Path Planning of Unmanned Air Vehicles Relay Communication Based on Lowest Power Loss

Ruiying Xiao¹, Fan Yang¹ and Zhenghong Dong¹

¹Space Engineering University, Beijing, 101416, People Republic of China

Abstract. Unmanned aerial vehicle (UAV) relay communication is an important means to realize long-range wireless communication, where the lowest power loss could prolong the air residence time and increase the duration of the relay communication of UAV. In this paper, we present a UAV relay communication path planning based on the minimum encircling circle algorithm for the UAV working at the lowest power loss. We acquired the minimum radius of UAV relay communication based on for moving platform positions, and then determined the 3D position and flight path of UAV. Compared with the centroid enclosing circle algorithm, our simulation can reduce the signal transmitting power, realize the path planning of UAV relay communication under the lowest power loss.

1. Introduction

Aiming at the problem that the communication distance in radio wave transmission is limited and easily affected by environmental factors such as topography and meteorology, many kinds of wireless communication relay methods are put forward in the world at present to expand the communication distance and improve the communication quality. Herein, the UAV platform has been widely used in civil and military fields because of its high flexibility and low cost [1-3]. In recent years, the researches focus on the impact of UAV path planning on communication performance and optimal layout based on the centroid enclosing circle algorithm. Kramer et al. [4] analysed the network capacity of different relay forwarding strategies. Fu et al. [5] shown the optimized search path planning and communication performance of UAV relay communication. Han et al. [6] gave four kinds of network connectivity criteria. In reference [7], UAV optimal path planning based on space-time block coded communication protocol is proposed. However, in practice, the long working time and the large relay range require sufficient power capacity of UAV for the process of mobile and communication. The lowest power loss could lead to prolong the air residence time and increase the duration of the relay communication of UAV. In this paper, we present a UAV relay communication path planning algorithm based on the lowest power loss for the motion law of the ground moving platforms, which ensures the duration of UAV relay operation is extended while the ground moving platforms are within the relay communication range at the same time.

2. Problem Description

The main two objectives of this paper are as follows: Firstly, make the anticipant ground moving platforms included in relay range, keep wireless link unblocked during the course of motion. Secondly, the transmit power of UAV antenna should be reduced as much as possible in order to prolong the single flight time and reduce the power loss of UAV.

The initial ground platforms are assumed randomly distributed in a rectangular range, with the random moving direction. Here, the range of motion is not necessarily limited to the initial rectangle. If the UAV adopts directional antenna, its relay communication range can be simplified to a circle with...
radius varying with flight altitude. The relay process of UAV to ground moving platforms is divided into two steps: First, search the ground platforms at a certain time to get their position coordinates. Second, on the basis of making sure that all the ground platforms are within the relay communication range, determine the position of the UAV at this time.

Figure 1. Relay communication scenario diagram.

The relay communication scenario diagram is shown in Figure 1. The black spots represent the ground communication platforms. The $n$ platforms are randomly distributed in the bounded rectangular region before the motion starts. The communication platform moves randomly at a fixed speed. The UAV carries a directional antenna, projecting a circular center and radius on the ground at a fixed angle. To ensure that all platforms can communicate with the UAV anywhere, the coverage circle should include all ground communication platforms. In order to prolong the single flight relay operation time, the antenna power loss of UAV should be minimized.

3. Problem Modelling

3.1. Modelling of motion platforms

It is assumed that each ground platform is a vehicle moving at a constant speed and that the direction of movement of each communication vehicle changes once every time ($t$ minutes). According to the actual situation, the instantaneous change angle of the driving direction of the vehicle should be $-45^\circ$ to $45^\circ$. Assuming that the speed of the communication vehicle be $v$, and take the random value $-45^\circ < \alpha < 45^\circ$ for each direction change angle, then the mode of the changing direction angle of the vehicle per minute is shown in Figure 2.

Figure 2. The model of changing the direction angle of ground moving platform.

Compared to the original direction of the vehicle, it turns to the left to be positive, that is $0^\circ < \alpha < 45^\circ$, to the right to be negative, that is $-45^\circ < \alpha < 0^\circ$. The position of the platform is calculated in $t$ minutes, and the platform is located at the point $a_0(x_0, y_0)$ before moving, and the angle is $\alpha_0$ relative to the plane coordinate system. The coordinate of the platform moving after $t$ minutes is
\[ a_t(x_t + vt \times \cos(\alpha_t + \alpha_t), y_t + vt \times \sin(\alpha_t + \alpha_t)) \]  

(1)

By analogy, the motion paths of each communication vehicle can be obtained in \( t \) minutes.

3.2. Modelling of optimal flight path for UAV

The optimal flight path of UAV should ensure minimize the transmit power of UAV while the ground platforms located in the relay coverage area. Assuming that the UAV relay communication performance indicators are known, the average received signal power of the ground user is [8]:

\[ P_r = P_t G_t G_r (A_r \Delta L)^{-1} \]  

(2)

\[ A_r = (4\pi d / \lambda)^2 \]  

(3)

Here, the transmit power of UAV is \( P_t \), the antenna gain is \( G_t \), the receiving antenna gain is \( G_r \), the extra loss caused by weather, feeder and other factors is \( \Delta L \), the signal free space propagation path loss is \( A_r \), the propagation distance of unmanned signal is \( d \) and the communication wavelength is \( \lambda \).

According to the model of UAV relay communication coverage area proposed by Zhu et al. [9], the radius of UAV relay communication coverage circle is obtained as follows:

\[ r \leq (R - \frac{P_t G_t G_r \lambda^2}{16\pi^2 \Delta L K R T_0 \gamma_0} - H^2)^{1/2} (R + H)^{-1/2} \]  

(4)

Here, the radius of the earth is \( R \), the altitude of the UAV is \( H \), the Polzeman constant is \( K \) and the noise temperature at the receiver end of the signal is \( T \) and the minimum threshold of receiver SNR is \( \gamma_0 \).

Equation (4) shows that the transmit power \( P_t \) of UAV with the same performance index is positively correlated with its relay coverage radius \( r \). In order to reduce the transmit power of UAV, the radius of coverage circle should be minimized. As all ground platforms are located within the relay coverage area of UAV, the circle coverage area should include all the coordinate positions of communication vehicle. Therefore, the lowest transmit power of UAV can be converted into the minimum radius of coverage circle. According to the minimum enclosing circle algorithm [10], the minimum enclosing circle can be obtained by the following four steps according to the coordinates of \( n \) points in the plane:

The first step is the random selection of three points in the \( n \)-point set.

The second step is to make a minimum circle containing the three points A, B and C either on the circle (as shown in Figure 3) or two points on the circle at both ends of the diameter of the circle and the other point in the circle.

The third step is to traverse the point D which is the farthest point from the second step in the residual point of the point set. If D is located in or around a circle, the second step is to obtain the circle, which is the minimum encircling circle of the point set, otherwise.

The fourth step is to generate a minimum circle of three points in each of the four points ABCD and select the smallest circle from all the circles. The selected three points are set to the new points A, B, C and return to the second step.

If only two points of ABCD are located on the circumference of the circle generated in the fourth step, then the two points are set to the new point A and point B, and any of the remaining two points is taken as the new C point.
For the position coordinates of $n$ communication platforms in the initial rectangle, the minimum radius of relay communication for the initial UAV can be obtained by using the minimum bounding circle algorithm, in which the center position is the plane position of the UAV. As shown in Figure 4.

At this point, according to the communication scene Figure 1, the altitude of UAV is

$$h = r \tan \theta$$

(5)

The random motion of $n$-th point set is the motion of ground vehicle. Therefore, the motion model of $n$-th point set is the same as that of section 3.1, and the direction of motion of each point changes every minute. The coordinates of $n$ points are updated every minute according to the moving platform model, and the center position of the minimum enclosing circle is obtained again. The minimum radius of UAV relaying to the moving platform and its flying height can be obtained for a period of time.

4. Analysis of Simulation Result

In the simulation, the initial vehicle range is set to a rectangle of $20km \times 10km$.

![Moving path of 30 vehicles.](image)
Suppose there are 30 ground communication vehicles, the initial position of the vehicle is a random point in the rectangle, and each vehicle moves at the speed of $20 \text{km/h}$ at a uniform speed. If the direction of movement of the vehicle is randomly changed at $-45^\circ \sim 45^\circ$ per minute, all vehicle tracks are shown in Figure 5 after an hour. Different color is used to describe every track of 30 vehicles. The rectangular frame is the random range of the initial vehicle, and the asterisks represent the random position of the vehicles in the original rectangle.

Assuming that the antenna direction angle of UAV is $\theta = 60^\circ$, the minimum enclosing circle position can be obtained according to the position of ground communication vehicle per minute. The initial position of the vehicle relay circle and the position of the relay circle after one minute of motion of the vehicle are obtained as Figure 6.

![Figure 6. First two-condition of minimum enclosing circle.](image)

The moving path of UAV can be obtained as Figure 7, with the changes of the center of every circle in 60 minutes.

![Figure 7. Moving path of UAV.](image)

Different colors are used to represent the changes in the moving path of UAV from 0 to 60 minutes. According to the minimum enclosing circle position in the first 60 minutes, the three-dimensional position diagram of UAV flight can be obtained.
Figure 8. Moving path of UAV in 3 dimensions. Different colors are used to represent the change in position of the UAV’s flight path from 0 to 60 minutes.

Figure 8 shows how the UAV’s flight path changes over time due to the random motion of the ground platform. Note that the overall flight height is increasing.

In order to improve the connectivity between UAV and the ground nodes, Xu et al. [11] proposed a weighted centroid UAV flight model. The research object of his model is fixed communication nodes on the ground. After giving different weights to each communication node, the centroid position is calculated to cover the circular center as the relay communication of UAV. In order to ensure that all platforms are located in the UAV relay communication circle, the radius of the circle is the distance between the center and the furthest communication platform.

If $n$ communication platforms are regarded as the same weight nodes, the centroid enclosing circle algorithm can be used to calculate the position and radius of the center of relay communication coverage of UAV. According to formula (5), the altitude of UAV can be further obtained. Using one minute as the simulation step, comparing the circle radius of the UAV relay communication and the flight height calculated by the centroid enclosing circle algorithm and the minimum enclosing circle algorithm within one hour, plotted as Figure 9.

Figure 9. The comparison of circular radius variation and the altitude variation of UAV between the simulation results from the centroid enclosing circle algorithm and the minimum enclosing circle algorithm.

As can be seen from the comparison in the figure, compared with the enclosing circle UAV relay communication path planning method, the UAV relay communication path method based on the lowest power loss is more effective in reducing the radius of the relay circle and reducing the height of
the drone. When relaying the mobile communication platform with initial position in the \(20\text{km} \times 10\text{km}\) rectangle, the altitude is between 6km and 10km. Due to the positive correlation between the transmit power and the relay communication radius, the method of this paper is superior to the centroid enclosing circle algorithm in reducing the total power consumption. The simulation results show that the UAV relay communication path method based on the lowest power loss can achieve the goal of extending the air stay time and the relay operation time of a single UAV after take-off.

5. Conclusion
In this paper, the path planning and UAV performance optimization are studied in the course of relay communication between UAV and ground moving platforms. Aiming at the random moving law of the ground motion platform, we present a method of UAV relay communication path planning based on the lowest power loss, and adopts the minimum enclosing circle algorithm. According to the dynamic changes of each vehicle, the UAV flight path and altitude are adjusted in time, so that the UAV can reduce the signal transmission power on the basis of supporting all ground motion platforms to communicate, thus reducing the total power loss of the UAV signal emission. It is shown that the proposed method can achieve the lowest power loss by reduce the radius of the relay communication coverage circle and reduce the UAV flight altitude, then prolong the air residence time and increase the duration of the relay communication of UAV.

References
[1] Gu D L, Ly H, Hong X Y, Gerla M, Pei G Y, Lee Y Z 2000 IEEE: Wireless Communications and Networking Conference 2 879
[2] Xu K X, Hong X Y, Gerla M, Ly H, Gu D L 2001 IEEE: Military Communications Conference 1 230
[3] Perumal S, Baras J S, Graff C J, Yee D G 2008 IEEE: Military Communications Conference 1 7
[4] Kramer G, Gastpar M, Gupta P J 2005 IEEE: Trans. Inf. Theory 51 3037
[5] Fu X W, Cheng S M, Gao X G 2008 J. Syst. Eng. Electron. 36 890
[6] Han Z, Swindlehurst A L, Liu K J R 2009 IEEE: Trans. Veh. Technol. 58 3533
[7] Liu H T, Zhao W Q, Lee C M, Lee D X 2017 J. Aeronaut. 38 274
[8] Feng Q, McGeehan J, Nix A R 2007 IEEE: Vehicular Technology Conference 65 954
[9] Zhu Q M, Zhou S K, Huo S K, Ren X M, Xu D Z 2014 Acta Aeronaut. Astronaut. Sin. 35, 223
[10] Wang W, Wang W P 2000 J. Software 11 1237
[11] Xu X Z, Yuan J, Wang Y, Zhang Y D, Yi L T, Huo J H, Huo Z M 2011 J. Tsinghua Univ.: Nat. Sci. Ed. 2 150

Acknowledgments
We acknowledge the funding from the National Natural Science Foundation of China (No. 61602516).