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Energy-saving and Reliable Routing Mechanism based on FC-GA for Flying Ad Hoc Network

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Abstract

Aiming at the problems of limited node energy, high-speed node movement and reliability of data transmission in flying ad hoc networks, a reliable energy-saving routing optimization mechanism based on fuzzy control genetic algorithm was proposed (FC-GARE). Firstly, the residual energy, moving speed and boundary evaluation factors of the nodes are fuzzy processed, and the candidate forwarding nodes are determined after fuzzy reasoning and defuzzification process. Then genetic algorithm is used to determine the forwarding node. Compared with EEUC and LEACH, the simulation results show that FC-GARE significantly improves the packet delivery rate and energy consumption.

Keywords

Routing Optimization; Reliable Energy-Saving; Fuzzy Control; Genetic Algorithm.

1. Introduction

Flying ad hoc networks (FANETs) is a special mobile ad hoc networks (MANETs) composed of multiple UAVs. The routing mechanisms in MANETs based on topological awareness [1], geographic location [2], beacon-free opportunity [3] and bio-heuristic strategy [4] can improve packet delivery rate, prolong network life cycle and improve network scalability. However, the structure of flying ad hoc networks is highly dynamic, and there are great differences in node density and network deployment compared with MANETs [5]. To ensure the safety and reliability of data between aircraft and base station between aircraft and vehicles and between aircraft to carry out efficient communication is particularly important [6].

Literature [7] proposes a multi-objective routing algorithm for flying ad hoc networks, which takes into account the basic characteristics of FANETs and the transmission performance of routes, as well as the influence of the mobility of UAV nodes and the energy of each node on the entire network, and ensures the lifetime and safety of the network. Chain mechanism combining reinforcement learning and fuzzy logic, according to the performance of the link and the path choice to reach the destination node optimal routing paths, each path with a path parameters of fuzzy system, the link between the parameters including UAVs transmission rate and energy status and flight status, and data delivery and path parameters include the hop rate; Path parameters are dynamically updated by reinforcement learning. Each path of the algorithm has a fuzzy system, which results in high complexity of the algorithm.

Literature [8] proposed a strategy routing mechanism for intersection selection based on fuzzy multi-factor decision making, which is divided into two parts, namely, vehicle decision management and intersection decision management. In vehicle decision management, the distance between vehicles, the number of neighbors and the relative speed are considered when the vehicles at the intersection choose the path. In intersection decision management, candidate nodes are selected from the two-hop neighbors of the current intersection, and the life of each link is considered to obtain the optimal

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routing path. This routing algorithm achieves good performance in the network of vehicles, but it does not consider the constraint condition of node energy consumption and does not satisfy FANETs, which is highly limited by node energy.

In reference [9], a hybrid routing protocol based on fuzzy logic and ant colony algorithm is proposed to eliminate the hot node problem in wireless sensor networks. The routing protocol divides the network into unequal clusters based on the remaining energy of nodes, the distance between nodes and base stations, the distance between nodes and neighbors, the degree of nodes and the degree of node centrality. In addition to periodic data transmission, the protocol also uses threshold concept to transmit and record the emergent situation in the network environment. To achieve load balancing, a new routing strategy is adopted, in which threshold-based data transmission takes place in the shortest path and periodic data transmission takes place in the unused path. Compared with existing protocols, the proposed method achieves the maximum lifetime, eliminates the hot nodes, and effectively balances the energy consumption between nodes.

Literature [10] proposed a directional location routing mechanism based on fuzzy logic. In order to select the optimal relay node for efficient and reliable data transmission, this mechanism takes the distance between nodes, node speed, proximity, node data transmission rate and node movement direction as a fuzzy logic set. Compared with existing protocols, the data packet transmission delay and routing cost are superior to existing protocols.

In summary, the high speed of node movement in FANETs presents a major challenge in designing routing mechanisms. As the distance between nodes increases, more node energy will be consumed when transmitting data packets, which will greatly affect the life cycle of nodes. In this paper, based on FC-GA energy-saving and reliable flying ad hoc networks routing optimization mechanism (FC - GARE), the mechanism movement speed, the node's residual energy and the boundary evaluation factors as input variable of fuzzy system, fuzzy processing to obtain candidate forwarding nodes, through the genetic algorithm to determine the forwarding nodes, ensure real-time and reliability of data transmission.

2. System Model

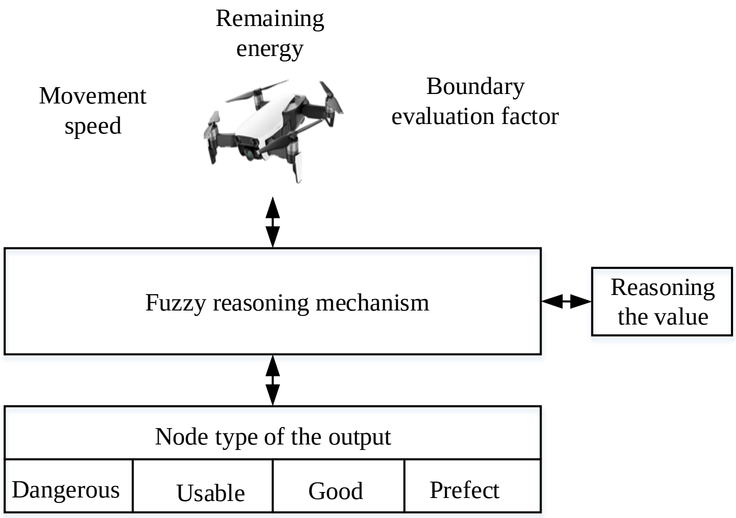

Fig. 1 Fuzzy control process

The candidate forwarding node is determined by fuzzy control and the optimal forwarding node is determined by using the output of fuzzy system as input of genetic algorithm. Therefore, a node with strong processing power is required to be responsible for the iteration of genetic algorithm. FANETs consists of numerous aircraft nodes and a base station.

Model hypothesis:

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1) The positions of all nodes are known.

2) Each node has the same initial energy.

3) All nodes have the same effective communication range.

4) Base station has strong information processing capability.

3. FC-GARE Routing Mechanism

The residual energy, moving speed and boundary evaluation factors of nodes are used to establish a fuzzy control model, and the fuzzy control process is shown in Figure 1. Firstly, triangular fuzzy function is used as the input of fuzzy system after fuzzy processing. THEN, fuzzy decision is made by if-then fuzzy rules and max-min principle. Then, four types of nodes are obtained through the center of gravity method, and the set of excellent nodes is taken as candidate forwarding nodes. Finally, the fitness value of excellent nodes is estimated by the fitness function of genetic algorithm, and the node with the maximum fitness value is selected as the forwarding node.

Firstly, the calculation methods of residual energy, moving speed and boundary evaluation factor of nodes are given. Then, the concrete realization process of fuzzy control and the construction method of fitness function of genetic algorithm are given.

Remaining energy: refers to the difference between the initial energy of the node and the energy consumed by the node to receive and transmit data packets. The calculation expression is as follows.

$$RE = E_{in}(i) - \sum \left[E_{tx}(i) + E_{rx}(i) \right] \tag{1}$$

Where, $E_{in}(i)$ represents the initial energy of the node, $E_{tx}(i)$ represents the energy consumed by the node to send data, and $E_{rx}(i)$ represents the energy consumed by the node to receive data.

Moving speed: The relative moving speed of node i and node j is calculated as follows:

$$MV = \frac{D(i,n) - D(j,n)}{dl(i,j)} \tag{2}$$

$$dl(i,j) = d\_mac(i,j) + d\_que(i,j) \tag{3}$$

Where, $D(i,n)$ represents the distance between node i and node n, $D(j,n)$ represents the distance between node j and node n, $dl(i,j)$ represents the one-hop delay of node i, $d\_mac(i,j)$ represents the MAC delay, and $d\_que(i,j)$ represents the time when the packet arrives at the head of the transmission queue.

Boundary evaluation factor: nodes at the edge of communication are prone to failure of packet transmission due to link fracture. Therefore, the position relationship between nodes is measured to improve link stability. The formula is as follows:

$$BF = \lg\left(1 + \frac{l}{R}\right) \tag{4}$$

Where, l represents the distance between nodes, and R represents the effective signal range of nodes.

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3.1 Fuzzy Control Process

Fuzzification: The input variable belongs to the control variable, but the control variable cannot be directly used as the input of the fuzzy inference machine, so the input variable needs to be fuzzified.

Firstly, the aircraft node senses its own moving speed, residual energy and boundary evaluation value, and takes the data collected by the aircraft node as the input of the fuzzy system. Therefore, it is necessary to defuzzification the moving speed, residual energy and boundary evaluation factors, and adopt (low, medium and high) fuzzy language to express the results of defuzzification. Quantify each variable into three levels. For example, the moving speed, residual energy, and boundary evaluation factors are quantified into three grades (low, medium, and high). The domain of each input variable after normalization is [0,1], and the membership function of the input variable is established according to the domain, as shown in formula (5)-(13).

$$u_{low}\left(RE\right)=\begin{cases}-2.5RE+1,\ 0\le RE\le 0.4\\ 0,\ RE<0\,\&\,RE>0.4\end{cases} \tag{5}$$

$$u_{mid}\left(RE\right)=\begin{cases}2.5RE\text{-}0.25,\ 0\le RE\le 0.6\\ -2.5RE+2.25,0.5\le RE\le 0.9\\ 0,\ RE<0.1\,\&\,RE>0.9\end{cases} \tag{6}$$

$$u_{high}\left(RE\right)=\begin{cases}2.5RE\text{-}1.5,\ 0.6\le RE\le 1\\ 0,\ RE<0.6\,\&\,RE>1\end{cases} \tag{7}$$

$$u_{low}\left(MV\right)=\begin{cases}-2.5MV+1,\ 0\le MV\le 0.4\\ 0,\ MV<0\,\&\,MV>0.4\end{cases} \tag{8}$$

$$u_{mid}\left(MV\right)=\begin{cases}2.5MV\text{-}0.25,\ 0\le MV\le 0.6\\ -2.5MV+2.25,0.5\le MV\le 0.9\\ 0,\ MV<0.1\,\&\,MV>0.9\end{cases} \tag{9}$$

$$u_{high}\left(MV\right)=\begin{cases}2.5MV\text{-}1.5,\ 0.6\le MV\le 1\\ 0,\ MV<0.6\,\&\,MV>1\end{cases} \tag{10}$$

$$u_{low}\left(BF\right)=\begin{cases}-2.5BF+1,\ 0\le BF\le 0.4\\ 0,\ BF<0\,\&\,BF>0.4\end{cases} \tag{11}$$

$$u_{mid}\left(BF\right)=\begin{cases}2.5BF\text{-}0.25,\ 0\le BF\le 0.6\\ -2.5BF+2.25,0.5\le BF\le 0.9\\ 0,\ BF<0.1\,\&\,BF>0.9\end{cases} \tag{12}$$

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$$u_{high}\left(BF\right)=\begin{cases}2.5BF\text{-}1.5,\ 0.6\le BF\le 1\\ 0,\ BF<0.6\,\&\,BF>1\end{cases} \tag{13}$$

Where, $u\left(RE\right)$ represents the membership function of residual energy, $u\left(MV\right)$ represents the membership function of moving speed, and $u\left(BF\right)$ represents the membership function of node boundary evaluation factor. Fig. 2 show the membership function curves of input variables.

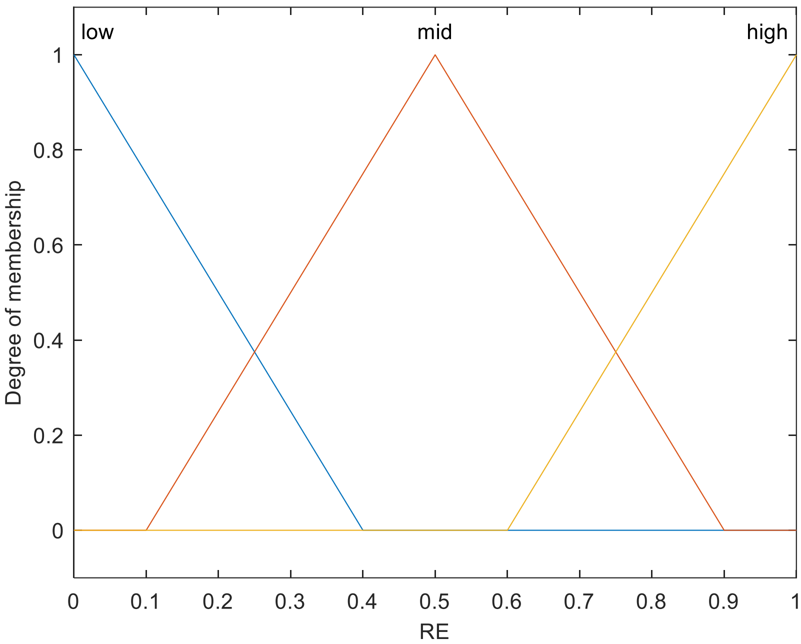

Fig. 2 Input variables membership function curve

The output variables are quantified into four levels: danger, usable, good, and prefect. The membership function expressions of the output variables are shown in formula (14)-(17). Fig. 3 shows the membership function curves of the output variables.

$$u_{dan}\left(HZ\right)=\begin{cases}-\dfrac{10}{3}HZ+1,\ 0\le HZ\le 0.3\\ 0,\ HZ<0\,\&\,HZ>0.3\end{cases} \tag{14}$$

$$u_{usa}\left(HZ\right)=\begin{cases}\dfrac{10}{3}HZ,\ 0\le HZ\le 0.3\\ -\dfrac{10}{3}HZ+2,0.3\le HZ\le 0.6\\ 0,\ HZ<0\,\&\,HZ>0.6\end{cases} \tag{15}$$

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$$u_{good}\left(HZ\right)=\begin{cases}\frac{10}{3}HZ\text{-}\frac{4}{3},0.4\leq HZ\leq 0.7\\ -\frac{10}{3}HZ+\frac{10}{3},0.7\leq HZ\leq 0.1\\ 0,\ HZ<0.4\&HZ>1\end{cases} \tag{16}$$

$$u_{pre}\left(HZ\right)=\begin{cases}\frac{10}{3}HZ-\frac{7}{3},\ 0.7\leq HZ\leq 1\\ 0,\ HZ<0.7HZ>1\end{cases} \tag{17}$$

Where, $u\left(HZ\right)$ represents the membership function of the output variable.

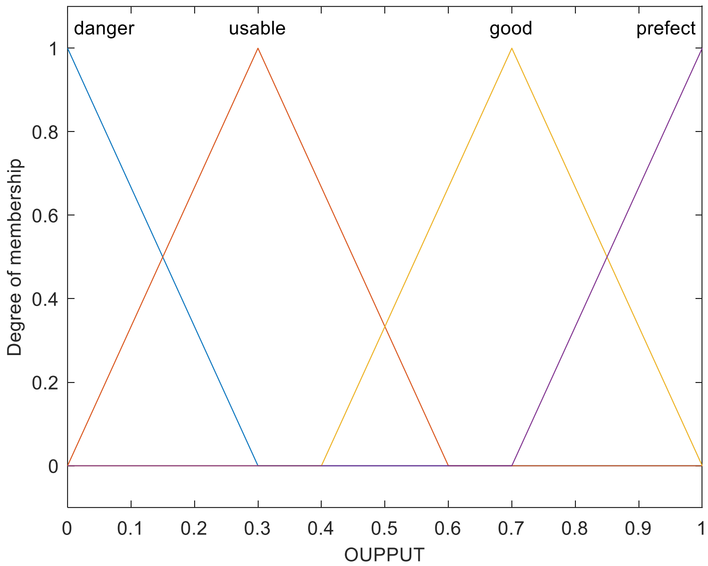

Fig. 3 Membership function curve of output variable

Table 1. Fuzzy rules

Rules	MV	RE	BF	OUT
1	low	mid	low	danger
2	low	mid	mid	usable
3	low	high	mid	good
4	high	high	high	prefect
5	high	low	low	danger
6	high	mid	mid	usable
7	high	high	mid	good
8	high	high	high	good

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Fuzzy reasoning: MANDANI type fuzzy reasoning method is adopted, and if-THEN conditional statements are used as fuzzy rules of fuzzy reasoning. Table 1 shows the Settings of fuzzy rules.

Defuzzification: the fuzzy output can be obtained by fuzzy reasoning. Only after the fuzzy output can be defuzzification, it can be used as the input of genetic algorithm. The fuzzy output value obtained by defuzzification by using the center of gravity method is smoother.

3.2 Construct Fitness Function

Genetic algorithm sorts individuals according to fitness function, higher fitness value represents better individuals to create better offspring in the search space. The fitness function is composed of the remaining energy of nodes, the moving speed of nodes and the boundary evaluation factor as decision parameters. The maximum node with fitness value is selected as the forwarding node, and the calculation formula is as follows.

$$Fitness = \lg\left[\omega_1 \sin\left(\pi\omega_1 \times f_1\right) + \omega_2 \sin\left(\pi\omega_2 \times f_2\right) + \omega_3 \sin\left(\pi\omega_3 \times f_3\right)\right] \tag{18}$$

Where, $\omega_1, \omega_2, \omega_3$ represents the constant whose value range is [0,1],and $\omega_1+\omega_2+\omega_3=1$, f_1, f_2, f_3 respectively represents the remaining energy of the node, the moving speed of the node and the boundary evaluation factor.

3.3 FC-GARE

The FC-GARE routing mechanism consists of initialization, route selection, and data transmission. The detailed implementation process is as follows.

In the initialization stage: each node sends a Hello packet to each other to determine the neighbor node of the node. The Hello packet contains the node ID, remaining energy, node movement speed, boundary evaluation factor and other information. Inside each aircraft node, the neighbor table will be established or updated according to the information in the Hello packet.

Routing phase: The first step is to get the candidate forwarding node through the fuzzy system. The node uses its residual energy, moving speed and boundary evaluation factor as the input of fuzzy inference machine after fuzzy processing by triangle fuzzy function. THEN fuzzy decision is made by if-then fuzzy rule and Max - min principle. Then, dangerous nodes, available nodes, good nodes and excellent nodes are obtained by gravity defuzzification, and the set of excellent nodes is taken as candidate forwarding nodes.

The second step is to obtain the forwarding node by calculating the fitness function of the genetic algorithm. The output of fuzzy control is taken as the input of the genetic algorithm. The fitness function constructed in 3.2 is used to calculate the fitness value of the candidate forwarding node, judge the fitness value of the forwarding node, and select the node with the maximum fitness value as the forwarding node. Otherwise, the forward node can be obtained by mutation of offspring and crossover of parents through roulette algorithm.

Data transmission stage: When the node has data transmission, judge whether the fitness value of the node after the genetic algorithm initialization is the maximum. If the fitness value is the maximum, the data shall be directly transmitted; otherwise, the forwarding node shall be obtained through the second step of 3.3 for data transmission until the data packet is transmitted to the destination node.

4. Simulation Analysis

The simulation experiment of FC-GARE routing mechanism is carried out on python platform. The simulation parameters were set as follows: In the simulation area of 1km*1km, the effective communication radius of nodes is 300m, the number of nodes is 50 and 100, the size of packets is 512Byte, the simulation time is 10min, the node movement model is Way Point, and the initial energy is 0.5J. Transmit energy 50nJ/bit, receive energy 50nJ/bit. In the simulation environment with 50

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nodes and 100 nodes, the residual energy and packet delivery rate of FC-GARE routing mechanism are compared and analyzed with LEACH and EEUC routing mechanism.

Fig. 4 shows the remaining energy analysis of the three routing mechanisms in a 50-node scenario. It can be seen that the residual energy of EEUC, LEACH and FC-GARE shows a decreasing trend. In addition, the residual energy of FC-GARE routing mechanism is always higher than that of EEUC and LEACH, but the residual energy of FC-GARE routing mechanism decreases more slowly than that of EEUC and LEACH. This is because the remaining energy of nodes is used as evaluation index by FA-GARE mechanism when determining candidate forwarding nodes, avoiding the use of nodes with low remaining energy to transmit data and reducing the retransmission of data packets. Therefore, the remaining energy of FC-GARE routing mechanism is always higher than that of LEACH and EEUC. However, the residual energy of EEUC routing mechanism is slightly higher than that of LEACH mechanism, because EECU mechanism divides nodes into two types according to the residual energy of nodes in the process of route discovery, and selects nodes with high residual energy as forwarding nodes.

Fig. 5 shows the remaining energy of the three routing mechanisms in a 100-node deployment scenario. It can be seen that the remaining energy of FC-GARE, LEACH, and EEUC is significantly lower than that of LEACH and EEUC when 50 nodes are deployed, but the remaining energy of FC-GARE routing mechanism is significantly higher than that of LEACH and EEUC. This is because in the intensive network, communication edge congestion leads to link instability, the number of data retransmission increases, and the network energy consumption increases. In addition, the FC-GARE routing mechanism takes the remaining energy of nodes into consideration, which is the same as the reason analysis of the experimental results in Fig. 6. Therefore, the remaining energy of FC-GARE routing mechanism is significantly higher than that of the other two routing mechanisms.

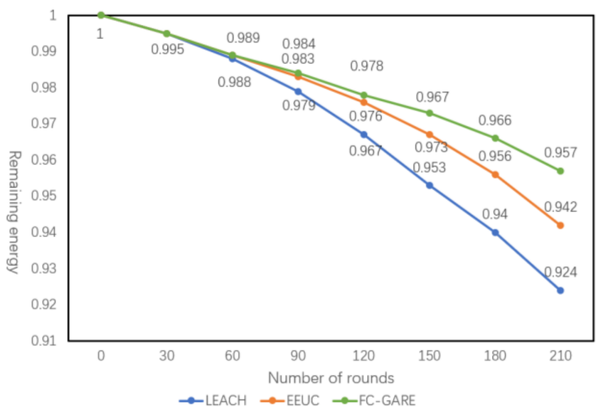

Fig. 4 Analysis of remaining energy at 50 nodes

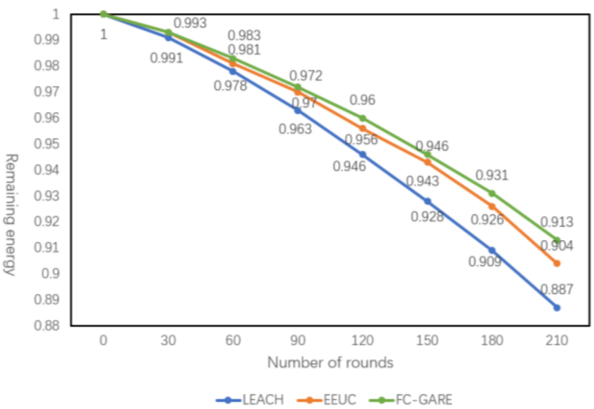

Fig. 5 Analysis of remaining energy at 100 nodes

Fig. 6 shows the packet delivery rate of the three routing mechanisms in a scenario with 50 nodes deployed. It can be seen that the packet delivery rate of the three routing mechanisms shows a decreasing trend, but when the number of rounds is greater than 90, the packet delivery rate of FC-GARE is significantly slower than that of EEUC and LEACH. In addition, when the number of rounds is less than 60, LEACH packet delivery rate is higher than LEACH and FC-GARE. This is because the stability of the link is affected by node mobility. The higher the node movement speed is, the more frequent the network topology changes and the higher the probability of link disconnection, leading to the decrease of packet delivery rate. The FC-GARE mechanism considers the influence of node movement speed on link quality and stability and increases the robustness of the path. The packet delivery rate of FC-GARE routing mechanism is better than that of EEUC and LEACH. However, LEACH mechanism is optimized on the basis of the active routing mechanism. The active routing mechanism constructs the routing table first and improves the link quality. Therefore, the

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packet delivery rate of LEACH is higher than the other two routing mechanisms when the number of rounds is less than 60.

In a scenario with 100 nodes deployed, Fig. 7 shows the packet delivery rate of the three routing mechanisms. The packet delivery rate of FC-GARE, LEACH, and EEUC is significantly lower than that of LEACH and EEUC when 50 nodes are deployed. However, when the number of rounds is greater than 90, the packet delivery decline trend of FC-GARE is significantly slower than that of LEACH and EEUC. This is because the index of boundary evaluation factor is considered in the design of FC-GARE routing mechanism. In the low-density network environment, the average link length is smaller than the effective communication range of nodes. In a high-density network environment, the average link length is close to the communication range of nodes, resulting in increased edge effect and link instability. Therefore, the packet delivery rate of FC-GARE routing mechanism is higher than that of the other two routing mechanisms. However, similar to the reason analysis of the experimental results in Fig. 8, LEACH is optimized on the basis of the active routing mechanism. When the number of rounds is less than 60, the packet delivery rate of LEACH is higher than that of the other two routing mechanisms.

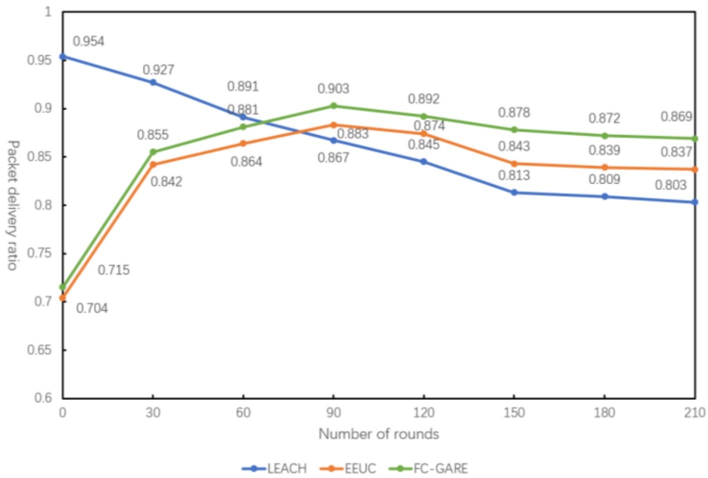

Fig. 6 Analysis of packet delivery ratio at 50 nodes

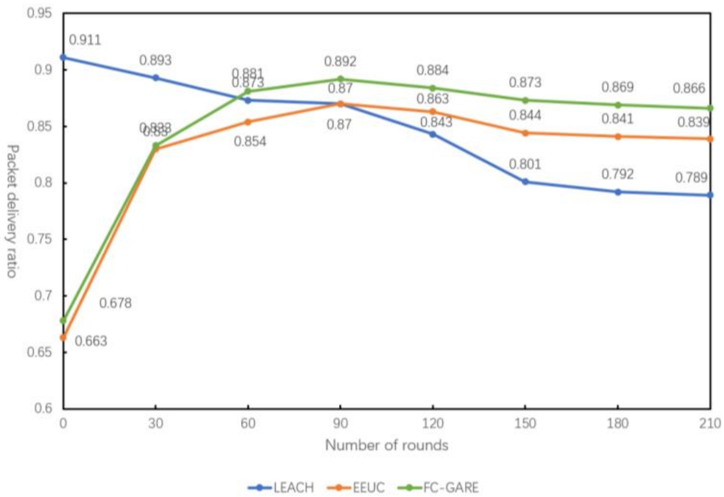

Fig. 7 Analysis of packet delivery ratio at 100 nodes

5. Summary

This paper proposes an energy-saving and reliable routing optimization mechanism based on FC-GA in flying ad hoc networks. Firstly, the residual energy of nodes, boundary evaluation factors and node moving speed were defuzzification by fuzzy control, and then the candidate forwarding nodes were obtained by fuzzy reasoning based on fuzzy rules. Then, the forwarding node is determined based on genetic algorithm. Simulation results show that compared with existing LEACH and EEUC mechanisms, FC-GARE can improve the performance of packet delivery rate and residual energy.

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