



Spectrum Allocation Algorithm for Energy-Constrained UAV in Interweave Cognitive IoT Network Based on Satellite Coverage

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Abstract. Today, the internet of things (IoT) has become an inevitable trend in the development and integration of communication and information technology. The rapid increase of IoT terminals has led to scarcity of spectrum resources. Therefore, if cognitive radio (CR) technology can be added to IoT, it is bound to better meet the frequency requirements of the development of the IoT. In order to solve this problem, this paper uses unmanned aerial vehicles (UAVs) to access cognitive spectrum holes with CR in interweave cognitive IoT network. In the satellite coverage area, the UAV's GPS signal will be stronger. Therefore, this paper comprehensively considers the spectrum hole quality, UAV power limitation and satellite coverage issues, and proposes a spectrum allocation algorithm, which preferentially selects channels with high communication quality, and comprehensively considers UAV power control when implementing the algorithm. Simulation results show that the algorithm improves communication quality and spectrum allocation and realizes power control.

Keywords: IoT · UAV · Satellite coverage · SNR · Spectrum allocation

1 Introduction

The huge scale of the internet of things (IoT), as well as the wireless-based characteristics of information interaction and transmission, are destined to make the IoT a major consumer of spectrum resources. However, today's wireless networks adopt a fixed spectrum allocation policy, that is, the planning and use of wireless spectrum resources are stipulated by government departments, and the use of transceivers by spectrum needs to be authorized by the government department. When the authorized spectrum is free, these resources cannot be used by other users. The survey and research of the FCC's Spectrum Policy Task Force show that at any given moment, people use only 2% to 6% of the available spectrum resources and a lot of expensive spectrum resources will be wasted. However, the wireless spectrum is a limited, non-renewable resource. Today, available spectrum resources in many countries and regions have been divided, and China is also facing the threat of depletion of spectrum resources. It can be seen that the lack of spectrum resources restricts the development of the IoT. In order to solve this problem, cognitive radio (CR) emerged as a new type of radio technology. It

is based on the allocation of spectrum resources. The basic idea is: Rental User or Second User (RU or SU) continue to detect authorized spectrum resources and ensure that Licensed User or Primary User (LU or PU) give priority to use and under the condition that its performance is almost not impaired, perform spectrum detection and find spectrum holes and dynamically access idle spectrum to realize the secondary utilization of spectrum resources, so as to achieve the purpose of improving spectrum utilization.

The ultimate goal of CR technology is to obtain spectrum resources through cognition and reconfiguration, so finding spectrum holes through spectrum detection is an essential step [1, 2]. The so-called spectrum hole refers to the frequency band that has been allocated to the main user but is not currently used, so it can be used by the perception user. The spectrum detection is to estimate the interference temperature of the observed frequency band. For the interference temperature obtained by spectrum estimation, the interference temperature limit can be given. Through the interference temperature limit, the observed spectrum holes can be selected. Interference or other noise beyond the boundary are all spectrums that do not meet the communication requirements. After that, the spectrum holes mentioned in this paper are all the spectrum that meets the requirements. At the same time, broadcasting can only achieve communication between users accessing holes in the same spectrum. Communication between users accessing holes in different spectrums needs to be achieved through external equipment, which requires a lot of manpower and material resources. The emergence of unmanned aerial vehicles (UAVs) solved this problem.

UAV, as a product of high-tech in the information age, have the characteristics of small size, light weight, and free movement in the air. It has been widely recognized in the world and is currently a hot research topic in the field of communications [3–6]. Therefore, we can combine UAV with CR to give full play to the advantages of low cost and free movement of unmanned aerial vehicles and add the characteristics of cognitive users' active spectrum sensing and spectrum access to the UAV control system. Allowing cognitive users to quickly find and access idle channels can reduce the detection range and increase the success rate. But how to let cognitive users find the optimal spectrum? We can use the Signal-to-noise ratio (SNR) to measure the quality of spectrum holes.

In order to improve communication quality, the paper also adds the factor of satellite coverage. In the satellite coverage area, the UAV's global positioning system (GPS) signal will be greatly enhanced. And in the area covered by multiple satellites, UAV interest will increase. At the same time, in order to make the energy consumption of the UAV system as low as possible, this paper comprehensively considers the spectrum hole quality, the limited UAV power and the satellite coverage issues, and proposes an interwoven cognitive IoT network based on satellite coverage. The spectrum allocation algorithm of the restricted UAV improves the communication quality and spectrum allocation and realizes the power control.

2 Related Works

A large number of spectrum allocation algorithms have appeared in spectrum access technology, many of which are based on game theory [7–10] (game theory, studies the interaction between formulaic incentive structures, considers the predicted and actual behavior of individuals in a game, and studies their optimal strategies), and some are based on C-means clustering, deep reinforcement learning [11] and so on.

Ref. [12] uses Nash equalization to solve the problem of spectrum allocation or power control in non-cooperative situations. Ref. [11] designed a dynamic spectrum access algorithm based on Q-learning. Cognitive users learn through continuous interaction with the environment and quickly select the channel with the highest return rate for data transmission, but the algorithm only considers A single cognitive user perceives and accesses the current idle spectrum without considering the priority and competition issues caused by multiple users simultaneously needing to access the network. Ref. [13] proposes a decentralized cognitive MAC protocol, which ensures that in the presence of conflicts and spectrum sensing errors, synchronous hopping in the spectrum between the transmitter and receiver can be used to optimize the performance of secondary users. While limiting the interference perceived by the main user. Ref. [14] designed a spectrum allocation algorithm based on pricing theory. A primary user sells available spectrum to multiple competing secondary users. Ref. [15] establishes repeated games with punishment mechanism, which effectively improves the efficiency of non-cooperative games. Ref. [7] proposed a probability update algorithm based on uncertain network environment for dynamic spectrum access technology, and incorporated the status information of cognitive users within the system into the consideration of model construction, and then proposed user status-based Feedback learning algorithm, but this algorithm considers all authorized users as a whole when constructing the system model, analyzes the situation of cognitive users separately, and does not take into account the actual situation of authorized users. Ref. [8] uses potential games to analyze the game behavior between secondary users, and considers the mutual interference between primary users and secondary users into the revenue function of secondary users, which effectively improves the throughput of the system. Ref. [9] proposes a dynamic spectrum access technology based on C-means clustering algorithm. By establishing a multi-objective matrix model of accessible channels and using multi-object clustering to accurately divide the channel spectrum pool, it can not only meet the different business needs of cognitive users, but also effectively improve the efficiency of spectrum utilization.

Although these algorithms solve the problem of spectrum allocation and improve the spectrum utilization rate, they do not consider the effect of channel quality on spectrum allocation due to their complexity and limited functions. Therefore, this paper proposes a spectrum allocation algorithm for energy-limited UAVs in an interwoven cognitive IoT network based on satellite coverage, which improves communication quality and spectrum allocation, and realizes power control.

When a spectrum hole is detected, the time the user needs to decide whether to access free frequencies, as well as the spectrum hole track, spectrum perception changes, avoiding interference to the primary user. Once the primary users are using

channels, other users need to empty out the spectrum and continue to look for spectrum hole to connected to the signal. But when the detection range is larger, the success rate of the is smaller. So a spectrum access algorithm is proposed in this paper, using unmanned aircraft to move this feature, narrow the scope of the detection and effectively detect spectrum hole.

3 System Model

The system model diagram is shown in Fig. 1. When a user of the IoT layer communicates, the frequency band not occupied by the main user is a spectrum hole, so the IoT layer is a spectrum hole layer. To simplify the problem, we assume that all UAVs fly on a certain level. Suppose the position coordinate of a certain spectrum hole is, and the position coordinate of a certain UAV is, then the distance between the UAV and the spectrum hole can be expressed as.

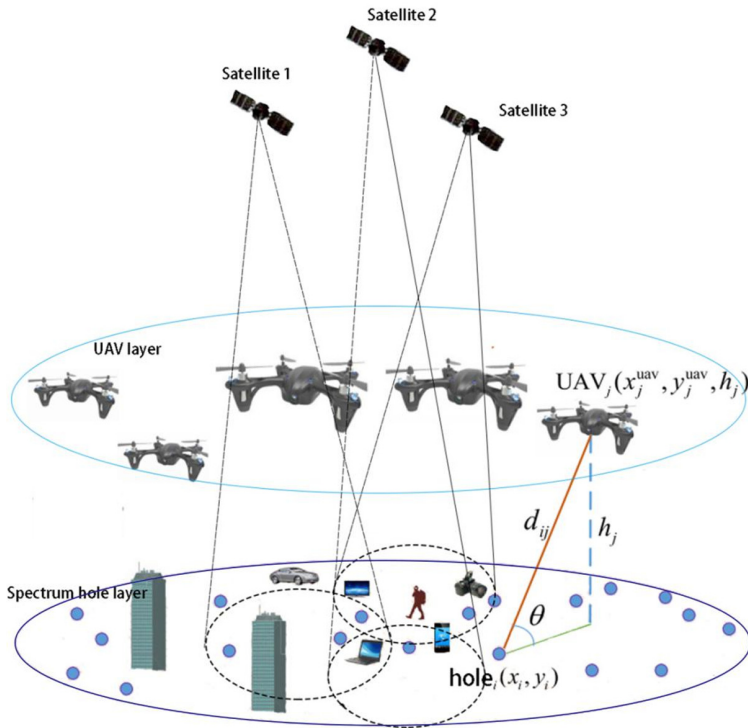


Fig. 1. System model.

$$d_{ij} = \sqrt{(x_j^{uav} - x_i)^2 + (y_j^{uav} - y_i)^2 + h_j^2} \quad (1)$$

The satellite coverage projection map is shown in Fig. 2. Suppose there are three satellites. In the figure, area *A* is covered by three satellites at the same time, area *B* is covered by two satellites, area *C* is covered by only one satellite and area *D* is not covered by satellites. In areas covered by satellites, the UAV’s GPS signal will increase and in different areas, UAVs have different interests, that is, the UAV’s GPS signals in areas *A*, *B*, *C*, and *D* will gradually weaken and the communication quality will also be reduced. It will fall. Therefore, UAVs in area *A* will have priority access to spectrum holes. Assuming that the numbers of UAVs in areas *A*, *B*, *C*, and *D* are *a*, *b*, *c*, and *d*, respectively, they are numbered: $m_A(i)$, ($i = 1, 2, 3 \dots, a$), $m_B(i)$, ($i = 1, 2, 3 \dots, b$), $m_C(i)$, ($i = 1, 2, 3 \dots, c$), $m_D(i)$, ($i = 1, 2, 3 \dots, d$).

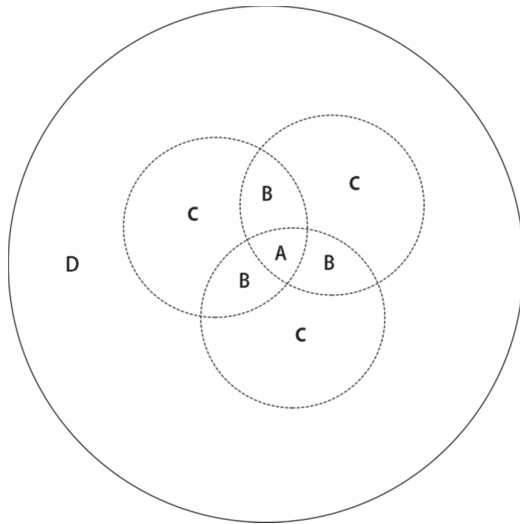


Fig. 2. Satellite coverage projection.

Assuming that there are *n* spectrum holes in the spectrum hole layer, number these *n* spectrum holes as $n(i)$, ($i = 1, 2, 3 \dots n$); we use *SNR* to measure the quality of spectrum holes. Due to the limited energy of UAVs, the launch power P_t of UAVs must be considered. Therefore, the *SNR* can be expressed as

$$SNR = \frac{P_t \times (h + L)}{N_0} \tag{2}$$

Among them, P_t is the UAV transmission power, *h* is the small-scale fading, it can be modeled as a normal distribution, N_0 is Gaussian noise, *L* is the path loss, which is related to d_{ij} and can be expressed as

$$L = \beta_0 \left(\sqrt{\frac{L = \beta_0 d_{ij}^{-2}}{(x_j^{uav} - x_i)^2 + (y_i^{uav} - y_i)^2 + h_j^2}} \right)^{-2} \quad (3)$$

where β_0 denotes the channel power at the reference distance $d_0 = 1\text{m}$.

In order to reduce the energy consumption during the flight of the UAV, the power of the UAV must be controlled. Ref. [4] is an initial attempt to conduct energy-efficient UAV communication by optimizing the UAV trajectory to maximize the energy efficiency of the UAV communication system in a given time. To achieve this goal, the UAV power consumption is modeled as a function of UAV flight speed and acceleration, and finally a simplified power consumption model of UAV straight flight is obtained:

$$P = \left| a_1 V^3 + \frac{a_2}{V} + m a' V \right| \quad (4)$$

Among them, a' is the acceleration of horizontal straight flight, V is the speed of horizontal straight line, and a_1 and a_2 are constants related to aerodynamics and aircraft design. It can be seen from formula (4) that with the increase of speed and acceleration, the power consumption of the UAV is gradually increasing, but at the beginning it increases slowly, and the power consumption increases rapidly after a certain point. Therefore, we can call this point the power stability point. At this time, the speed and acceleration of the UAV have been determined. The UAV flying at this point can not only ensure that the speed and acceleration are not too small, but also control power consumption. When the UAV is flying at the speed and acceleration of the power stability point, the flight time depends on the distance between the UAV and the spectrum hole, and the energy consumption of the UAV also depends on this distance. Therefore, the UAV will select $n/2$ spectral holes that are located closer to itself for comparison.

We assume that the transmission power of the UAV is a certain value, then the SNR of each spectrum hole can be calculated, which is recorded as $s(i)$, ($i = 1, 2, 3 \dots n$).

Specifying the value function $R = \{R(i)\}$, ($i = 1, 2, 3 \dots n$), $R(i)$ is the final value function of the spectrum hole numbered $n(i)$, then

$$R(i) = \frac{s(i)}{s(i) + s(i+1)} + \frac{d(i+1)}{d(i) + d(i+1)} \quad (5)$$

$$R(i+1) = \frac{s(i+1)}{s(i) + s(i+1)} + \frac{d(i)}{d(i) + d(i+1)} \quad (6)$$

If $R(i) > R(i+1)$, remove $R(i+1)$ from the set R and then continue to traverse the set R . Finally, the spectrum hole corresponding to the remaining value function in R is the spectrum hole that the UAV will choose to access.

4 Algorithm Design

4.1 Source of Algorithm Inspiration

The algorithm is inspired by the 3rd RoboCup Simulation Robot 11VS11 Football League of Beijing University of Science and Technology held in 2019 by the Institute of Advanced Engineers. The rules of the game are that the side with the most goals in the specified simulation time wins.

Here, the stadium can be regarded as a certain frequency domain and the UAV acts as a robot. Certainly, there is only one ball on the field, but let's expand it. Assuming there are multiple balls, the ball can be regarded as a spectrum hole. In the game, the robot closest to the ball has to grab the ball in the direction of a straight line distance, so it can be imagined that the UAV chooses the way to access the spectrum hole close to its own distance. At the same time, the communication quality should be considered, so priority should be given to selecting the spectrum hole access with high comprehensive index.

4.2 Algorithm Steps

Step 1: Number the UAVs in areas A , B , C , and D respectively. Cognitive users in areas covered by satellites will be allocated spectrum first;

Step 2: Calculate the distance between the UAV in area A and the spectrum hole according to formula (1);

Step 3: Calculate the SNR according to formulas (2) and (3);

Step 4: Calculate the value R according to formula (5) and (6). The UAV chooses the R value of $n/2$ spectrum holes that are closer to itself and compares it, and continuously traverses the set R , and finally the remaining value function in R is the spectrum hole that the UAV should choose to access;

Step 5: Repeat steps 2, 3, and 4 to find the spectrum holes that the UAVs in the B , C , and D areas choose to access.

5 Simulation Results

20 UAVs are used in a certain frequency domain, assuming that the number of UAVs in the A , B , C , and D areas are 2, 6, 7, and 5 respectively. Through spectrum detection, six spectral cavities meeting the communication requirements were found. Assuming that the flying height of the UAV is 270 m and the transmitting power is 15 dBm, the SNRs obtained are: -25 dB, -21 dB, -19 dB, -17 dB, -13 dB, -10 dB.

Figure 3 is a channel allocation diagram after the algorithm is executed. It can be seen from the figure that spectrum holes with high SNR are allocated more cognitive users, and most of them exist in satellite coverage areas (A , B , and C areas). Cognitive users who are not covered by satellites (area D) will be allocated to spectrum holes with a small signal-to-noise ratio.

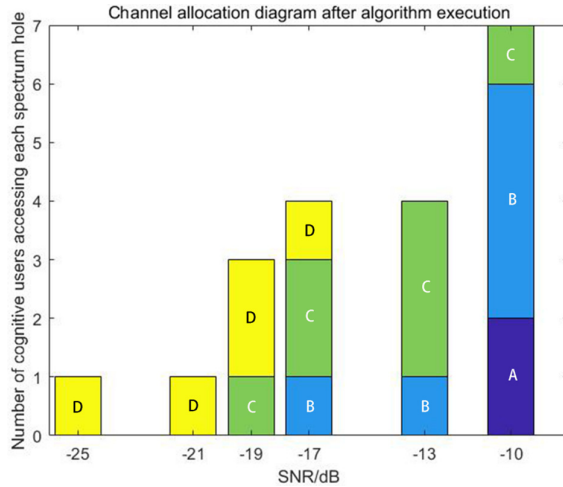


Fig. 3. Channel allocation diagram after algorithm execution.

The simulation results show that the algorithm integrates factors such as the channel quality of the IoT, satellite coverage, and UAV power control, which improves the channel utilization and improves the communication quality and spectrum allocation.

6 Conclusion

This paper mainly discusses the problem of spectrum resource allocation, briefly describes the main technologies of current spectrum resource allocation and points out their shortcomings. In this regard, this paper proposes a spectrum allocation algorithm for energy-constrained UAVs in an interwoven cognitive IoT network based on satellite coverage. The algorithm takes into account the spectrum hole quality, UAV power limitation and satellite Coverage issues, in which the application of UAV technology enables cognitive users to find spectrum holes faster and will be more dominant in the competition for spectrum resources. Simulation results show that the algorithm improves communication quality and spectrum allocation, and realizes power control.

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