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# A Distributed Cooperative Continuous Coverage Strategy of UAVs for MEC Services of Smart Grids Considering Energy Consumption

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**Abstract.** Unmanned aerial vehicles (UAVs) play an essential role in scenarios such as smart grid data collection and power line inspection for their maneuverability and low cost. However, the most obvious defect of UAVs is still the energy problem. The battery life of UAVs is too short of completing long-term tasks. Therefore, this paper proposes a distributed cooperative and continuous coverage strategy for UAVs. When the UAV is short of power, we select the path through the relay algorithm and send backhaul information such as the remaining power to the macro base station (mBS). mBS will send auxiliary UAVs to replace UAVs with weak power to complete the task of UAV replacement. We jointly optimize the relay information transmission path and UAV trajectory to achieve the goal of minimizing the total energy consumption of the system. The simulation results show that the optimization algorithm can significantly reduce the energy consumption of UAVs.

**Keywords:** unmanned aerial vehicle base stations (UAV-BSs), distributed cooperative, relay backhaul, continuous coverage, trajectory optimization

## 1 Introduction

In recent years, unmanned aerial vehicles (UAVs) have attracted extensive attention due to their high flexibility and low cost. With the rapid development of the UAV-assisted network, applications based on UAV are becoming more and more diversified, such as UAV assisted base stations (BSs), transmitting the information as a relay, and collecting information [1], etc. The maneuverability of UAV makes them deploy rapidly, provide ubiquitous communication, and improve coverage. However, UAV's most obvious defect is the energy problem, and the battery life is too short of completing long-term tasks. The unique characteristic of UAVs also poses challenges, such as high mobility and energy-constraint. To fulfill the UAVs' potentials, joint resource allocation and trajectory design for UAV-aided networks is crucial.

In order to solve the problem of UAV energy, [2] formulate an optimization problem with the aim of minimizing the overall energy consumption of all user UAVs, under the constraints of task completion deadline and computing resource. [3] formulate an optimization problem to minimize the total energy consumption of the UAV through joint region partitioning and UAV trajectory scheduling. [4] proposed a three-dimensional UAV scheduling scheme with energy replenishment capability, UAVs served users and charged in time to replenish energy. [5] proposed a power allocation scheme for UAV-assisted heterogeneous networks, which effectively utilizes the resources of UAV and ground networks to meet the QoS of mobile nodes. [6] studied a UAV communication system with an energy acquisition function. UAV transmits energy to users in half-duplex or full-duplex mode, and users collect energy and transmit data to the UAV. [7] proposed a multi-UAVs coverage model energy-saving

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communication based on UAV coverage's research status. Equalization considers coverage maximization and power control. [8] designed an energy-efficient UAV relay communication system that considers both throughput and propulsion energy consumption, thus solving UAV's energy-saving relay problem to the greatest extent. [9] assumed that the UAV flies at a fixed altitude. Through the design of the UAV trajectory, it can avoid high obstacles, communicate efficiently and energy-saving. [10] proposed a method to maximize energy utilization efficiency by controlling the transmission power and relay UAV position in the UAV relay transmission system. [11] assisted ground communication by jointly optimizing the communication time allocation of UAVs and their speed and trajectory, so that UAVs can keep flying on a circular orbit with high efficiency and energy saving. [12] proposed energy-efficient Coverage Path Planning (CPP) methods to minimize energy consumption using multiple Unmanned Aerial Vehicles (UAVs) of the coverage area. The work in [13] investigated an energy-efficient UAV communication via designing the UAV trajectory path and considered throughput and the UAV propulsion energy consumption jointly. [14] aimed to maximize the energy efficiency (EE) of the UAV by jointly optimizing the user scheduling and UAV trajectory variables. In [15], the authors proposed an optimal energy-saving deployment algorithm by jointly balancing heterogeneous UAVs' flying distances on the ground and final service altitudes in the sky.

The above articles proposed solutions to UAVs' energy problems, but most of them reduced UAVs' energy consumption in collecting information by optimizing the trajectory path. At present, a large number of scholars have focused on the deployment of UAVs as air base stations, mainly including the research on the deployment of UAVs in three-dimensional space and the research on the flight trajectory of UAVs under energy optimization. The edge cell users of the UAV assisted ground base station are studied. The minimum throughput of all users in the cell is maximized by optimizing the trajectory of the UAV and the bandwidth distribution and user division between the UAV and the ground base station. The optimization problem of communication scheduling and user association of UAV supporting multi-users in multi-UAV system is studied. By decomposing the problem, the convergence speed of the algorithm is accelerated and the throughput is improved. However, these scenarios do not consider that the user's location will change with time. When the user's location changes, the communication throughput of the entire system will change. Little attention is paid to the energy consumption of UAV-assisted BS coverage. However, the UAV battery's limited power will limit the service time of the UAV, and coverage vulnerabilities may occur due to energy depletion or damage during coverage tasks, thus affecting the quality of service (QoS) of users in the area. In order to solve this problem, some articles consider adding an additional UAV to fly, collecting energy information from other UAV-BSs, and then transmitting it to macro base stations (mBS). This method adds an additional energy consumption for UAV flight and communication, while also brings pressure to mBS.

Therefore, this paper proposes a strategy of distributed cooperation and continuous coverage of UAVs. Distributed deployed UAVs transmit the remaining power of UAV-BSs through communication links. When the UAV's power is short, other UAVs cooperate to relay and backhaul information such as electricity and service user equipments (UEs) to mBS. After receiving the information, mBS will send an auxiliary UAV to replace the UAV, which has weak electricity to continue the coverage task. In contrast, the UAV with weak electricity quantity will fly back to the BS to supplement electricity quantity after being replaced by the auxiliary UAV. In this paper, the relay information transmission path and UAV trajectory are jointly optimized to achieve the goal of minimizing the total energy consumption of the system.

In this paper, a distributed cooperative continuous coverage strategy for UAVs is proposed. By jointly optimizing the relay information transmission path and UAV trajectory, the total energy consumption of the system is minimized. First of all, this paper considers an auxiliary scenario for distributed UAV to feedback power and user information. In order to minimize the energy consumption of multi-hop information transmission and auxiliary UAV power consumption, we divide the solution process into two sub-problems: minimizing the energy consumption of information transmission and minimizing the energy consumption of generalization. Secondly, based on two sub-problems, this paper proposes two algorithms: UAVs relay routing algorithm and path optimization algorithm for auxiliary UAV.

The rest of this paper is organized as follows. Section 2 introduces the system model which includes multi-hop backhaul, time relationship, routing constraint and UAV flight trajectory and the optimization problem. In Section 3, a distributed cooperative and continuous coverage strategy for UAVs is proposed to solve the optimization problem. Section 4 provides the simulation results. Finally, we conclude the paper in Section 5.

## 2 Manuscript Preparation

The scene diagram of this paper is shown in Fig. 1. In this paper, we propose a strategy of distributed cooperation and continuous coverage of UAVs. And the relay information transmission path and UAV trajectory are jointly optimized to achieve the goal of minimizing the total energy consumption of the system. The system energy consumption consists of information relay energy consumption and auxiliary UAV flight energy consumption. Therefore, in this chapter, minimizing system energy consumption is decomposed into two sub-problems of information shortest path relay transmission and auxiliary UAV path optimization for modeling and discussion.

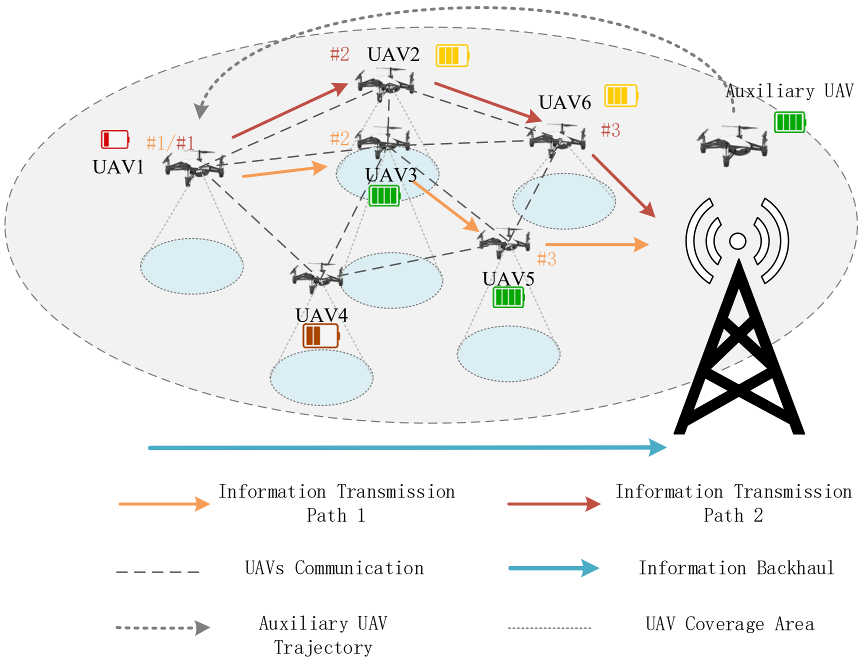


**Fig. 1.** System model diagram

### 2.1 Multi-Hop Backhaul

We construct a three-dimensional coordinate system model, where $K$ represents the total number of UAV-BSs, and $N$ represents the number of UAVs through which information is transmitted in multi-hop. The $\text{UAV}_k$ means the number of UAV is $k$, where $k \in K=\{1, 2, ..., K\}$, the three-dimensional coordinates of the UAV are $\omega_k = (x_k, y_k, z_k)$. Moreover, assuming that the UAV is the $i$ -th node through which information will pass in multi-hop transmission, where $1 \le i \le N$. For UAV-assisted communication scenarios, because UAVs are deployed at a certain height, the communication link between UAVs and users is a line-of-sight (LoS) channel, which is more advantageous than other channel damages small-scale fading or shadows. Similarly, the communication link between UAVs is less shielded, and communication is also carried out through the LoS link. Therefore, we model the channel gain between the k-th UAV and the next UAV as

$$h_k = \frac{\rho_k}{\left\|\omega_k - \omega_{k+1}\right\|^2}, k \in \kappa , \tag{1}$$

where $\rho_k$ represents the unit channel gain, when the distance between $\text{UAV}_k$ and $\text{UAV}_{k+1}$ is $1m$ and the transmission power is $1W$.

The transmission speed between UAVs can be obtained by Shannon formula

$$R_k = B\log_2\left(1+\frac{Ph_k}{\sigma^2}\right) , \tag{2}$$

where $B$ is the communication bandwidth of the returned information between UAVs, $P$ is the transmission power of the returned information between UAVs, and $h_k$ is the channel gain between $UAV_k$ and $UAV_{k+1}$.

Through the distributed cooperation of other UAVs, the UAV sends back information such as electricity quantity and UEs' location to mBS in multiple hops. We assume that UAV's information to the mBS is $L$ bit. The following formula can express the delay of information transmitted by $UAV_k$ to $UAV_{k+1}$.

$$t_k = \frac{L}{R_k} . \tag{3}$$

Then the transmission energy consumption between $UAV_k$ and $UAV_{k+1}$ can be expressed as

$$E_k = t_k P_k . \tag{4}$$

So the total transmission energy consumption and the total time delay of the information multi-hop transmission can be obtained as follows

$$\begin{aligned} E_{tran} &= \sum_{i=1}^{N} E_i \\ T_{tran} &= \sum_{i=1}^{N} t_i \end{aligned} . \tag{5}$$

## 2.2 Time Relationship

Assuming that each UAV-BS's total battery power is the same, a battery threshold is set. When the remaining power of $v$ ($v \in K=\{1, 2, ..., K\}$) is one-third of the total power, the power consumption reaches the threshold. The UAV will send backhaul information such as electricity quantity and service UEs' location to the mBS through distributed cooperation of other UAVs. The amount of returned information is $L$ bit, and the emission energy consumption of returned information is $E_0$. Assuming that the UAV's maximum launch power is certain. The launch power of each UAV can meet the launch power demand for communication with each UEs, the launch power provided by the UAV to each UE is certain, all of which is $p_0$. UAVs are deployed in three-dimensional space with a deployment height of $H$. There are the following relationship $\theta = \tan^{-1}\frac{H}{r}$ between deployment height and radius, where $\theta$ is the optimal elevation angle between the ground coverage area and the UAV. When the UEs density in the coverage area of the UAV is $\rho$, the communication between the UE and the UAV will consume the emission power of the UAV as $P_U$ and $P_U = S\rho p_0 = \pi r^2 \rho p_0$. The flight energy consumption $E_{reserve}$ is reserved for the low-power UAV flying back to the BS for charging, the formula of energy consumption and power as

$$E_{residue} - E_{reserve} - E_0 = P_U T_{limit} . \tag{6}$$

where $E_{residue}$ represents the remaining one-third of the UAV's energy consumption, and $T_{limit}$ is the tolerance time of the whole process. In this tolerance time, multi-hop path selection and information transmission between UAVs should be completed. At the same time, in order to ensure that the UAV can provide uninterrupted service, the flight time of the new UAV will also be constrained by the tolerance time

$$\begin{aligned} T_{limit} &= T_{tran} + T_{fly} \\ T_{fly} &= T_{limit} - T_{tran} \end{aligned} . \tag{7}$$

### 2.3 Routing Constraint

UAVs are deployed at different heights, with different coverage areas and different service UEs. Therefore, the amount of information available to UAVs in different regions is different. When the UAV coverage area, and the number of service UEs is too large, its remaining communication resources will not be sufficient to send backhaul information from other UAVs. Therefore, in multi-hop routing, we should ensure that the UAV in the next-hop can transmit information so that the UAV's information can reach mBS as soon as possible. At the same time, the whole energy consumption is as small as possible. Therefore, the remaining information $L_k \geq L$ of $UAV_k$ is constrained. Only when this formula is satisfied can $UAV_k$ become a multi-hop node for information transmission.

### 2.4 UAV Flight Trajectory

UAVs' propulsion energy consumption is also quite large. Assuming that the time interval is small enough and the flight time is divided into $M$ time slots, the UAV's flight in each time interval can be regarded as a constant flight $v[m]$. Taking a fixed-wing UAV as an example, its propulsion energy consumption at time slot $m$ can be expressed as

$$E_{fly}[m] = \tau(\theta_1 v^2[m]), m \in M \ . \tag{8}$$

where $\tau = \frac{T_{fly}}{M}$.

When the auxiliary UAV goes to the replace location, in addition to planning the flight path and speed of the UAV, it is also necessary to ensure that the flight time of the auxiliary UAV to the designated location at $T_{fly}$ time. In the process of UAV propulsion, in order to prevent collisions between UAV-BSs, new UAV are prohibited from passing through the positions of deployed UAV -BSs. Assuming that the trajectory $q[m]$ of UAV in $m$ time slot can be expressed by discrete-time position $q[m]=(x[m], y[m], z[m])$, we can obtain the constraint condition $q[m] \neq \omega_k$ of the UAV path. $\omega_1$ represents the launch position of the UAV, and $\omega_v$ represents the termination position of the UAV.

According to the above description, this paper aims to jointly optimize the multi-hop path and UAV trajectory of information transmission to minimize the overall total energy consumption.

$$\begin{aligned} &\min_{\{L,q,T\}} (E = E_{tran} + E_{fly} \\ &C1: T_{fly} = T_{limit} - T_{trans} \\ &C2: \mathrm{q}[1] = \omega_1 \\ &C3: \mathrm{q}[M] = \omega_v \\ &C4: \left\| \mathrm{q}[i+1] - q[i] \right\|^2 \leq (v_{\max}\Delta)^2, i \in \tau \\ &C5: L_k \geq L,\ k \in \kappa = \{1,2,\ldots,K\} \\ &C6: q[m] \neq \omega_k,\ k \in \kappa = \{1,2,\ldots,K\} \end{aligned} \ . \tag{9}$$

## 3 Proposed Algorithm

This paper considers an auxiliary scenario based on distributed UAVs cooperating to return power and user information. The mBS provides auxiliary UAV to replace low-power UAVs to ensure uninterrupted service for UEs. In order to minimize the energy consumption of multi-hop information transmission and the power consumption of auxiliary UAV. We divide the solution process into two sub-problems: minimizing energy consumption for information transmission and minimizing energy consumption for promotion.

For information backhaul, the amount of information returned, the bandwidth allocated by each UAV to return information, and the transmission power used for transmission between UAVs are fixed. The energy consumption of the information return will be proportional to the time of information return. Therefore, the energy consumption sub-problem of information return is transformed into the path selection problem of information multi-hop transmission. The path with the lowest time consumption is selected to ensure the minimum energy consumption of information returns. We consider using the Dijkstra algorithm [16] to solve the routing problem of information transmission. Selecting the path with the lowest time consumption is the path with the lowest final energy consumption.

### 3.1 UAVs Relay Routing Algorithm

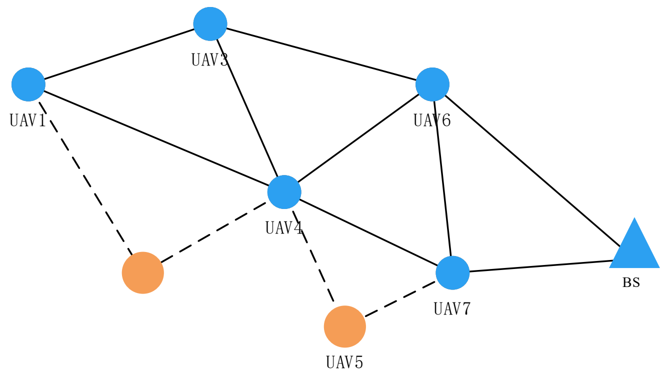


**Fig. 2.** UAVs relay routing diagram

Dijkstra algorithm is a classical method to solve the shortest path in graph theory. This paper considers using it to find the shortest path from the beginning to the end. The algorithm's idea is to generate the shortest track from a certain source point to each vertex in the graph in the order of increasing track length. The total time complexity of the algorithm is $O(n)^2$. The distributed deployment of UAVs is shown in Fig. 2, in which $UAV_1$ represents the starting point of data return, and BS represents the ending point. Orange nodes represent that UAV communication resources are mostly used to serve users and cannot bear returned data transmission. Their connection lines with other UAV nodes are dotted lines, which are regarded as unconnected, and the returned data will not pass through these nodes during multi-hop transmission. The starting point's structural information, ending point, and UAV in the graph are converted into an adjacency matrix **A** for storage. The adjacency matrix is expressed as an n-order square matrix **A** as follows

$$\mathbf{A}=\begin{bmatrix} a_{00} & \cdots & a_{0j} & \cdots & a_{1(n-1)} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ a_{i0} & \cdots & a_{ij} & \cdots & a_{i(n-1)} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ a_{(n-1)0} & \cdots & a_{(n-1)j} & \cdots & a_{(n-1)(n-1)} \end{bmatrix},$$

where $(0 \le i, j \le n-1)$.

$$a_{ij}=\begin{cases} t_{ij} & \text{if i and j can communicate normally} \\ \infty & \text{if i and j cannot communicate normally} \\ 0 & \text{if i=j} \end{cases},$$

where $t_{ij}$ represents the communication delay between UAVs. In this paper, time is used to replace the traditional track. Dijkstra algorithm steps as follows:

(1) Set array $s(i)$ to record nodes. If the initial node is $v$, then there is $s(i) = v$, $(i = 1, 2, ..., n)$ at the beginning. That is, there is only the source point $v$ in the vertex set. Set the auxiliary array $dist(n)$ to record the shortest track from the source point to each node, and the initial value of $dist(n)$ is the first row of the **A** matrix.
(2) One node $u$ is selected from nodes $W$ that have not found the shortest track so that $dist(u) = \min\{dist(W)\}$. Node $u$ is an end point of the shortest track currently obtained, and node $u$ is added to $s(i)$.
(3) Taking $u$ as the newly considered intermediate point, modifying the distance of each vertex in $dist(u)$; If the distance from the starting point $v$ to the vertex $w$ (passing through the vertex $u$) is shorter than the original distance (not passing through the vertex $u$), that is, $dist(u) + a_{uw} \le dist(w)$. Then the distance value of vertex $w$ is modified, and the modified distance value is the distance of vertex $u$ plus the weight of the edges $dist(w) = dist(u) + a_{uw}$.
(4) Repeat the above steps until all nodes are contained in array $s$.

The algorithm is illustrated as Algorithm 1.

**Algorithm 1.** UAVs relay routing algorithm

**Input:** **A**, $v$, $P$

**Output:** $S$, $T_{tran}$, $T_{fly}$, $E_{tran}$

1: Initialize: $s(i)$, $dist(i)$ and iteration $i = 0$;

2: choose node $u$, $dist(u) = \min\{dist(W)\}$, add $u$;

3: if $dist(u) + a_{uw} \le dist(w)$, change the distance value of vertex $w$, $dist(w) = dist(u) + a_{uw}$;

4: Repeat the above steps until all nodes are contained in array $S$, and all transmission times $T_{tran}$ are calculated. $E_{tran} = T_{tran}P$;

5: $T_{fly} = T_{limit} - T_{tran}$.

### 3.2 Path Optimization Algorithm for Auxiliary UAV

For the problem of minimizing energy consumption, we need to let the UAV fly to the designated position at $T_{fly}$ time, which restricts the flight speed of the UAV. The flight position of the UAV is restricted on the propulsion path to avoid collision with other UAV-BSs. We can solve the optimal trajectory of UAV and make it meet the constraints. The trajectory is solved by convex optimization.

Different UAVs to be charged have different tolerance delays, so the flight time is also different. We divide the flight time equally into $M$ parts. Since each time slot is small, we consider that the UAV is constantly flying under this time slot, so $v[m] = \frac{\|q[i+1]-q[i]\|}{\tau}$. Under the maximum tolerant flight delay, the optimized trajectory minimizes the flight energy consumption. At the same time, we restrict the starting point and ending point of the flight trajectory. Besides, the flight trajectory of the UAV requires avoiding the position of the UAV in service. By solving the second derivative of $q[i]$, we can find that the above problem is convex. We use the CVX toolbox in MATLAB to solve the problem.

$$
\begin{aligned}
&\min_{\{q,T\}} \sum_{m}^{M} \tau\left(\theta_1\left(\frac{\|q[i+1]-q[i]\|}{\tau}\right)^2\right)\\
&C1: T_{fly} = T_{limit} - T_{trans}\\
&C2: q[1] = \omega_1\\
&C3: q[M] = \omega_v\\
&C4: \|q[i+1]-q[i]\|^2 \le (v_{\max}\Delta)^2, i \in M\\
&C6: q[m] \ne \omega_k,\ k \in \kappa = \{1,2,\ldots,K\}
\end{aligned}
\quad . \tag{10}
$$

The algorithm is illustrated as Algorithm 2.

| **Algorithm 2.** Path optimization algorithm for auxiliary UAV |
|---|
| **Input:** $T_{fly}$, $\omega_1$, $\omega_v$ |
| **Output:** $Q^{out}$, $E_{fly}$ |
| 1: Solve the convex problem of (10) by CVX method, so as to obtain $Q^{out}$ with $T_{fly}$; |
| 2: Obtain $E_{fly}$ with $Q^{out}$ through (8). |

## 4 Performance Analysis

We considered a 1.2*km* × 1.2*km* urban scene and designed 8 UAV-BSs, which were distributed and deployed in the three-dimensional scene. When the distance between UAVs is less than 600*m*, it means that there is a communication link between UAVs and relay transmission can be carried out. If the distance is more than 600*m*, communication cannot be carried out between UAVs. The data used in the simulation are shown in the following Table 1.

**Table 1**. System parameter

| Parameters | Value |
|---|---|
| The channel power gain $\rho_k$ at a reference distance of d0=1m | -50dB |
| Communication Bandwidth of UAV Return Information *P* | 300kHz |
| The noise power $\sigma$ | -100dB |
| UAV launch power *P* | 2W |
| Return information bit *L* | 2Mbit |

Fig. 3 is a schematic diagram of cooperative relay between UAVs, in which purple nodes represent that the UAV has the additional capability to provide services for relay transmission information, and yellow solid lines between nodes represent that the UAV can communicate normally and the link is smooth. The red node means that the UAV has no additional capability to relay and transmit information. Red dotted lines indicate the communication link between the node and other UAVs. The green path represents the shortest time for the returned information to be transmitted to the mBS through the relay node after the shortest route selection using the Dijkstra algorithm and the transmission path with the least energy consumption.

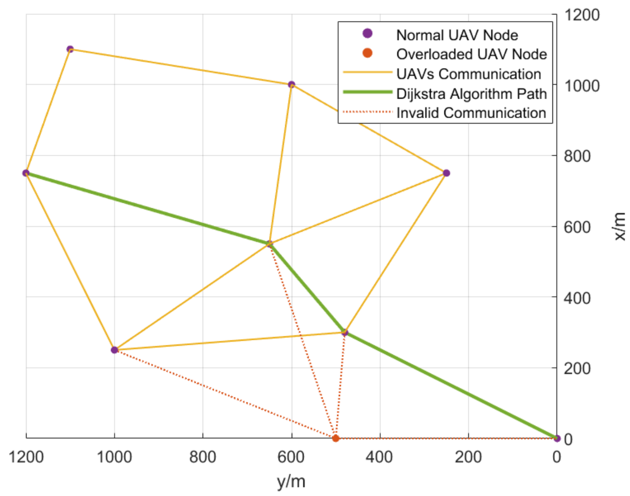


**Fig. 3.** UAVs cooperation and optimal relay path diagram

Fig. 4 is a three-dimensional diagram of the auxiliary UAV's path optimization, showing the optimal path planning with the shortest energy consumption for the auxiliary UAV to go to the alternative location. Red nodes represent UAV-BSs' distributed deployment, which communicates according to Fig. 3. We divide the flight time into 30-time slots. Orange nodes represent the position where the UAV flies in each time slot. The connection of nodes is the optimized flight trajectory of the UAV. The path of the UAV has a convex part in the middle of the straight line. The reason for the convex part is that the auxiliary UAV should consider the distance with other UAVs during the flight to prevent collision with other UAV -BSs during flight.

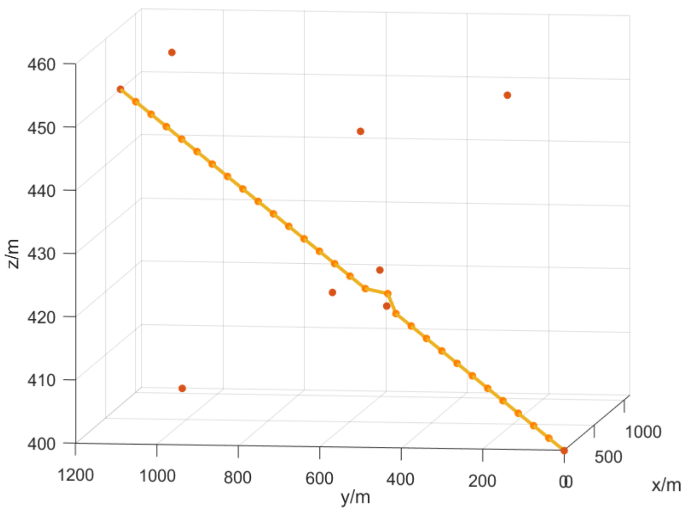


**Fig. 4.** Optimizing trajectory of auxiliary UAV

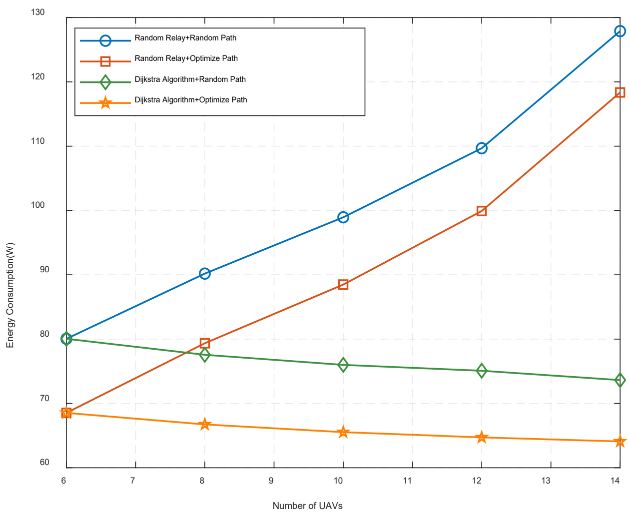


**Fig. 5.** Relationship between number of UAVs and transmission energy consumption

Fig. 5 is a diagram showing the relationship between the number of nodes deployed in distributed UAVs and the energy consumption of relay transmission. According to the figure, it can be found that the energy consumption using the Dijkstra routing algorithm decreases slowly with the increase of nodes. In contrast, a random relay's energy consumption increases rapidly with the increase in UAVs. As the number of nodes increases, the number of next-hop nodes that relay information can be selected increases. The probability of the Dijkstra algorithm selecting the shortest path also increases, reducing the energy consumption of relay transmission. However, with the increase of nodes, random paths are more likely to be traversed by all nodes before reaching the destination node, so its energy consumption will increase instead. However, with the increase of nodes, more UAV-BSs need to be avoided during the flight, thus increasing the flight energy consumption. The decrease in energy consumption using the Dijkstra algorithm will offset part of the increase in flight energy consumption, and the energy consumption will show a slow downward trend. In the random routing scenario, both kinds of energy consumption are superimposed so that they will increase rapidly.

Fig. 6 compares the relationship between the distance between the initial node position and the mBS and the sum of energy consumption by changing the node's position with insufficient power. According to the line chart, as the distance between UAV nodes and mBS increases, the energy consumption will also increase. With the increase of distance, the path of information relay is farther. The relay energy consumption increases, and the flight energy consumption will also increase due to the increase in distance. Thus the energy consumption increases faster, and the slope of the broken line is larger. However, the energy consumption and growth using Dijkstra routing and path optimization algorithm are relatively flat, there is no sudden increase, and the performance is better than other baseline algorithms.

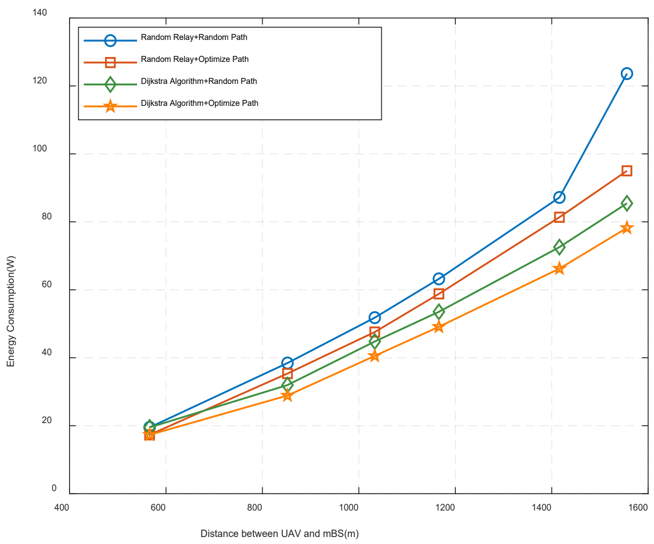


**Fig. 6.** Relationship between UAV distance and energy consumption

Fig. 7 depicts the relationship between the UAV-BS's transmission bandwidth and the sum of energy consumption. With the increase of bandwidth, the transmission rate of UAV transmission information increases, and the corresponding transmission time decreases, affecting energy consumption. The auxiliary UAV's flight energy consumption has nothing to do with the increase of bandwidth, so the relay energy consumption determines the overall energy consumption. Comparing the lines in the figure, we can find that the energy consumption and the decreased speed under the random relay algorithm are faster. The difference between the random relay algorithm's energy consumption and the energy consumption of the Dijkstra relay algorithm gradually decreases.

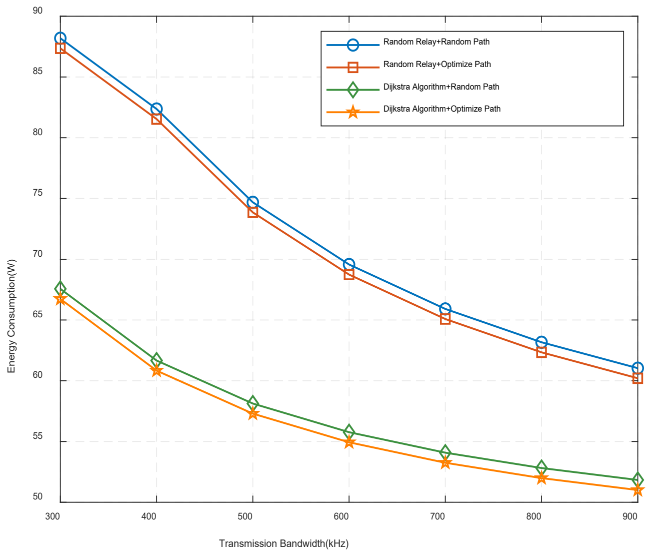


**Fig. 7.** Relationship between transmission bandwidth and energy consumption of UAVs

## 5 Conclusion

In this article, we consider the problem of limited energy in the deployment of UAVs, and propose a strategy of distributed cooperation of UAVs, relaying and returning insufficient power information to mBS. Then, mBS send auxiliary UAVs to replace UAVs with weak power, and maintaining continuous coverage by auxiliary UAVs. We use Dijkstra algorithm for relay routing, and use convex optimization algorithm to optimize the flight path of the auxiliary UAV to minimize the system energy consumption composed of information transmission energy consumption and UAV promotion energy consumption. The system energy consumption using the optimization algorithm is compared with the energy consumption generated by the baseline algorithm. The simulation results show that the optimization algorithm can greatly reduce the energy consumption of UAVs. The proposed strategy can also complete the UAV replacement task while minimizing the energy consumption of the UAV and providing continuous communication for user equipment. Therefore, the proposed algorithm solves the problem that the limited power of the UAV battery limits the service time of the UAV, thus increasing the user's quality of experience. The optimization problem for task allocation mechanism in the UAV-enabled MEC system, where UAVs are served as an IoT platform, will be studied in our future work.

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