Heterogeneous network handover algorithm for unmanned aerial vehicles based on categorical fuzzy inference

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Abstract. In order to meet the requirements of 5G connected unmanned aerial vehicle (UAV) communication, wireless local area network (WLAN) and satellite network are integrated into UAV communication link, and form UAV heterogeneous communication network together with 5G. In order to achieve fast and reliable handover decisions and uninterrupted service, this paper presents a vertical handover (VHO) algorithm based on classification fuzzy reasoning. Here, this paper introduces six parameters of UAV terminal and divides them into two categories for decision-making. The received signal strength (RSS), remaining available bandwidth (RBW), and propagation delay were taken as the key variables, while the network cost, expected dwell time (EDT) and security were taken as the non-key variables. In the handover decision, the pre-screening based on the received signal strength threshold and the stabilization time is firstly carried out, and the classification fuzzy logic system is used to make the next decision on the candidate networks that meet the requirements. Finally, the output of each fuzzy system is weighted according to user requirements to obtain the final judgment index. Through simulations, it has been proved that the algorithm proposed in this paper can accurately make the handover decision according to the user's requirements, avoid the ping-pong effect, and effectively improve the system performance.

Keywords: Unmanned aerial vehicle (UAV), Heterogeneous network, Fuzzy logic, Variable classification, Vertical handover (VHO).

1 Introduction

With the development of 5G network, the integration of UAV and 5G network has become the future development direction of UAV industry. In cooperation with Huawei, China Telecom completed the first flight test of 5G UAV in April 2018. In May 2020, China Mobile Research Institute jointly with Shenzhen DJI, Chengdu Zongheng, Chongqing Guofei, Beijing Dagong and other UAV head enterprises held a press conference of "5G Enabled networked UAV", and its independently developed Hubble-1 (communication terminal) and China Mobile Lingyun (management platform) realized the

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beyond-horizon control of UAV. It has realized the control of the UAV in Shenzhen thousands of miles away from the Chengdu command center, and sent high-definition images back in real time through the 5G network. However, the current 5G infrastructure in China is limited, and there are a large number of areas without 5G signal, including remote areas and small areas with weak signal caused by densely built-up urban areas. In view of the security control requirements of 5G connected UAVs, the adoption of heterogeneous communication network has become a feasible method to solve this problem, while the composition of heterogeneous network and the corresponding handover strategy have become the key and difficult points to be broken through in this study.

Based on 5G network, this paper proposes a UAVs heterogeneous communication network based on WLAN-5G-Satellite networks, and designs a network handover strategy based on classification fuzzy reasoning according to UAVs communication characteristics. Simulation results prove the effectiveness of this strategy.

2 Related research

Since traditional point-to-point communications cannot meet the needs of long-range UAVs, using mobile cellular networks to control UAVs provides extended range coverage and secure wireless communications, which can enhance control and safety using UAVs in a variety of missions[1]. According to Refs. 2, cellular network has the characteristics of perfect infrastructure, extensive radio coverage, high throughput and low delay, which can be used as a solution for air-to-ground communication links of UAVs, and the feasibility has been demonstrated through flight tests. Refs. 3 proposed a UAV communication architecture based on LTE/3G, SMS and satellite, designed a baseline algorithm based on heartbeat method for local and remote faults that may occur in UAV communication, and further optimized based on link signal strength to speed up local fault detection. Refs. 4 comprehensively studied the cellular supported UAV communication, elaborated the innovative 5G technology, and realized the integration of UAV cellular spectrum communication.

At present, the research on vertical handover technology at home and abroad mainly relies on the Internet of vehicles, but there are few researches on the UAV network with high mobility and spatial mobility. The traditional vertical handover method of the Internet of vehicles cannot be simply applied to the UAV, but needs to be improved according to its characteristics. According to different research methods, vertical handover algorithms can be roughly divided into the following categories: decision algorithm based on received signal intensity[5,6], multi-attribute decision algorithm[7,8] and decision algorithm based on artificial intelligence[9,10]. Among them, the algorithm based on received signal intensity is the simplest, but it is easy to cause ping-pong switch. The algorithm based on multi-attribute decision considers more decision factors, such as network bandwidth, handover delay, network fee, etc., and needs to give a weight to each parameter, which can reflect user preference. The decision algorithms based on artificial intelligence include decision strategy based on context awareness neural network algorithm and pattern recognition algorithm. The first two decision methods are used when the attribute values of the decision factors are determined, but in the actual network, the attribute values required for handover decision are usually uncertain, so fuzzy logic can be used to solve this kind of problem.

In Refs. 11, forward difference prediction algorithm is used to predict terminal signal strength, and a handover algorithm based on fuzzy logic is proposed. However, it takes few parameters into consideration, and the handover result is not reliable enough. In Refs. 12, multi-layer feedforward network is used for mobility prediction, and fuzzy logic is used to make decisions with data rate, reliability, signal strength, battery quantity and mobility as inputs. However, the fuzzy system is too complex and time consumption is high. Refs. 13

proposed a vertical handover algorithm based on interval type II fuzzy neural network for ultra-dense heterogeneous wireless networks, which can improve the total network throughput while ensuring low time cost. However, it does not consider the movement direction and residence time of UAV in different networks, which lacks predictability.

Therefore, aiming at the shortcomings of the above work, this paper designs a vertical handover algorithm based on classification fuzzy reasoning, and makes handover decisions by classifying variables. The received signal strength and remaining available bandwidth, transmission delay, cost, expected dwell time and security are selected after comprehensive consideration of UAV movement characteristics. It is divided into key variables and non-critical variables for fuzzification respectively. The fuzzy results are given different weights according to the personalized requirements of users, and the outputs assigned with different weights are used as the basis for handover.

3 Handover mechanism based on classification fuzzy reasoning

The schematic diagram of the decision algorithm is shown in Fig. 1. At the same time, in order to avoid the ping-pong effect caused by frequent handover between base stations and different networks, a pre-screening stage is added to the algorithm proposed in this paper to assist in network selection, which greatly reduces the number of input fuzzy system networks and reduces the system overhead.

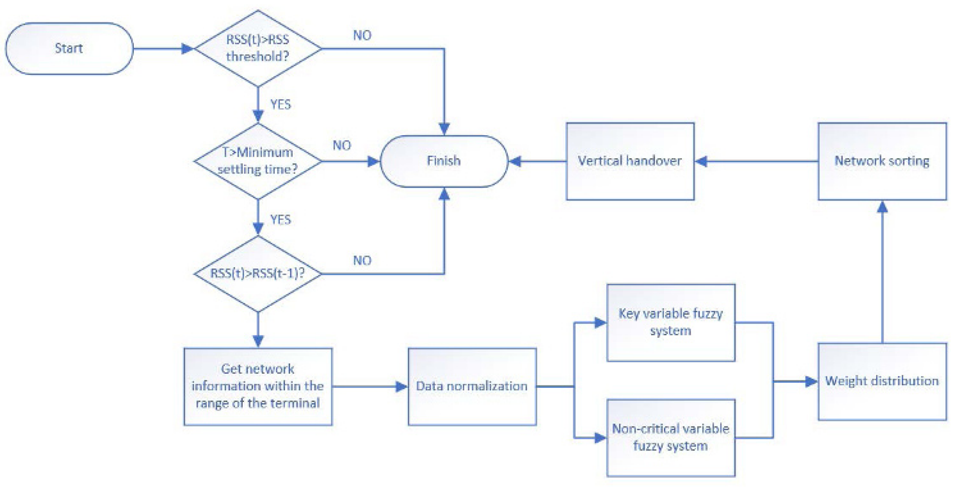


Fig. 1. Schematic diagram of decision algorithm.

3.1 Fuzzy system parameters

In order to make a better choice of network handover, it is necessary to consider various network performance indicators comprehensively to ensure that the user service quality is not affected after the switchover. Therefore, different fuzzy systems based on variable classification are designed in this paper, and variables are divided into critical and non-critical categories according to their importance to the communication network. Among them, RSS, RBW and Delay are taken as key variables, while Cost, EDT and Security are taken as non-critical variables. RSS indicates the signal transmission quality between the user and the network. If the RSS value is lower than the threshold, the communication quality will be poor or even interrupted. The remaining available bandwidth indicates the maximum transmission rate that the network can provide, and the delay is the time it takes for data to be transmitted end-to-end.

RSS is determined by the transmitting power of the base station and the transmission distance of the signal, and is not affected by the environment. Its expression is

$$RSS(t) = \rho_a - \gamma \lg(d) + \varepsilon \tag{1}$$

Where ρ_a is the transmitting power of network a, γ is the path loss factor of network a, d is the distance from terminal to access point, and ε is a Gaussian random variable subject to (0, δ2).

Assuming that the bandwidth obtained by all users in the same network is equally divided, the bandwidth allocated to users in network a at time t is BWa(t). Assuming that the total network bandwidth is BW_totel, the remaining available bandwidth of the network at time t is

$$RBW\left(t\right) = BW\_totel - nBW_a \tag{2}$$

Where n is the total number of users accessing network a at time t. Propagation delay refers to the time it takes for electromagnetic wave to propagate in the channel, and its calculation formula is as follows:

$$Delay = \frac{L}{V} \tag{3}$$

Where L is the transmission channel length and V is the signal propagation rate in the transmission medium. Considering that UAV flight speed tends to choose communication network, taking speed as a variable directly will greatly increase the time cost of the algorithm, so this paper defines the EDT as one of the input indicators. This variable represents the time when the UAV is expected to receive the network signal. If the UAV is moving away from or about to leave network a, the tendency of handover strategy to enter network a should decrease; otherwise, it should handover earlier to maintain long-term communication stability. The variable can be obtained by two adjacent location and the speed of network information obtained. UAV flight speed can be collected in two ways, one is to calculate the speed value by detecting the change of RSS intensity perceived by the terminal by establishing the base station signal attenuation model. However, it is difficult to measure the accurate RSS value because the signal is often disturbed by the refraction and absorption of obstacles in the propagation process. The second method is to use GPS speed measurement service to obtain the real-time speed and direction of UAV.

3.2 Fuzzy system design

In order to reduce unnecessary switching decisions, in the first stage of the algorithm, RSS parameters are used to pre-filter the network. RSS represents the signal transmission quality between the user and the network, and is also one of the important indicators indicating the quality of the network. The pre-filtering through the RSS threshold can reduce unnecessary handover decisions and reduce the time cost. The ping-pong effect is further eliminated by setting the dynamic minimum stability time which is inversely proportional to the speed.

The second stage of the algorithm is the judgment stage of fuzzy logic. First, the input variables are normalized, and the processed data is used as the input of the fuzzy system. After the fuzzy system fuzzifiers the input data, the membership degree of each network parameter is obtained. Then fuzzy inference is carried out according to the defined fuzzy rules to get the corresponding fuzzy output. Finally, the final output is obtained by de-fuzzification.

Fuzzification: Fuzzification is the process of describing precise parameter values in fuzzy language, converting them to the universe of discourse through membership functions, and using fuzzy subsets to describe the process of measuring physical quantities. The six input variables selected in this paper are fuzzified, and their input and output membership diagrams are shown in Fig. 2 and Fig. 3.

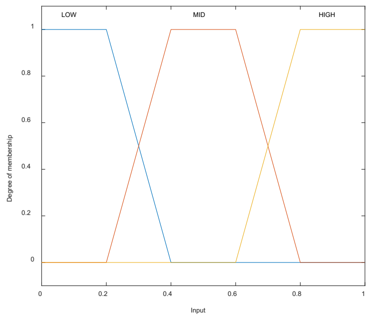


Fig. 2. Membership diagram of the input.

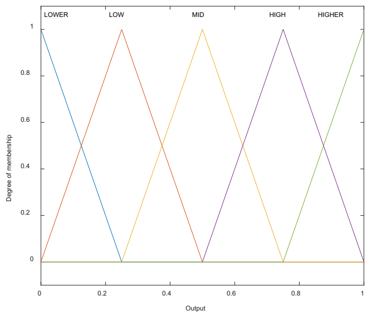


Fig. 3. Membership diagram of the output.

Table 1. 1 ~ 9 Scaling method.

Importance scale	Comparison of importance
1	Equally important
3	The former is slightly more important than the latter
5	The former is obviously more important than the latter
7	The former is far more important than the latter
9	The former is extremely more important than the latter
2,4,6,8	The median of adjacent values

Table 2. Real-time business key variables pairwise comparison matrix.

Real-time business	RSS	RBW	Delay
RSS	1	5	1/2
RBW	1/5	1	1/5
Delay	2	5	1

Table 3. Real-time business non-critical variables pairwise comparison matrix.

Real-time business	RSS	RBW	Delay
RSS	1	3	3
RBW	1/3	1	1
Delay	1/3	1	1

Table 4. Fuzzy rules for key indicators.

RSS	RBW	Delay	INDEX1
LOW	LOW	LOW	LOWER
LOW	MID	MID	LOW
MID	MID	MID	MID
HIGH	LOW	MID	HIGH
HIGH	HIGH	HIGH	HIGHER

The input membership function adopts three trapezoidal membership functions, whose fuzzy grade is divided into {LOW, MID, HIGH}. The output membership function adopts triangle membership function, and the fuzzy grade is divided into five levels.

Fuzzy reasoning: This paper uses analytic hierarchy process (AHP) to get the weight of different variables, and designs fuzzy rules by the way of variable weighting. Taking real-time business as an example, Table 2 and Table 3 are pairwise comparison matrices based on the importance of different variables by the method of Table 1. The eigenvectors of the matrix are the weights of the input variables. Since the fuzzy system input membership function is defined as 3 levels, and the fuzzy output is obtained by the weighted sum of the inputs, the result is located at [1,3]. Because the fuzzy output is set to 5 grades, the fuzzy rule table can be obtained by dividing the output values into [1,1.4), [1.4,1.8), [1.8,2.2), [2.2,2.6), [2.6,3]. According to the input variable of the permutation and combination, the layer has 3 ^ 3 = 27 rules. Compared with the single fuzzy system (3 ^ 6 = 729 rules), its complexity dropped by an order of magnitude. Table 4 shows some rules of the fuzzy rule base of key indicators. Inference rules all adopt the "IF... and..., Then..." statements.

Defuzzification: Defuzzification is to convert the fuzzy value obtained by fuzzy reasoning into a specific output value, which is usually accomplished by the barycentre method. In this paper, the classification fuzzy system can obtain two fuzzy output values INDEX1 and INDEX2, which respectively represent key variables and non-critical variables. Considering that users have different demands in data rate, signal stability, mobility and other aspects, the weight of the output value can be dynamically adjusted according to the needs of users, and the weighted comprehensive index value can be used as the judgment basis for handover. Compared with the decision method based on general fuzzy logic (FL), this method considers more user factors and designs different network requirements for different users, so the switch decision index obtained is more reasonable.

3.3 Fuzzy system analysis

This paper adopts WLAN, 5G and satellite communication networks, and the simulation scene Settings are shown in Fig. 4. In Fig. 4, cellular represents 5G network, gray cellular represents area without 5G signal, circular area represents WLAN network coverage, and satellite network is assumed to have full coverage. The straight line in Fig. 4 is the movement path of UAV.

Fig. 5 and Fig. 6 show the 3D output of key variables and non-critical variables. X-axis and Y-axis respectively represent the membership degree of the two input variables, and Z-axis represents the fuzzy system output. As can be seen from Fig. 5, RSS and delay have significant effects on fuzzy output, while available bandwidth has no significant effects on output. Fig. 6 shows that the three non-critical variables all play a certain role in the output, and their effects are obviously stepped.

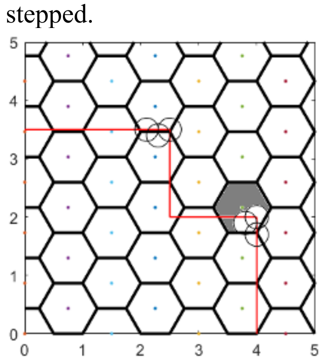
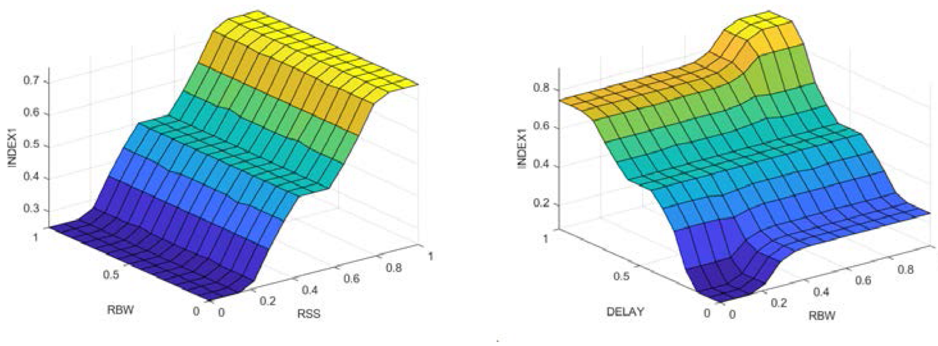
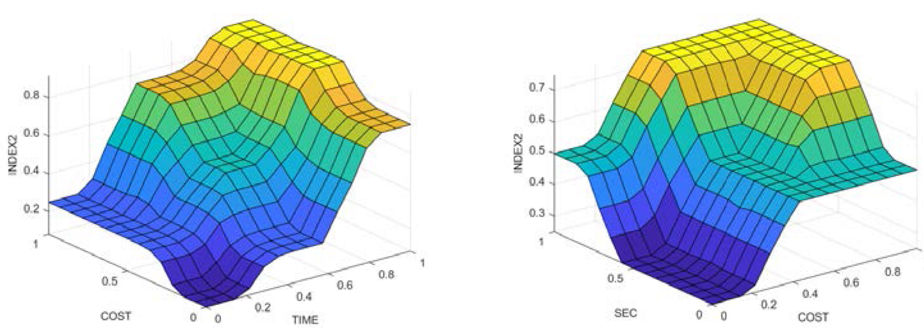


Fig. 4. The simulation scene.



(a) (b)

Fig. 5. Key Variable Surface Plot.



(a) (b)

Fig. 6. Non-critical Variable Surface Plot.

Some simulation parameters are set as shown in Table 5, and the simulation parameters are quantified by the method of Refs. 14.

Table 5. Simulation parameters.

Network	Coverage radius[km]	Delay[ms]	Cost	Security
WLAN	0.2	6	Very low	Low
5G	0.5	5	Middle	High
Satellite	Full coverage	270	Very high	Low

4 Simulation results and analysis

The simulation object in this paper is a small fixed-wing UAV. When the flight speed is 36km/h, 72km/h and 108km/h respectively, the handover decision of the network is shown in Fig. 7. It is clear that the time to handover from 5G to WLAN for the first two times at different speeds decreases as the speed increases. This is due to the dynamic settling time used in the simulation, and the handover decisions made at different speeds are basically the same.

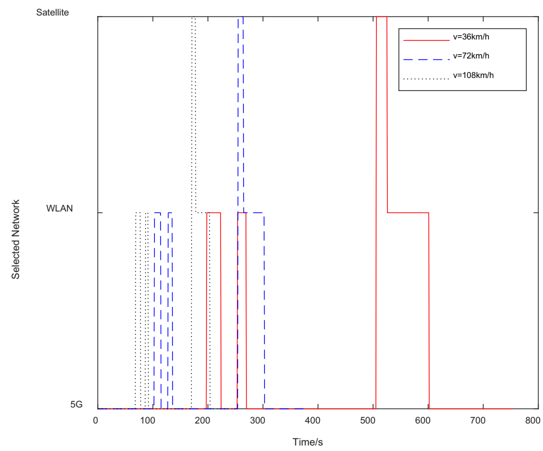


Fig. 7. Handover decisions at different speeds.

Fig. 8 shows the handover times of the three algorithms at different speeds. It can be found that the handover times of the classification fuzzy strategy proposed in this paper are better than the FL-based and RSS-based methods at all speeds, and there is no significant difference in communication quality.

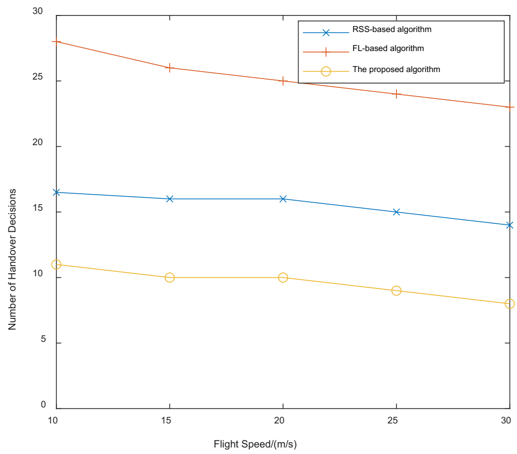


Fig. 8. Total number of handovers versus flight speed.

Fig. 9 shows the relationship between the handover failure rate and the number of entry handover decisions. The algorithm proposed in this paper adopts a pre-screening strategy, so the handover failure rate can be kept at a low level stably. However, there are too many invalid decisions in the FL-based algorithm and the RSS-based algorithm, resulting in a greatly increased failure rate.

Fig. 10 compares the time cost of the three algorithms. After repeated simulations, it can be found that although the time cost of the RSS-based method is small, its failure rate is high, which will cause waste of network resources. However, the time overhead of the FL-based algorithm is too large due to the complexity of the fuzzy system. The algorithm proposed in this paper can achieve high-efficiency handover decisions with low time overhead. In the modern society with increasingly complex network environment, the strategy proposed in this paper can effectively reduce the number of UAV communication network handovers. While maintaining the communication stability of the UAV, it can reduce the energy consumption of the UAV and the waste of network resources.

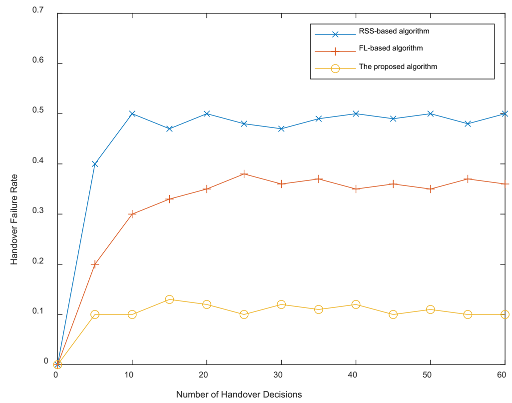


Fig. 9. Handover failure rate versus number of handover decisions.

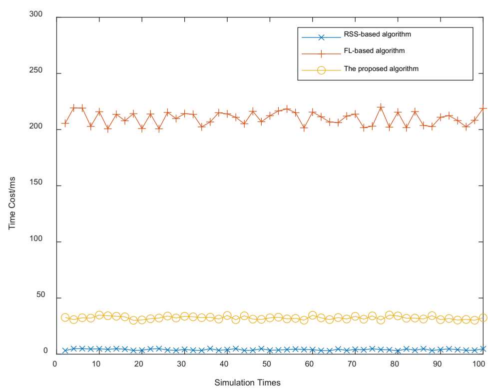


Fig. 10. Time cost versus simulation times.

5 Summary

In this paper, a switching decision algorithm for UAV communication network based on classified fuzzy reasoning is proposed to solve the problem that the complexity of fuzzy system is greatly increased due to too many input variables, which is characterized by high robustness and high fault tolerance. This paper designs fuzzy systems for different types of variables by means of variable classification, and puts forward a fuzzy rule design method based on analytic hierarchy process. Finally, the weighted summation of the outputs of different fuzzy systems is carried out according to the user requirements to obtain the final decision index. The simulation analysis shows that the algorithm proposed in this paper can accurately make the handover decision according to the user's needs, and avoid the ping-pong effect. It effectively improves system performance and reduces terminal energy consumption while reducing system complexity. Compared with the traditional handover strategy, it has obvious advantages and has some reference value for the current UAV communication strategy.

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