum of 400. This is because the ACFTR of the four protocols decreases as the

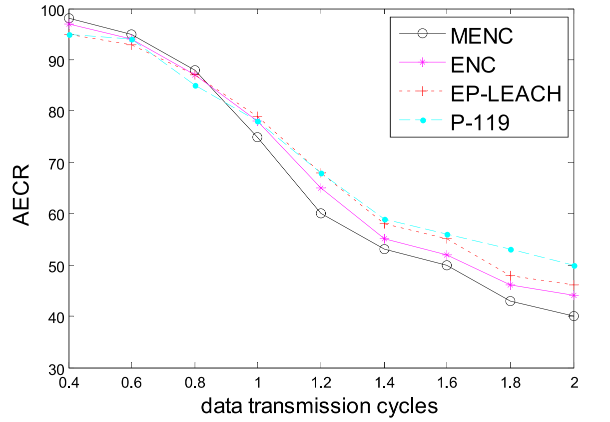


FIGURE 9. The comparison of AECR for different data transmission cycles.

data transmission period increases until the minimum value is zero. In addition, the figure shows that the ANTR of the MENC protocol is greater than the ANTR of the other three protocols before the ATTR of the four protocols reaches the maximum. This is because the ACFTR of the MENC protocol is smaller than the ACFTR of the other three protocols, and the cluster head node in the MENC protocol adopts the multi-hop data transmission mode, thereby making the energy consumption more efficient. In addition, it can be seen intuitively from Figure 8 that the ANTR of the four protocols always changes between 170 and 400, and the upward trend is first presented, and finally remains unchanged after reaching 400.

As shown in Figure 9, the AECR of the four protocols decreases with the increase of the data transmission cycle, because when the data transmission cycle increases, the nodes have more time to obtain energy from the external environment in one round. When the data transmission cycle is less than 0.8T, the cluster failures of the MENC protocol are less than those of the other three protocols, so more cluster-head nodes need to consume energy to transmit data to the base station, resulting in AECR larger than the other three protocols. From Figures 6, 7 and 9, the following conclusions can be drawn: among the four protocols, MENC protocol has the highest energy efficiency. This is because: when the data transmission cycle is greater than 1.2T, the AECR of the MENC protocol is smaller than the other three protocols, while ACFTR is approximately equal to the other three protocols, that is, when the same amount of data is transmitted, the energy consumption of the MENC protocol is less and the efficiency is higher. Because the cluster-head nodes in the MENC protocol adopt multi-hop data transmission mode, and the other three protocols adopt single-hop data transmission mode, the above conclusion is consistent with the conclusion that the energy efficiency of multi-hop inter-cluster data transmission is higher than that of single-hop inter-cluster data transmission.

Figure 10 shows the comparison of the average number of cluster failures per round ACFTR of MENC, ENC, EP-LEACH and P-119 protocols for different sensor field sizes. The cluster-head nodes in the MENC protocol adopt

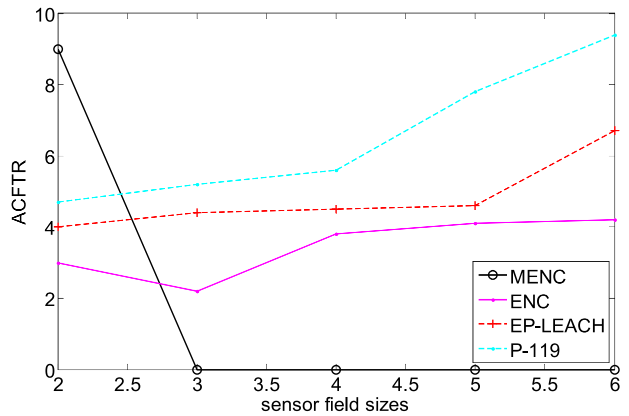


FIGURE 10. The comparison of ACFTR for different sensor field sizes.

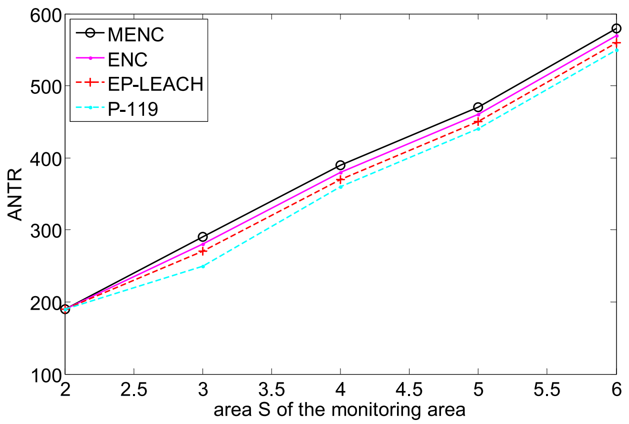


FIGURE 11. The comparison of ANTR for different sensor field sizes.

multi-hop data transmission mode. When the protocol is applied to large-scale networks, the cluster-head nodes do not need to directly transmit data to a longer-distance base station. The graph also shows that the ACFTR of ENC, EP-LEACH and P-119 protocols increases with the increase of the sensor field sizes. Moreover, the ACFTR of the P-119 protocol has been higher than the ACFTR of the ENC and EP-LEACH protocols. However, the ACFTR of the MENC protocol decreases as the sensor field sizes increase until it is zero.

The average throughput ANTR of the MENC, ENC, EP-LEACH and P-119 protocols was compared under area S of the monitoring area. Figure 11 shows that the ANTR of the four protocols increases with the area S of the monitoring area. This is because the total number of nodes in the network is proportional to S. As S increases, more nodes in the network will collect data and send it to the base station. Among them, the ANTR of the MENC protocol is always higher than the ANTR of the other three protocols.

D. NETWORK LIFE CYCLE AND TOTAL NETWORK ENERGY CONSUMPTION

1) NETWORK LIFE CYCLE

The network life cycle is a good test of the performance of the designed routing protocol in terms of energy consumption, which reflects the effectiveness of the network operation, so it is necessary to make a comparative analysis of the network life cycle. Figure 12 shows the change in the number of surviving nodes in the network as the number of survival time / round changes.

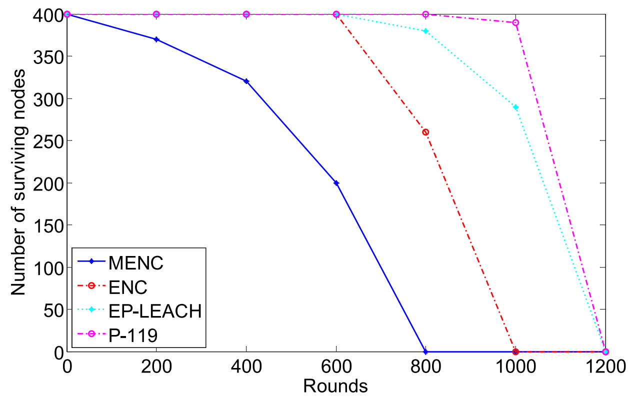


FIGURE 12. Survival time / round.

As can be seen from the figure 12, the P-119 is superior to the other three protocols regardless of the number of failures of the first node or the last node. This is because P-119 utilizes the node average energy equivalent method for clustering, and uses energy protection mechanism to achieve load balancing in the routing process, and uses multiple alternate paths to forward data, effectively balancing the cluster head node energy. Compared with ENC, the P-119 protocol has increased the network lifetime by 40%, which is 15% higher than EP-MENC. This is because the ENC protocol adopts a competition radius strategy in the clustering stage, but only local information is used when establishing routes between clusters, and the energy of the relay node is considered poorly, and the EP-MENC protocol is improved compared with ENC. However, the forwarding path and cluster reconstruction are considered poor. It can be seen that the P-119 protocol effectively extends the network lifetime.

2) TOTAL NETWORK ENERGY CONSUMPTION

The comparison of total network energy consumption is to further prove the superiority and inferiority of the routing protocol in terms of energy consumption. Figure 13 shows the total remaining energy of the network.

As can be seen from the figure 13, in the initial stage of network operation, the energy consumption of the P-119 protocol is significantly lower than that of MENC and ENC, and the network energy consumption of the P-119 protocol is better than the EP-MENC protocol as the rounds increase. This is because the MENC protocol randomly selects the cluster head and broadcasts the cluster information on the whole network. The route is a single hop, which consumes a lot of energy. Although ENC better controls the cluster radius and adopts the multi-hop routing method, the protocol needs to maintain the adjacent cluster head set when

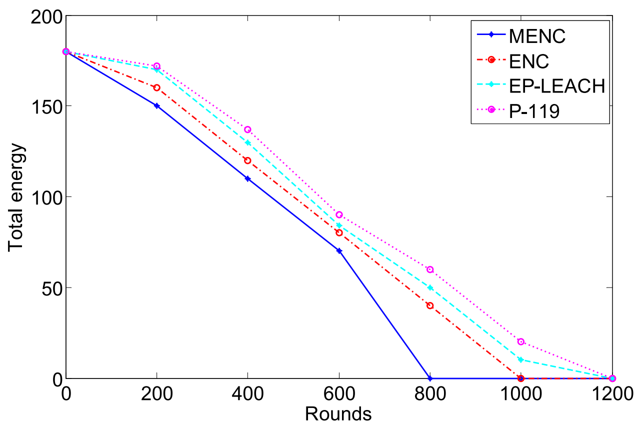


FIGURE 13. Network residual energy for various protocols.

selecting the cluster head, and excessive exchange of information consumes energy. Although the EP-MENC protocol reduces the energy consumption of maintaining the candidate cluster head set compared with ENC, only the energy factor is considered when selecting the cluster head, and the location factor is ignored, and the cluster head selection is not optimized, which is not conducive to reducing the energy consumption of the whole network.

The P-119 protocol consumes less energy in the clustering phase than the MENC, ENC, and EP-MENC protocols, optimizes the cluster head selection, and achieves dynamic multi-hop between clusters, effectively reducing energy consumption.

V. CONCLUSION

In this paper, the network clustering is obtained based on the improved K-means clustering. The fuzzy hierarchical comprehensive evaluation (FAHP) method is used to optimize the cluster head selection. In the stage, the node multi-hop routing method is constructed according to factors such as transmission distance, energy, and hop count. Simulation experiments show that KAF has significant improvements in reducing node energy consumption, extending network life cycle and increasing network throughput. And under different routing protocol, the performances of the algorithm are verified. The data transmission success rate is increased by using an opportunity routing strategy. When the candidate node set is selected, the transmitting node uses its own geographical location information to constrain the direction and angle of the candidate node set selection region, and adjusts the size of the candidate node set selection region to increase the reliability of the long-distance node data transmission and reduce the near-nearness. The simulation results show that the proposed protocol can effectively reduce the energy consumption of nodes, reduce the energy consumption difference between nodes, and prolong the network life cycle. In the next research work, the appropriate distribution function will be constructed to model the energy acquisition ability of the node, taking into account the heterogeneity of the energy acquisition ability of the node and the instability caused by the environment, so as to be closer to the actual situation.

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WEI HE was born in Xi'an, China, in 1968. He received the bachelor's degree from Sidian University, in 1995. From 1993 to 1995, he worked with Xijing Electric Corporation. Since 1995, he has been with the Xi'an University of Posts and Telecommunications. He has published five articles, one of which has also been indexed by SCI. His research interests include electronic engineer and communications engineering.