Resource Allocation Schemes Based on Improved Beetle Antennae Search Algorithm for Collaborative Communication of the Unmanned Aerial Vehicle Network

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Abstract. In this paper, the resource allocation problem for collaborative communication of unmanned aerial vehicle network is formulated and analyzed. In our scenario, the unmanned aerial vehicles (UAVs) are uniformly distributed in the network. We consider that multiple UAVs can share one channel resource. First, a system model is established and the resource allocation problem is formulated. Then a resource allocation scheme based on the improved beetle antennae search algorithm is proposed, which finds the optimum solution efficiently. Finally, the simulation results show that the performance of the proposed the improved beetle antennae search algorithm is better than that of random algorithm. This scheme provides an efficient optimization for resource allocation of collaborative communication of UAVs.

Keywords: Unmanned aerial vehicle (UAV) · Resource allocation · Beetle antennae search algorithm

1 Introduction

Unmanned aerial vehicle (UVA) is an aircraft operated by radio remote control equipment and automatic program control device. With the spread of the UAV project, UAVs have been introduced into application in recent years [1]. Therefore, the scarcity of the radio spectrum prompts us to consider improving the spectrum resources. Direct communication between UAVs can overcome the problem and improve the spectral efficiency.

In UAV communication system, when UAV pairs share the same spectrum resource with other UAV pairs, they will interfere with each other. So resource allocation is the important part of improving the spectrum resources which attracts many researchers all around the world. In [2], the authors analyze the deployment of an UAV as a base station to provide the wireless communications. The coverage and rate are mainly analyzed in two scenarios: a static UAV and a mobile UAV. Simulation results show that the optimal values for the UAV altitude can lead to maximum sum-rate and

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coverage probability. The small world network theory is introduced into wireless sensor networks to improve the network performance. The authors introduce this theory into real-time of UAV and use the ant colony algorithm to realize real-time update and data transmission [3]. In [4], an adaptive vertical array antenna technique into wireless broadband modem for UAV communication is proposed to overcome the problem of the altitude limitation. The authors propose the frame structure and a resource allocation algorithm to satisfy the high network throughput. The result shows that this algorithm can allocate the resource effectively [5]. This paper focus on the use of UAVs in the scenario of the disaster and the frequency resource is considered that shared by the adjacent UAVs. The radio resource management system is proposed to improve the communication of the data [6]. In [7], the cooperative game theory is proposed to solve the problem for the resource allocation of UAVs group performing a task. In [8], the authors mainly discuss the power control, capacity optimization and suppression of interference in D2D communication system. In [9], a combining call admission control and power control scheme is proposed under guaranteeing QoS of user equipment (UE).

The main contributions of our work are as follows:

1. We propose a resource allocation scheme based on the improved beetle antennae search algorithm for collaborative communication of unmanned aerial vehicle network.
2. We select the system capacity as a factor for evaluating system performance.

The rest of this paper is organized as follows. In Sect. 2, we describe the system model of unmanned aerial vehicles (UAVs) network. In Sect. 3, a resource allocation scheme based on beetle antennae search algorithm is proposed and discussed. In Sect. 4, the capacity of the UVAs as the performance of the communication system is simulated and analyzed. Finally, the conclusion is drawn out in Sect. 5.

2 System Model and Problem Formulation

2.1 Channel Allocation Mode

There are two types of UAVs in collaborative communication network: transmitting unmanned aerial vehicles (TUAVs) and receiving unmanned aerial vehicles (RUAVs). In this scenario, we consider TUAVs and RUAVs come in pairs. We assume that all UAVs in the network are uniformly distributed inside a cube with the side length A. We analyze the transmission in the communication network as show in Fig. 1. When the UAVs share the same spectrum resources, they get the same frequency interference. The solid black line represents the communication link between the UAV pair. The remaining dotted line represents the interference of the RUAV from the other TUAVs at the same frequency.

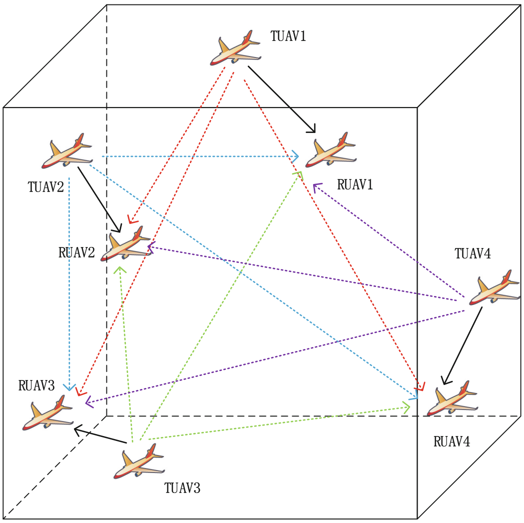

Fig. 1. The system model of the UAV

2.2 Problem Formulation

In the system model, M channel resources are allocated to N UAV pairs. We choose the maximum capacity to evaluate the performance. To guaranty the Quality of Service (QoS) of the system, the signal to interference plus noise ratio should be larger than SINR threshold β. When the UAVs communicate with each other, the interference of the RUAV j is:

$$I_j = \sum_{\substack{k \in \Re_m \\ k \neq j}} \frac{P_T}{d_{k,j}^{\alpha}} \tag{1}$$

Here, P_T is the transmitting power of the TUAV, $d_{k,j}$ denotes the distance between kth TUAV and jth RUAV, $\Re_m$ denotes the mth sub-channel, α is the path loss factor.

Therefore, during the communication period for the RUAV j, the SINR can be written as

$$SINR_j = \frac{P_T \big/ d_j^{\alpha}}{I_j + N_0} \tag{2}$$

Here, d_j denotes the distance between TUAV j and RUAV j, N_0 is the noise power.

For UAV pairs, the UAV piar j is considered as the package m. According to Shannon theorem, the capacity of the RUAV j is denoted as

$$C_j = B\log_2(1 + SINR_j) \tag{3}$$

Here, B is the bandwidth of the sub-channel.

Obviously, the sum of the capacity of the whole system is

$$C = \sum_{j=1}^{N} C_j \tag{4}$$

3 The Improved Beetle Antennae Search Algorithm

In 2017, the beetle antennae search algorithm (BAS) is a new efficient search optimization algorithm proposed. It is a bio-element heuristic algorithm developed inspired by the foraging behavior of the beetles [10]. This intelligent optimization algorithm is different from those swarm intelligence algorithms. There is only one individual search for the better solution in the each iteration. Therefore, the computational complexity of the algorithm is greatly reduced.

3.1 Description of the Beetle Antennae Search Algorithm

The beetles forage for food depending on the strength of the food smell. They have two antennae which are used to judge the direction of the food. If the left antenna receives a stronger smell than the right one, the beetle will fly to the left; otherwise it will fly to the right. Each foraging process corresponds to the each iteration of finding the optimal solution.

The initial solution of the beetle antennae search algorithm is the initial position of the beetle, which is randomly generated. x^t denotes the position of the beetle at t time instance. *dir* denotes the direction vector of the right antennae pointing to the left antennae and it is random in each step. The beetle can search in the k-dimension space, so that x^t and *dir* are k-dimension vector. *dir* is defined as follows:

$$\begin{aligned} dir &= rands(k, 1) \\ dir &= dir/norm(dir) \end{aligned} \tag{5}$$

Here, the rands (.) denotes the random function, and the norm (.) denotes the normalization function.

Step represents the search step and changes with the iteration times. The initial step is larger for search for global optimal solution. *eta* is the attenuation coefficient of the search step. d_0 represents the distance between the two antennae. c is a constant and the ratio of *step* to d_0. n denotes the iteration times. The initial values of these parameters are as follows: *step* = 10, *eta* = 0.95, c = 5, n = 100.

After the initialization, the value of objective function of the left antennae and right antennae can be generated according to the Eq. (6).

$$\begin{aligned} f_l &= f(x + dir * d_0) \\ f_r &= f(x - dir * d_0) \end{aligned} \tag{6}$$

The objective function values are judged by the function sign (.). The expression of the x^t is as followed:

$$x^t = x^{t-1} - \text{step}^t dir * sign(f(x_l - x_r)) \tag{7}$$

By comparing f(x^t) and f(x^{t-1}), keep the maximum value of the function is preserved.

The solution of the algorithm will eventually evolve to a convergence with enough the iteration times. We will obtain the solution and optimal objective function value.

3.2 The Improved Beetle Antennae Search Algorithm

The beetle algorithm is originally used to solve the optimal problem of continuous function, but the practical application problem in this paper is combinatorial optimization. We refer the mutation operation of genetic algorithm to carry out mutation operation on the position of the beetle. Therefore, we can improve the diversity of solutions and avoid falling into the local optimum too early in the iteration process. The detailed steps of the improved beetle antennae search algorithm are as follows:

1. **Initialization**
   x^t is randomly generated as the initial solution. Each value of vector x^t represents which channel the UAV pair is in. For example, x^t = (3, 2, 5, 1, 3, 4, 1, 5, 2…) denotes the UAV_1 and UAV_5 share the third sub-channel, UAV_2 and UAV_9 share the second sub-channel, UAV_3 and UAV_8 share the fifth sub-channel and so on. The value of the vector x^t is an integer limited between 1 and 5.
2. **Search for the new solution**
   The spatial dimension of the optimal solution searched by the algorithm is *k*. When *k* is larger than 2, the direction of the left or right doesn't make much sense anymore. We consider the left and the right is a random direction in *k*-dimension space. We refer the mutation operation of genetic algorithm, randomly selecting a value in the *k*-dimension vector and mutating it. The mutation operation is to randomly select a part of the position to mutate to produce a better position. The purpose of doing so is to maintain the diversity of the position.
3. **Stopping criteria**
   With the increasing of the iteration times, the solution of the improved algorithm will evolve to a convergence. Finally, we achieve the best solution and global optimal objective function value (Table 1).

Table 1. Improved beetle antennae search algorithm specific steps

Improved beetle antennae search algorithm specific steps:
1. Parameter settings. 2. First, randomly generate the solution corresponding to the left and right antennae, and then calculate the objective function values. 3. Compare the values of objective function and select the larger value f(x^t) to compare with the value of f(x^{t-1}). Keep the maximum value of the function is preserved 4. Judge whether the iteration is over. If not, return to step 2.

4 Simulations and Discussions

In our simulation, we assume that TUAVs follow a uniform distribution in the cube. The side length of the model is A. The RUAVs follow a uniform distribution centered on the corresponding TUAVs in the sphere of the radius L. Simulation parameters are summarized in Table 2.

Table 2. Simulation parameters.

Parameter	Value	Parameter	Value
Model length A	200 m	The number of UAV pairs	20
L	30 m	The bandwidth of the sub-channel B	0.2 MHz
Path loss factor α	4	The transmission power of UAV	0.01 W
SINR threshold β	4.6 dB	N_0	−90 dBm

Figure 2 shows the capacity of UAV communications with the change of the iteration times by using different algorithms. We make this simulation by Monte Carlo method. We analyze the system capacity performance of the beetle antennae search algorithm and random algorithm. The blue line represents the minimum value during the iterative process. It can be seen that beetle antennae search algorithm has the ability of searching the global optimal solution and is not easy to run into the local optimization solution. Compared with the random algorithm, the beetle antennae search algorithm has better performance and the fast convergence speed.

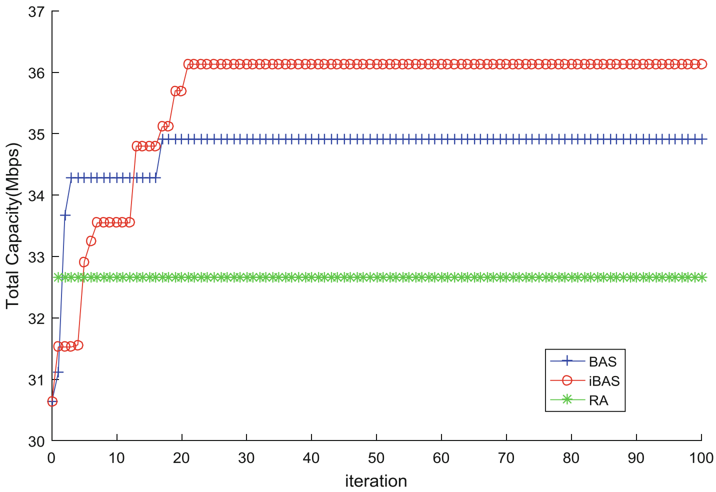

Fig. 2. The capacity of UAV communications

5 Conclusions

In this paper, the resource allocation problem for collaborative communication of unmanned aerial vehicle group is formulated and analyzed. In our scenario, UAVs are uniformly distributed in the network. We establish a system model and formulate the resource allocation problem. To improve the performance of the system communication, a resource allocation scheme based on beetle antennae search algorithm is proposed. Beetle antennae search algorithm finds the optimum solution efficiently. Finally, the simulation results show that the performance of the proposed beetle antennae search algorithm is better than that of random algorithm. This result can be applied for the resource allocation UAVs collaborative communication.

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