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Multi-UAV base station deployment strategy combining whale swarms and virtual forces

Guangming Yuan

School of Aerospace Information, University of Aerospace Engineering, Beijing 101407, China

ygm20200101163@163.com

Abstract

Aiming at the problem of user communication coverage in local hotspots, this paper aims to maximize user communication coverage, constructing a UAV base station solution model. This paper uses the idea of distributed deployment, combining whale swarm algorithm and virtual force to solve the model. The simulation results show that the scheme proposed in this paper can effectively increase the communication coverage and reduce the coverage redundancy, and at the same time realize the interconnection between UAV base stations. The research results have positive reference significance for related research on the deployment and application of UAV base stations.

Keywords

UAV base station, whale swarm algorithm, virtual force.

1. Introduction

There are many natural disasters on the earth every day. Some natural disasters cause huge troubles to human activities, earthquake is one of them. When natural disasters or man-made disasters occur, effective communication and resource coordination are required between rescuers and rescued personnel, in order to save lives and other community resources [1]. To solve the problem of emergency communication in a sudden environment, the deployment of UAV base stations can be used to achieve network communication coverage and ensure smooth communication.

However, the deployment of UAV base stations also faces many difficulties. First, the number of UAV base stations is limited, and the deployment location of UAV base stations needs to be allocated reasonably; in addition, the deployment of UAV base station networks is best to adopt a distributed deployment scheme. In order to achieve rapid deployment. Therefore, UAV base stations need to form a network to keep the network open.

This paper proposes a distributed deployment scheme, which solves the UAV base station deployment model through joint virtual force and whale swarm algorithm, which can effectively improve user coverage and maintain network connectivity in a limited resource environment.

2. Model construction

2.1. Scene description

Suppose there is a sudden earthquake disaster in a certain place, causing the damage of the local ground base station and unable to communicate. An existing emergency communications team has several UAV base stations, which can provide temporary communications support for the local area by deploying a UAV base station communication network. As shown in the figure, there is a hot spot l in a square geographic area $(N \times N)$. There is a user set M in the hotspot area, and the user is represented by t, and the size of the set is m, then $1 \le t \le m$, User distribution is Gaussian. The user's location can be known by the vision sensor equipped with the drone within the line of sight [2]. The initial position of the emergency communication team is D, so the drone base station can only take off from point D. UAV base stations performing tasks are homogeneous, and they have the same flight performance and communication performance. The communication radius of the drone base station is R_C. The user accesses the UAV base station using the Boolean perception model, which means that the UAV base station takes itself as the center of the circle and the ground communication distance is the radius to construct the perception range. If the user is within this range, the user is considered to be able to communicate. In addition, the UAV base station network formed after networking is fully connected.

2.2. Objective function construction

In this paper, the deployment of UAV base stations is used to cover users in the hotspot area, so the objective function is to solve the communication coverage of users.

$$f(s) = x / m \tag{1}$$

x is the number of all covered users in the current area, and m is the number of all users in the current area.

3. Joint solution of whale swarm algorithm and virtual force

3.1. Virtual force model construction

The virtual force algorithm regards the sensor nodes as particles in the electric potential field, there are virtual electric field forces between nodes and between nodes and the coverage area[3]. This paper constructs three kinds of virtual forces, one is the attraction of UAV base stations and hot spots, the other is the repulsion of neighboring UAVs, and the third is the attraction between UAV base stations and users.

3.1.1. The attraction of drone base stations and hot spots

The users in the hotspot area present a Gaussian distribution, so the attractiveness of the UAV base station and the hotspot area can be constructed. It can control the UAV base station network to fly to the hotspot area, so as to achieve communication coverage for users in the area. The attractiveness of UAV base stations and hot spots is constructed as follows:

$$F = \begin{cases} K_1 d_{ul} & d_{ul} > 0 \\ 0 & d_{ul} = 0 \end{cases} \tag{2}$$

$$d_{ul} = \sqrt{(x_u - x_l)^2 + (y_u - y_l)^2} \tag{3}$$

K_1 is the attraction factor, which is a constant, indicating the importance of the covered area; d_{ul} is the distance between the UAV base station and the center of the hotspot. The position coordinate of u is (x_u, y_u), the position coordinate of l is (x_l, y_l).

3.1.2. Neighbor drone repulsion

It is not difficult to find that under the above attraction, the UAV base station will quickly approach the hotspot center. As a result, it is difficult to maintain a stable topology, and collisions between UAV base stations will occur, UAV base stations will also generate communication redundancy. The repulsive force between the UAV base station and the UAV base station can ensure the proper distance between the UAVs, and reduce the communication redundancy while avoiding collisions. The neighbor drone repulsion is constructed as follows:

$$F=\begin{cases} K_2\dfrac{1}{d_{un}} & d_{un}<R_C \\ 0 & \text{others} \end{cases} \tag{4}$$

$$d_{un}=\sqrt{(x_u-x_n)^2+(y_u-y_n)^2} \tag{5}$$

K_2 is the repulsion coefficient, which is a constant; d_{un} is the distance between neighboring drone base stations. The position coordinate of u is $(x_{u,}y_u)$, the position coordinate of n is $(x_{n,}y_n)$.

3.1.3. Attraction between UAV base stations and users

When the UAV base station network covers the hotspot center, it begins to calculate the attractiveness between UAV base stations and users. Due to the limited number of UAV base stations, it may not cover all users. In order to maintain the UAV network Connectivity, the attractiveness coefficient between the UAV base station and the user is smaller than the attractiveness coefficient between the UAV base station network and the hotspot center.

$$F=\begin{cases} K_3 d_{ut} & d_{ut}>R_C \\ 0 & \text{others} \end{cases} \tag{6}$$

K_3 is the attraction coefficient, which is a constant; d_{ut} is the distance between the UAV base station and the user. The position coordinate of u is $(x_{u,}y_u)$, the position coordinate of t is $(x_{t,}y_t)$.

3.2. Description of Whale Swarm Algorithm

Whale swarm algorithm is a new type of meta-heuristic algorithm. It is developed by simulating the behavioral characteristics of whales communicating with their companions through ultrasound during group activities in nature. [4]

The whale swarm algorithm has the following characteristics:

a. Few parameter settings

b. Good optimizing ability

c. Easy to program

The whale swarm algorithm contains three mechanisms: looking for prey, surrounding prey, Bubble-net predation. [5]

3.2.1. Search target

In the target search stage, the target location is unknown to the current population of individuals, so individuals obtain the target location through joint cooperation. Whales use random individual positions in the current population as navigation targets to find food. Its mathematical model is described as follows:

$$D=\left|C\cdot X_{\mathrm{rand}}-X\right| \tag{7}$$

$$X(t+1)=X_{rand}-A\cdot D \tag{8}$$

X_{rand} represents the position of a random individual in the current population, D represents the distance between the random individual and the current individual, $A\cdot D$ is a coefficient vector, A and C are defined as follows:

$$A=2a\cdot r_1-a \tag{9}$$

$$C=2\cdot r_2 \tag{10}$$

r_1 and r_2 represent random numbers between [0,1], a represents the convergence factor, and its value decreases linearly from 2 to 0 with the iterative process.

3.2.2. Surrounding prey:

Whales can identify the position of prey and surround them. In the WOA algorithm, first assume that the position of the best individual in the current population is the position of the prey, and other whale individuals in the population surround the best individual. The mathematical model is described as follows:

$$D = \left| C \cdot X^*(t) - X(t) \right| \tag{11}$$

$$X(t+1) = X^*(t) - A \cdot D \tag{12}$$

t represents the current number of iterations, X^* represents the optimal individual position in the current population.

3.2.3. Bubble Net Attack

The whale population swims to the position of the prey and attacks through the spiral bubble-net method. The mathematical model is described as follows:

$$X(t+1) = D' \cdot e^{bl} \cdot \cos(2\pi l) + X^*(t) \tag{13}$$

$D' = \left| X^*(t) - X(t) \right|$ represents the distance between the optimal individual in the tth generation and the current individual, b is a constant used to define the shape of the logarithmic spiral, l represents a random number between [-1,1]..

The encircling prey mechanism of whales and bubble-net predation is a synchronous behavior. In the description of the mathematical model, the probability of the two methods is usually the same, the description is as follows:

$$X(t+1) = \begin{cases} X^*(t) - A \cdot D & p < 0.5 \\ D' \cdot e^{bl} \cdot \cos(2\pi l) + X^*(t) & p \geq 0.5 \end{cases} \tag{14}$$

3.3. Algorithm steps

Step 1: Initialize the environment, given node parameters, UAV base station parameters, coverage rate and other indicators.

Step 2: Calculate the user coverage and determine whether it has increased. If there is no increase, go to step 3, otherwise go to step 5.

Step 3: Calculate the size of the virtual force, use the whale swarm algorithm to update the position, and update the position coordinates of the UAV base station.

Step 4: Determine whether the algorithm has reached the number of cycles. If it reaches step 5, it does not reach step 3.

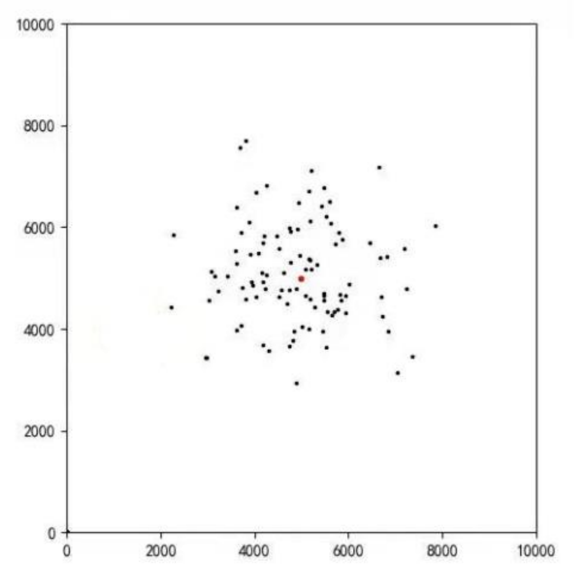
Step 5: Move the UAV base station to the target point, and output the UAV base station position coordinates and coverage rate.

4. Simulation results and analysis

Verify the algorithm on Python. The parameter settings are shown in the table below:

Table 1: Part of the simulation parameter settings

Area size	amount of users	Number of drones	UAV communication radius	Maximum moving step	Algorithm iterations
10000m*10000m	100	18	600m	10	130



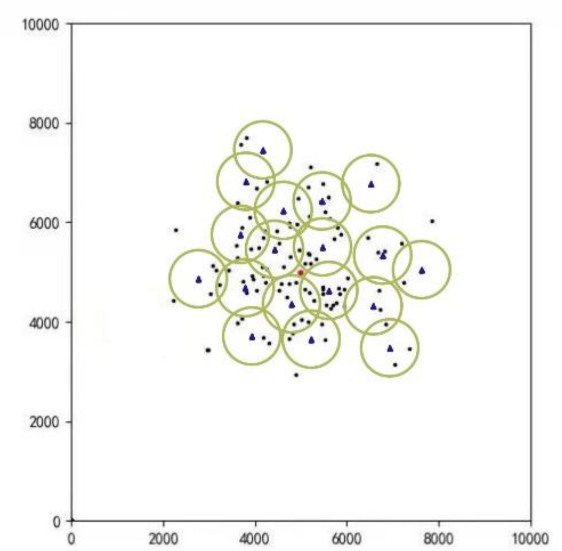


Figure 3-1: Initial distribution diagram Figure 3-2: Finished layout diagram

As shown in Figure 3-1, the UAV base station is initially located at point A, the red dot is the center of the hotspot area, and the base station is deployed from point A. After 130 iterations, Figure 3-2 shows the coverage map of the hotspot area of the UAV base station. It can be seen that most users are already under the communication coverage of the UAV base station network, and the coverage rate at this time is 95%.

Under the condition that the communication radius of UAV base stations is constant, this paper studies the change of user coverage with the number of UAV base stations. As shown in Figure 3-3, with the increase in the number of UAV base stations, the user coverage rate shows a simultaneous increase. When the number of UAV base stations reaches 15, the coverage rate reaches 90%, and the coverage rate begins to decrease. This is because there are individual users who are too far away from the center of the hotspot area. Due to the limited number of UAV base stations, and the UAV base stations are more attractive to the hotspot area, it is necessary to give priority to serving most users.

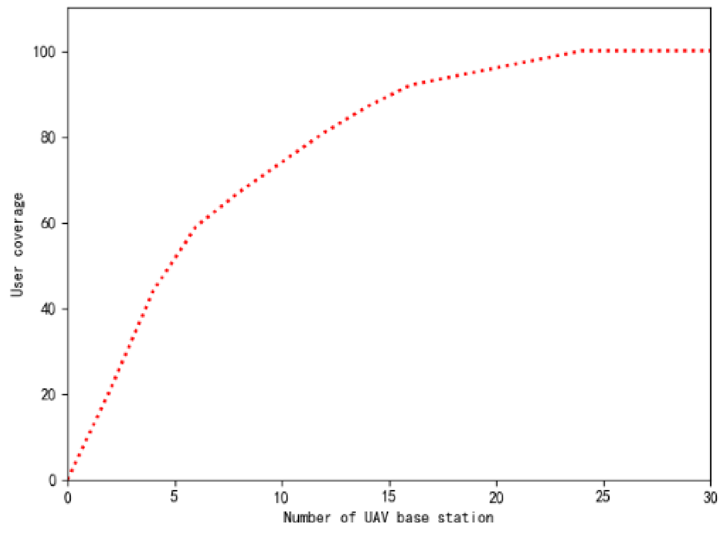


Figure 3-3: Change in coverage rate with the number of UAV base stations

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5. Conclusion

The deployment of UAV base stations is an important solution to the temporary communication problem under emergency conditions. This paper studies the local hotspot area when the ground base station is damaged and cannot be used. In order to ensure the smooth communication of users in the area, a deployment model with the goal of solving coverage is established, and the UAV is proposed through the joint virtual force and the whale swarm algorithm. Deployment strategy. The experimental results show that the algorithm not only guarantees the user communication in the local hotspot area, but also realizes the interconnection and intercommunication between the base stations, avoids communication redundancy, and saves base station resources.

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