Downlink User Power Allocation and Joint Rate Maximization in UAV-Relayed Assisted SWIPT-NOMA System

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Downlink user power allocation and joint rate maximization in UAV-relayed assisted SWIPT-NOMA system

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Abstract: In this paper, in order to improve the performance of 5G wireless communication system and save power consumption to achieve the optimal power distribution and maximize the total user rate in a multi-user cluster of non-orthogonal multiple access (NOMA) system downlink, a SWIPT-NOMA system assisted by dynamic unmanned aerial vehicle (UAV) relay is constructed. The UAV relay dynamic programming under two-hop communication was firstly studied, and the global optimal power allocation strategy for downlink users of SWIPT-NOMA system is found. Finally, the optimal relay selection algorithm was used to maximize the total user rate, which was verified by Monto Carlo simulation. The simulation results show that the performance of the proposed system model is better than that of the traditional FDMA system scheme in terms of outage probability, energy consumption and total user rate under different distribution scenarios for the multi-user cluster deployed with dynamic UAV relay system.

Keywords: non orthogonal multiple access, Wireless energy carrying communication, Power distribution, Dynamic programming, Monte Carlo simulation

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1 Introduction

Under the background of the information age, the mobile communication industry is developing rapidly, the user's wireless data service demand is growing geometrically, and the spectrum resources are relatively limited, which can not be met by the existing multiple access technology. With the arrival of a new generation of mobile communication system, that is, the fifth generation mobile communication, it provides us with a potential non orthogonal multiple access technology to achieve greater system throughput and higher spectral efficiency [1, 2, 3]. Non orthogonal multiple access technology realizes that multiple users share the same time slot, frequency band and code resources for communication through power domain multiplexing. The dynamic grouping optimization scheme of user cluster can provide convenient preconditions for effectively solving the power allocation problems in mobile communication, which have attracted extensive attention [4,5,6,7]. In reference [4], considering the combinatorial nature of mixed integer nonlinear programming problem, a low complexity suboptimal user grouping scheme is proposed to optimize the power allocation of users and maximize the throughput of the whole system. Literature [5] studies the experience quality requirements of typical applications of cognitive radio (CR) platform, and puts forward that user grouping and power management in OFDM and NOMA systems can maintain the user perception level and reduce the transmission power. Reference [6] studies the resource allocation of energy-saving NOMA system in coordinated multipoint networks, and proposes a practical application scenario: incomplete channel state information, incomplete continuous interference cancellation and data interruption. Compared with NOMA and OFDMA algorithms, the performance of energy-efficient is improved. Antonio et al. Proposed Masaracchia et at.[7] that the shortcomings of user mobility are not considered in the design of NOMA communication video system, and the mobility of users is considered in NOMA transmission system, which opens a new idea for relevant research. However, the resource allocation problem under dynamic programming is not involved in literature [4,5,6,7].

On the other hand, unmanned aerial vehicles (UAV) are widely used in mobile communication. Using the mobility of UAV, it can more conveniently expand the wireless communication connection mode, to improve the transmission rate and service quality, and promote the system performance and application scenario selection of the next generation wireless communication. Due to the high mobility and good line of sight quality of UAV, UAV can also be applied to some special scenarios, such as natural disasters and harsh ground communication environment [8]. The superiority of various performance indexes of UAV assisted mobile communication has been confirmed in literature [9,10,11,12,13,14]. In addition, the combination of UAV and NOMA is a way to realize large-scale connection [15,16,17]. Reference [15] studies the trajectory and power allocation optimization of joint unmanned aerial vehicle (UAV) based on non-orthogonal multiple access protocol in cognitive radio networks. In the Jz, A et al [16], it analyzes the security interrupt performance of UAV relay non orthogonal multiple access system, in which one source has eavesdroppers. The superimposed signal under NOMA protocol is sent to two users through UAV decoding and forwarding relay. Based on PDF and CDF expressions, the analytical expression of the security outage probability of two users is derived. In the Chen et al [17] reference. Proposed a power allocation scheme for circular orbit NOMA-UAV network, which maximizes the total rate of ordinary users while ensuring the security of specific users. Considering the energy limitation of UAV, the UAV system with NOMA
was also studied in [18,19,20,21,22,23,24]. In reference X Sun et al [18], the closed expressions of security outage probability and effective security throughput in simultaneous wireless information and power transmission (SWIPT) UAV network with directional modulation scheme are derived. The authors in the Hourani et al [19] first proposed a layout optimization strategy and PA optimization scheme to meet the rate threshold of secure users, and then used beamforming to ensure secure transmission. Zhang et al. [20] studied the security interruption performance of low altitude UAV group security network with multiple UAV eavesdroppers. Considering that the legal UAV receiver and eavesdropping UAV are randomly distributed, the analytical expressions of SOP and average confidentiality rate of UAV Communication system are derived in [21]. The author in [22] studied the security performance of NOMA-UAV network under three different eavesdropping situations, such as one eavesdropper, non-collusive eavesdropper and collusive eavesdropper. A new cooperative jamming scheme is proposed in [23], which is based on SWIPT UAV auxiliary NOMA system with multiple ground passive receivers to enhance the security performance. Assuming that the transceiver has residual hardware damage, Li et al. [24] analyzed and asymptotically analyzed the reliability and rate of UAV assisted NOMA multi-channel relay system. Finally, the accuracy of the derived formula is verified by Monte Carlo simulation.

From the research and analysis in the above literature, it is an interesting and promising problem to study the UAV relay assisted SWIPT-NOMA system under the circumstances of ensuring the user's quality of service, especially when the information of double hop downlink is combined with NOMA technology, and both hops need to be relayed by dynamic UAV. Therefore, in this paper, according to SOP, we study the user service quality of UAV relay assisted SWIPT-NOMA system in Rayleigh fading channel when two hop information transmission needs dynamic UAV relay. The main contributions are as follows:

(1) The maximum total rate of multi-user UAV relay system with SWIPT-NOMA system is studied on Rayleigh fading channel. In addition, the sum of the total rate of two hop downlink is characterized.

(2) Based on these expressions, the analytical expression of two hop downlink SOP is derived, and the multi-user interrupt performance of dynamic UAV relay system is verified by Monte Carlo simulation.

(3) In addition, the system parameters that affect the total multi-user rate under different location deployment in the dynamic UAV relay system, that is, the distance between nodes and the budget power of UAV group, are also studied.

Next, section 2 describes the system model and deduces the mid-course probability. Section 3 is divided into two parts: Section 3.1 problem analysis and Section 3.2 problem solving. Numerical results are given in section 4 and conclusions are given in Section 5.

2 system model
As shown in Figure 1, we study a UAV assisted downlink SWIPT-NOMA system to solve the practical application scenario of insufficient base station coverage and weak signal under the
shelter of buildings. Among them, $n, (n > 1)$ users as the destination node will get the information on the source node of the base station (BS) through the UAV relay node. The UAV will use SWIPT technology to capture energy from the base station and distribute it to users for decoding. Both the source node and the destination node are equipped with a single antenna with receive and forward functions, while the relay node adopts dual antennas to receive and forward signals respectively.

As we know, the communication range of the base station is limited. In this paper, we assume that the user obtains the information from the base station through the UAV relay node. The communication channel between them adopts the Rayleigh fading channel model, in which the gain of each channel is constant and the gain between different channels changes independently. For convenience, we use $n$ to represent the nth user $n \in \{1, 2 \ldots N\}$. Therefore, the channel gain between the UAV and the nth user and the base station can be expressed as:

$$h_{U,n} = d_{U,n}^{-\alpha} \cdot g_{U,n} \quad \text{and} \quad h_{U,B} = d_{U,B}^{-\alpha} \cdot g_{U,B}$$

Among them $\alpha$ indicates the path loss index, $d_{U,n}$ and $d_{U,B}$ European distance from user to UAV and base station to UAV respectively:

$$d_{U,n} = \sqrt{(x_{U,n} - x_U)^2 + (y_{U,n} - y_U)^2 + H^2}$$

$$d_{U,S} = \sqrt{(x_{U,S} - x_U)^2 + (y_{U,S} - y_U)^2 + H^2} \quad (1)$$

$g_{U,n}$ and $g_{U,B} \sim \text{CN}(0,1)$ Represents the normalized Rayleigh fading channel state. The position of UAV relay can be moved. We assume that the channel state is an ideal channel. At this time, the normalized Rayleigh fading channel state is 1 (i.e. $g_{U,n} = g_{U,B} = 1$). It is
assumed that the UAV fully knows the information channel state (CSI) of each channel and meets the requirements $|h_{U,1}|^2 > |h_{U,2}|^2 > \ldots > |h_{U,N}|^2$. In addition, we also provide a power distributor and SIC at the receiver for each user to counteract the interference between users. Considering that the energy of the UAV relay node is limited, we use SWIPT technology at the UAV node to provide energy supply by capturing the RF signal of the source node, and work in full duplex mode. In the system model designed in this paper, the UAV is used as the relay node and adopts the full duplex working mode to receive and send signals in the same time period. These signals also include the self-interference signals generated by the UAV relay itself.

The working mode of UAV relay node is to amplify and forward the radio frequency signal (RF) from the source node through AF protocol, collect energy according to PS protocol, and decode the source node signal at the same time. All the collected energy is temporarily stored at the battery for signal transmission, and all energy is provided in time for power distribution. At the same time, the UAV relay node sends the source signal and self-interference signal to the user node according to the NOMA protocol for signal transmission. Then, the signal transmitted by the base station source node can be expressed as:

$$x_s = \sum_{n=1}^{N} \sqrt{P_s} x_n$$

(2)

Where, $P_s$ represents the transmission power of the source node and $x_n$ is the signal of the nth user. The signal received at the UAV relay node can be expressed as:

$$y_U = h_{U,\omega} x_s + \sqrt{P_U} h_{U,x} + \omega$$

(3) Where, $P_U$ represents the transmission power of UAV relay node, $x_s$ in order to meet Source node signal; $\omega$ It is additive Gaussian white noise in the channel and obeys the complex Gaussian random variable of independent and identically distributed, which satisfies $\omega \sim \left(0, \theta_{U,S}^2\right)$, The mean value in the channel is 0 and the variance is $\theta_{U,S}^2$; $\sqrt{P_U} h_{U,x}$ is the self-interference signal at the UAV relay node; $x_u$ The composite unit signal sent by UAV relay node meets

$$E\left(\left|x_u\right|^2\right) = 1.$$

The composite signal U at the UAV relay node includes the signal from the base station $x_s$ source node and the self-interference signal $x_u$ from the relay node. According to the NOMA protocol, all users have serial interference cancellation (SIC) receivers to eliminate
interference between signals. That is, U can be express it as:

\[ U = \sqrt{\sum_{i=0}^{N} \gamma_i P_U x_i} + \sum_{i=1}^{N} \gamma_i P_U x_i \]  

(4) Where, \( \gamma \) is the power distribution factor and meets \( \sum_{i=0}^{N} \gamma_i = 1 \).

Based on the PS protocol, the UAV relay node uses the collected energy for information transmission \( y_U \) and is divided into two parts according to the power allocation factor \( \beta \in (0, 1) \), that \( \beta \) is part for information transmission and \( 1-\beta \) part for energy collection. Therefore, the information flow received at the UAV relay node and the collected energy flow can be expressed as:

\[ y_U^\beta = \sqrt{\beta y_U} + \omega \]  

(5) \[ y_U^{1-\beta} = \sqrt{1-\beta y_U} \]  

(6) Based on NOMA technology, SIC technology is adopted in each node to eliminate the interference between different user signals. After self-interference is eliminated by using its characteristics through self-energy recovery technology at the UAV relay node [25], the received signal of the relay node is updated to the interference expression that can eliminate its own signal:

\[ y_U^\beta = \sqrt{\beta} h_U, s x_s^* + \omega^* \]  

(7) Where \( \omega^* \) is additive white Gaussian noise and \( \omega = \sqrt{\beta} \omega + \omega \) According to (5), the signal transmission from the base station node to the UAV relay node can be obtained. The expression of signal interference noise ratio received by denote U is:

\[ SINR_U = \frac{\beta P_s |h_{U,B}|^2}{\beta \Theta_{U,S} + \Theta_{U,S}} \]  

(8) Assuming that the system bandwidth of the system model is \( B \) Hz, the obtained transmission rate from the base station node to the UAV relay node can be expressed as:

\[ R_{U,S} = B \log_2 (1 + SINR_U) \]  

(9) Compared with RF signal, considering that there is little energy collection generated by noise, the energy collection in this system can ignore the energy of noise. Then we can get the expression of the total energy collected as:

\[ E_U = \eta (1-\beta)(P_s |h_{U,S}|^2 + P_u |h_U|^2) \]  

(10) Where, \( \eta \in (0,1) \) represents the energy conversion efficiency, and the unmanned relay uses the collected energy for transmitting signals, i.e.

\[ P_u = \frac{E_U}{T}. \text{Let } T = 1, \text{Therefore,} \]
the simplified expression of UAV relay transmission power can be further obtained as
\[
P_U = \frac{\eta(1-\beta)P_s|h_{U,S}|^2}{1-\eta(1-\beta)|h_U|^2}
\]  
(11)  

The information is transmitted from the UAV relay node to the nth user, and the signal received by the nth user is expressed as:
\[
y_n = h_{U,n}\sqrt{\gamma_n P_U x_n} + h_{U,n} \sum_{i=1, i\neq n}^{N} \sqrt{\gamma_i P_U x_i} + \omega
\]  
(12)  

Then the signal to interference noise ratio[26] of the nth user received signal is:
\[
SINR_n = \frac{\gamma_n P_U|h_{U,n}|^2}{|h_{U,n}| \sum_{i=1}^{N} \gamma_i P_U + \Theta^2}
\]  
(13)  

The information rate expression obtained by the nth user receiving the signal is:
\[
R_{U,n} = B \log_2(1 + SINR_{U,n})
\]  
(14)  

Therefore, using downlink NOMA transmission, the total transmission rate to the user node can be expressed as:
\[
R = \sum_{n=1}^{N} R_{U,n} = B \log_2 \left( \sum_{i=1}^{N} |h_{U,i}|^2 \frac{\gamma_i P_U + \Theta^2}{\Theta^2} \right)
\]  
(15)  

The delivery steps of the total transmission rate are shown in Appendix 1.  

Therefore, the total receiving rate of the system is:
\[
V = R_{U,S} + R
\]  
(16)  

In the system model design, we can see that the system is a two-hop transmission system model. Therefore, when considering system interruption, we will consider two parts: one is from the base station source node to the UAV relay node, and the other is from the UAV relay node to all user nodes. When the transmission rate of at least one part of the two parts is less than the transmission rate constraint, an interrupt will occur. Assume that the transmission rate constraint value is \(R_k^{\text{min}}\). Then the outage probabilities of the base station source node and the UAV interrupt node can be expressed as
\[
P_{out_s} = \Pr(\text{min}(R_{U,S}, R) < R_k^{\text{min}})
\]  

\[
= 1 - \lambda_s \int_{-\lambda_s x_0}^{\infty} e^{-\sum_{i=1}^{N} \lambda_i x_i} \, dx
\]  
(17)  

\[
P_{out_v} = \Pr(\text{min}(R_{U,1}, R_{U,N}) < R_k^{\text{min}})
\]  

\[
= 1 - \lambda_v \int_{-\lambda_v x_0}^{\infty} e^{-\sum_{i=1}^{N} \lambda_i x_i} \, dx
\]  
(18)  

The specific calculation steps of two-part outage probability are shown in Appendix 2.
3 problem analysis and problem solving
3.1 problem analysis

In this part, an optimal power allocation strategy aiming at maximizing the total transmission rate of the system will be proposed. Under the requirements of ensuring the communication quality in the system, the transmission power of the source node and the minimum energy collection value, the optimal power allocation will be achieved by optimizing the PS factor, so as to maximize the total transmission rate of the system.

In order to optimize the system and maximize the total transmission rate, the optimization objective of the system can be expressed as:

\[ P1: \max_{\{i \in R, \gamma_i\}} V = \max \left( R_{U,S} + R \right) \]

s.t

\[ C_1: \min(R_{U,i}, R_{U,N}) > R_{\text{min}} \]

\[ C_2: \min(R_{U,S}, R) > R_{\text{min}} \]

\[ C_3: E_U \geq E_{\text{min}} \]

\[ C_4: 0 \leq P_S \leq P_{\text{max}} \]

\[ C_5: 0 \leq \gamma_i \leq 1 \quad \sum_{i=1}^{N} \gamma_i = 1 \quad (19) \]

Where, \( R = \{1, ..., N\} \) for all collections of \( N \) users power allocation factor \( \gamma_i \) for users, for the minimum energy collection value \( E_{\text{min}} \), \( P_{\text{max}} \) is the maximum transmission power constraint of the source node of the base station. Constraints \( C_1 \) and constraints \( C_2 \) ensure the quality of communication service; The constraint \( C_3 \) represents that the energy collection of UAV relay node is not less than the limited minimum energy collection value; The constraint \( C_4 \) ensures that the transmission power of the source node of the base station is not greater than the limited maximum transmission power of the source node; Constraints \( C_5 \) represent the power allocation factor scale range and the upper sum limit.

At present, the optimization problem is still a nonlinear 0-1 programming problem which is difficult to solve. It is impossible to obtain the optimal location deployment \( \gamma_s \) and optimization coefficient of UAV. Therefore, a pair of coupled optimization problems are adopted for the original problem, which is divided into internal optimization problem and external optimization problem of selecting the optimal relay node. Firstly, for the internal optimization problem, the optimization objective function can be further simplified as:
\[ P2: \max_{\{i \in \mathbb{N}, \gamma_i\}} V = \max R_{U,i} + \max R_{U,n} \]

\[ C_4 \sim C_5 \]

\[ C_6: 0 < \gamma_n < 1 \quad (20) \]

### 3.2 Problem Solution

In this part, we divide the distance \( d_{U,i} \) between the user and the UAV into the farthest (U1), the nearest (U3) and the situation between them (U2), and derive the optimal closed-form solution of (20).

1. **The user furthest from the UAV \( n_i \)**
   
   We first consider the scenario when we are the farthest user from the UAV as 
   
   \[ d_{U,i} \geq d_{U,1} \geq d_{U,2} \geq \ldots \geq d_{U,N}, \quad (21) \]
   
   Then the channel gain sequence relationship of the user can be expressed as: 
   
   \[ 0 < |h_{U,i}|^2 \leq |h_{U,1}|^2 \leq |h_{U,2}|^2 \leq \ldots \leq |h_{U,N}|^2. \quad (22) \]
   
   The PA power allocation factor sequence relationship of users can be expressed as: 
   
   \[ \gamma_i \geq \gamma_1 \geq \gamma_2 \geq \ldots \geq \gamma_N > 0 \quad (23) \]
   
   According to (12), (13), (22) and (23), we can get: 
   
   \[ R_i \leq R_j \leq R_k, 1 \leq i \leq j \leq N \quad (24) \]

2. **The user closest to the UAV \( n_i \)**
   
   We will discuss the situation as the closest user of UAV. 
   
   \[ d_{U,1} \geq d_{U,2} \geq \ldots \geq d_{U,N} \geq d_{U,i} \quad (25) \]
   
   Then the channel gain sequence relationship of the user can be expressed as: 
   
   \[ 0 < |h_{U,1}|^2 \leq |h_{U,2}|^2 \leq \ldots \leq |h_{U,N}|^2 \leq |h_{U,i}|^2. \quad (26) \]
   
   The PA power allocation factor sequence relationship of users can be expressed as: 
   
   \[ \gamma_1 \geq \gamma_2 \geq \ldots \geq \gamma_N \geq \gamma_i > 0 \quad (27) \]
   
   According to (12), (13), (26) and (27), we can get: 
   
   \[ R_j \leq R_i \leq R_k, 1 \leq i \leq j \leq N \quad (28) \]

3. **Users between farthest and nearest \( n_i \)**
   
   In this case, we will discuss the general distance between UAV and user, which can be expressed as 
   
   \[ d_{U,1} \geq d_{U,2} \geq \ldots \geq d_{U,i} \geq d_{U,s} \geq d_{U,m+1} \geq \ldots \geq d_{U,N}, \quad (29) \]
   
   Then the channel gain sequence relationship of the user can be expressed as:
The PA power allocation factor sequence relationship of users can be expressed as:
\[ \gamma_1 \geq \ldots \geq \gamma_m \geq \gamma_s \geq \gamma_{m+1} \geq \ldots \geq \gamma_N > 0 \quad (31) \]

According to (12), (13), (30) and (31), we can get:
\[ R_i \leq R_j \leq R_s, 1 \leq i \leq j \leq m \]
\[ R_s \leq R_j \leq R_i, m+1 \leq i \leq j \leq N \quad (32) \]

In the three scenarios, we use the power allocation algorithm. In each flight cycle, the UAV dynamically allocates the transmission power to the user in each time slot. In algorithm 1, the closed solution of PA is derived in three cases according to the relative distance between the user and the UAV without any iteration. Therefore, compared with the existing nonconvex methods, the computational complexity of algorithm 1 is very low. The optimal UAV power allocation algorithm used in this paper is shown in algorithm 1.

**Algorithm1 Optimal UAV power allocation algorithm**

**input:**

1) \[ t = \frac{T}{N} \]

**Reset**

2) Get the position of the UAV at \( t \)

3) Calculate the distance between the UAV and the user according to equation (1) \( d_{U,1}, d_{U,2}, \ldots, d_{U,N}, \) and \( d_{U,s} \)

\[ \text{If } d_{U,s} \geq d_{U,1} \geq d_{U,2} \geq \ldots \geq d_{U,N} \text{ then} \]

4) Calculate according to equations (13) and (14) \( R_{u,i} \)

\[ \text{else if } d_{U,1} \geq d_{U,2} \geq \ldots \geq d_{U,N} \geq d_{U,s} \]

then

5) Set \[ t = t + \frac{T}{N} \]
\[ t = \frac{T}{N} \]

Obviously, (20) is a convex problem. We use the local search method to obtain the maximum system transmission rate under the optimal value \( \gamma_i^* \). These methods have been well studied and are suitable for solving quasi convex optimization problems. They will not be extended here. After obtaining the maximum system transmission rate under the corresponding optimal value in each scenario, we can conduct one-dimensional search for the optimal deployment distance between UAV relay node and user. The index of the selected optimal deployment distance can be expressed as

\[
\hat{i}^* = \arg \max_{i \in \{1,2,3\}} V_i(\gamma_i^*)
\]

Here are three different scenarios of the deployment distance between the UAV relay node and the user. We use the max min algorithm as shown below

\[
\hat{i}^* = \arg \max_{i \in \{1,2,3\}} \left\{ \min \left\{ h_{U,S}, h_{U,S}, h_{U,i}, h_{U,j} \right\} \right\}
\]

According to the above analysis, for the optimization problem \( P1 \), assuming that the UAV position is fixed in a time slot, the optimal target value of the inner optimization can be obtained by solving the internal optimization problem \( P2 \). Then, the optimal system transmission rate of the outer optimization formula is obtained according to the optimal target value of the inner optimization. That is, the optimal solution of the global optimization problem is obtained. In order to solve the PA optimization problem, the optimal UAV location selection algorithm designed in this paper is shown in algorithm 2

\[ \text{Algorithm 2} \quad \text{Optimal UAV location selection algorithm} \]

**Input:** Known parameters \( h_{U,S}, h_{U,S}, h_{U,i}, h_{U,j} \)

**Output:** Best UAV relay location index \( \hat{i}^* \), Optimal PS factor \( \gamma_i^* \), Maximum system transmission rate \( V_{\max} \)

1) Initialization parameters \( h_i \rightarrow (h_{U,S}, h_{U,S}, h_{U,i}, h_{U,j}) \)

2) According to equations (7) and (12), \( SINR_u \) and \( SINR_n \) the sum expression is obtained

3) \( SINR_u \rightarrow \min(\text{SINR}^*_u, \text{SINR}_n) \)

4) According to equation (12), the
\( \text{SINR}_{U,s}, \text{SINR}_{U,d}, \text{SINR}_{U,i} \)

5) \( \text{SINR}_{2i} \rightarrow \min(\text{SINR}_{U,s}, \text{SINR}_{U,d}, \text{SINR}_{U,i}) \)

\( V_{Ri} \rightarrow B \log_2(1 + \text{SINR}_{2i}) \)

6) \( V_i \rightarrow V_{Si} + V_{Ri} \)

7) for \( i = 1, 2, 3, ..., N \)

\( V_i^* \rightarrow 0 \)

for \( i = 1, 2, 3, ..., N \)

\( \gamma_i^* \rightarrow \arg \max_{\gamma_i \in (0,1)} V_i(h_i) \)

\( V_i^* \rightarrow V_i(\gamma_i^*, h_i) \)

If \( V_i^* \geq V_{\text{max}} \)

\( V_{\text{max}} = V_i^*, \gamma_i^* \rightarrow \gamma_i^*, \iota^* \rightarrow \iota \)

end if

end for

end for

8) return \( \iota^*, \gamma^*, V_{\text{max}} \)

---

### Table 1 system parameters

| parameter                                      | value                                      |
|------------------------------------------------|--------------------------------------------|
| Maximum transmission power of base station \( P_{\text{max}} \) | 46dBm                                      |
| Circuit self-consumption power \( P_c \)       | 30dBm                                      |
| UAV coverage                                   | A circle with a radius of 500 meters       |
| Wireless bandwidth \( W \)                    | 5MHz                                       |
| Number of users \( K \)                       | \{5, 10, 15, ..., 60\}                     |
| User distribution model                        | uniform distribution                       |
| X in NOMA                                       | \{2,4,6\}                                  |
| Minimum distance from user to UAV              | 20m                                        |
| Distance dependent path loss                   | \( 128.1 + 37.6 \log_{10}(d) \) dB, where \( d \) is in Km |
| Lognormal shadow standard deviation             | 8dB                                        |
| Small scale fading                             | Rayleigh flat fading                       |
4 Simulation Analysis

In order to illustrate the effectiveness of the system model and strategy in this paper, this section applies Monte Carlo simulation of more than 50000 channel implementations to evaluate the maximum number of users in different scenarios of SC-SIC, NOMA and SWIPT combination (also known as SWIPT-NOMA) \( U_{i}^{\text{max}}, i \in \{1, 2, 3\} \) Performance analysis between SWIPT-NOMA and FDMA. Analog parameter settings are shown in table I. Without losing generality, in our simulation, we apply a fast suboptimal user clustering method to SWIPT-NOMA flat fading channel proposed in alg. 1. In this method, we get the user distribution in three different scenarios, the change trend of the total user rate, and the influence of \( K (k = 2) \) rate among users. In the following, 'X-NOMA' refers to the with NOMA \( U_{i}^{\text{max}} = X \).

In Figure 2, UAV Communication coverage area and user distribution scenario 1, that is, when there are many users in close range of UAV, the budget power of UAV user group in this scenario is 2W. As shown in Figure 4, the relationship between user group and total user rate under UAV Communication coverage is in the SWIPT-NOMA scheme in this paper. With the increase of users, the total user rate increases slowly and remains stable. After reaching the maximum rate, the total user rate decreases slowly under the influence of the continuous increase of the number of users and the limited power of UAV. As shown in Figure 3, the overall performance of the scheme in this paper is better than the total user rate value under the FDMA scheme. Under the same limit of the number of users and UAV power, the total user rate value can be higher than 24-26mbps, and the overall performance is improved by 55%. In the case of more close users of UAV, it is closer to the ideal SC-SIC situation. In Figure 3, in this distribution scenario, the number of users far away from the UAV is \( X = 2 \). In the scheme in this paper, the rate of a single user is better than that in the FDMA scheme. With the change of user location and the influence of UAV power limitation, the channel gain is better, and the rate between users reaches a relative balance point to ensure the quality of service among the farthest users.

![Fig.2 users in close range of UAV](image)

![Fig.3 Rate relationship between two users](image)
In Figure 5, UAV Communication coverage area and user distribution scenario 2, that is, when there are many users at a long distance of UAV, the budget power of UAV user group in this scenario is 2W, as shown in Figure 7, which is the same as that in Figure 2 in scenario 1. In this scenario, compared with the FDMA scheme, under the same limit of the number of users and UAV power, the total user rate can be higher than 16-27mbps, and the overall performance can be improved by 40%. In this scenario, the scheme in this paper can ensure the effective communication of remote users. When there are many remote users, the second scenario is close to the ideal SC-SIC situation. In Figure 6, the performance is the same as that in Figure 2 in scenario 1, ensuring the quality of service among the farthest users.
In Figure 8, UAV Communication coverage area and user distribution scenario 3, that is, when there are many users at the general distance of UAV, the budget power of UAV user group in this scenario is 2W, as shown in Figure 9, which is the same as that in Figure 2 in scenario 1. In this scenario, compared with the FDMA scheme, under the same number of users and UAV power limit, the total user rate can be higher than 21-24mbps, and the overall performance can be improved by 47%. When there are many users in the general distance of UAV, the total user rate is between scenario 1 and scenario 2, which is close to the ideal SC-SIC situation. In Figure 10, the performance is the same as that in Figure 3 in scenario 1, ensuring the quality of service among the farthest users.

In the analysis process from Figure 2 to figure 10, we can find that compared with the three scenarios in this scheme, the performance is relatively poor in this scheme when there are more remote users of UAVs. Therefore, we focus on the impact of different minimum user rate constraints $R_{k}^{\text{min}}$ on the system outage probability and the average power consumed in this scenario.

As shown in Figure 11, when $R_{k}^{\text{min}} = 1.5\text{Mbps}$, the outage probability of X-NOMA and SC-SIC increases with the increase of the number of users, the performance gap between 2-NOMA and 4-NOMA is large, and the performance gap between 4-NOMA and 6-NOMA is...
small. As shown in Figure 12, at that time $R_{\text{min}} = 3\text{Mbps}$, the performance gap between X-NOMA and SC-SIC outage probability was small, and the outage probability increased slowly with the increase of the number of users. When the number of users reached 30, it increased sharply until it tended to 1. According to the above performance analysis, the outage probability of X-NOMA and SC-SIC tends to 1 with the increasing number of users. In short, the outage probability can be expressed as:

$$\text{SC} - \text{SIC} < 6 - \text{NOMA} \approx 4 - \text{NOMA} < 2 - \text{NOMA}$$

![Fig.11 Outage probability under the constraint of minimum rate of 1.5mbps](image1)

![Fig.12 Outage probability under the constraint of minimum rate of 3mbps](image2)

![Fig.13 Average total power consumption vs. number of users](image3)

As shown in Figure 13, under different dynamic UAV deployment scenarios, the average total power consumption gradually increases with the increase of the number of users. When the user distribution is generally far away from the UAV, the average total power consumption changes significantly compared with the other two scenarios.

5 Conclusion

Based on SWIPT-NOMA, we constructs a dynamic UAV relay system model, studies the maximum total rate of two hop downlink multi-user on Rayleigh fading channel, and ensures the user service quality of user cluster. Through the optimal relay selection algorithm, the problem of finding the global optimal power allocation is solved. By analyzing the relay
deployment of different UAVs and the distance distribution of multi-user, the numerical results show that the maximum total rate of multi-user cluster is affected by the number of users in the cluster and the distance distribution with UAV relay, and the total rate performance of the maximum total user is better than that of FDMA.

In addition, by increasing the number of users in the corresponding scenario, our numerical results show that the outage probability of the system will increase accordingly. When the number of users reaches a certain value, the outage probability of the system will tend to 1. Therefore, future research work will consider system performance under the cooperation of multiple UAV relay systems.

Compliance with ethical standards

Conflict of interest The corresponding author states that there is no conflict of interest.

Appendix A

Using downlink NOMA transmission, the derivation process of the expression of the total transmission rate to the user node substitutes (13) into (14) to obtain:

\[
R_{U,n} = B \log\left( \frac{\left|h_{U,i}\right|^2 \sum_{j=1}^{N} \gamma_i P_u + \theta^2}{\left|h_{U,j}\right|^2 \sum_{j=1}^{N} \gamma_j P_u + \theta^2} \right)
\]

Then the total downlink transmission rate can be pushed to:

\[
\sum_{n=1}^{N} R_{U,n} = B \log\left( \left|h_{U,1}\right|^2 \gamma_1 P_u + \theta^2 \right) + B \log\left( \left|h_{U,2}\right|^2 \gamma_2 P_u + \theta^2 \right) + \ldots + B \log\left( \left|h_{U,N}\right|^2 \gamma_N P_u + \theta^2 \right)
\]

\[
= B \log\left( \sum_{i=1}^{N} \left|h_{U,i}\right|^2 \gamma_i P_u + \theta^2 \right)
\]

(35)

Appendix B

derivation process of interrupt probability expression of base station source node and UAV interrupt node

Let
\[ \theta_{U,S} = \theta = 1 \]
\[ |h_{U,S}|^2 = x; |h_{U,n}|^2 = y; |h_{U,l}|^2 = z; |h_{U,N}|^2 = w \]
\[ a = \eta(1-\beta)P_S; b = \theta^2 \]
\[ m = \beta \theta_{U,S}^2 + \Theta^2; d = \beta P_S; x_0 = \frac{Lm}{d}; L = \frac{d x_0}{m} \]
\[ F = \frac{\gamma b}{x} \sum_{i=1}^{\gamma_i} \gamma_i L \]
\[ u(x) = F; P_u = \frac{ax}{b}; H = \frac{Lb}{\gamma_N} \]

Then the outage probability of the base station source node is
\[ P_{out} = \Pr(\min(R_{U,S}, R) \leq R_{min}) \]
\[ = 1 - \Pr(R_{U,S} \geq R_{min}, R \geq R_{min}) = \]
\[ 1 - \Pr(\text{Blog}(1 + SINR_{U,S}) \geq \text{Blog}(1 + L), \text{Blog}(1 + SINR_{U,l}) \geq \text{Blog}(1 + L)) = \]
\[ 1 - \Pr(\frac{\beta P_S |h_{U,S}|^2}{\beta \theta_{U,S}^2 + \Theta^2} \geq L, |h_{U,l}|^2 P_u \sum_{i=1}^{\gamma_i} \gamma_i \geq L) = \]
\[ 1 - \Pr(\frac{ax}{N} \sum_{i=1}^{\gamma_i} \gamma_i) \]
\[ 1 - \Pr(\frac{ax}{b} \geq L) \]
\[ 1 - \Pr(\frac{Lm}{d}, Y \geq 0) = \]
\[ 1 - \Pr(\frac{Lm}{d}, Y \geq \frac{Lb}{dx_0}) = \]
\[ 1 - \Pr(\frac{Lm}{d}, Y \geq \frac{b dx_0}{dx_0}) = \]
\[ 1 - \int_{0}^{\infty} \left( \int_{b d x_0}^{\infty} f_y(y) dy \right) e^{-\lambda_{x}x} dx = \]
\[ 1 - \lambda_{x} e^{\lambda_{x} \max \sum_{i=1}^{N} \gamma_i} e \]
\[ 1 - \lambda_{x} \int_{x}^{\infty} e^{-\lambda x} \]
\[ 1 - \lambda_{x} e^{-\lambda_{x} \max \sum_{i=1}^{N} \gamma_i} dx \]
\[ \text{(37)} \]

The outage probability of UAV relay node is:
\[ P_{\text{out}_{k}} = \Pr(\min(R_{U,1}, R_{U,N}) \leq R_{k}^{\min}) \]

\[ = 1 - \Pr(R_{U,1} \geq R_{k}^{\min}, R_{U,N} \geq R_{k}^{\min}) = \]

\[ 1 - \Pr(\text{Blog}(1 + \text{SINR}_{U,1}) \geq \text{Blog}(1 + L), \text{Blog}(1 + \text{SINR}_{U,N}) \geq \text{Blog}(1 + L)) = \]

\[ 1 - \Pr(\frac{\left|h_{U,1}\right|^2 \gamma_{1} P_{u}}{\sum_{i=1}^{N-1} \gamma_{i} P_{u} + b} \geq L, \frac{\left|h_{U,1}\right|^2 P_{u} \gamma_{N}}{b} \geq L) = \]

\[ 1 - \Pr(\frac{Z \gamma_{i} P_{u}}{Z \sum_{i=1}^{N-1} \gamma_{i} P_{u} + b} \geq L, \frac{W P_{u} \gamma_{N}}{b} \geq L) = \]

\[ 1 - \Pr(Z \geq \frac{L b}{\sum_{i=1}^{N-1} \gamma_{i} (L a x)}, W \geq \frac{L b}{a x \gamma_{N}}) = \]

\[ 1 - \Pr(Z \geq u(x), W \geq \frac{H}{a x}) = \]

\[ 1 - \int_{0}^{\infty} \Pr(Z \geq u(x)) \Pr(W \geq \frac{H}{a x}) dx = \]

\[ 1 - \int_{0}^{\infty} \left( \int_{u(x)}^{\infty} \lambda_{e} e^{-\lambda_{e} z} dz \int_{H}^{\infty} \lambda_{s} e^{-\lambda_{s} w} dW \right) \lambda_{e} e^{-\lambda_{e} x} dx = \]

\[ 1 - \lambda_{e} \int_{0}^{\infty} e^{-\left(\lambda_{e} x + \lambda_{e} u(x) + \lambda_{s} H\right)} dx \]

\[ (38) \]
References
[1] Islam, S., Avazov, N., Dobre, O. A., & Kwak, K. S. (2017). Power-domain non-orthogonal multiple access (noma) in 5g systems: potentials and challenges. IEEE Communications Surveys & Tutorials, 19(2), 721-742.
[2] Dai, L., Wang, B., Yuan, Y., Han, S., Chih-Lin, I., & Wang, Z. (2015). Non-orthogonal multiple access for 5g: solutions, challenges, opportunities, and future research trends. IEEE Communications Magazine, 53(9), 74-81.
[3] Ding, Z., Lei, X., Karagiannidis, G. K., Schober, R., Yuan, J., & Bhargava, V. (2017). A survey on non-orthogonal multiple access for 5g networks: research challenges and future trends. IEEE Journal on Selected Areas in Communications, PP(99), 1-1.
[4] Ali, M. S., Tabassum, H., & Hossain, E. (2017). Dynamic user clustering and power allocation for uplink and downlink non-orthogonal multiple access (noma) systems. IEEE Access, 4(99), 6325-6343.
[5] Rahdari, F., Movahhedinia, N., Khayyambashi, M. R., & Valaee, S. (2021). Qoe-aware power control and user grouping in cognitive radio ofdm-noma systems. Computer Networks, 189(2), 107906.
[6] Muhammed, A. J., Zheng, M., Ding, Z., Xiao, M., & Zhang, Z. (2021). Resource allocation for energy-efficient noma system in coordinated multi-point networks. IEEE Transactions on Vehicular Technology, PP(99), 1-1.
[7] Masaracchia, A., Nguyen, V. L., & Nguyen, M. T. (2020). The impact of user mobility into non-orthogonal multiple access (noma) transmission systems. Industrial Networks and Intelligent Systems, 7(24).
[8] Zhang, Rui, Zeng, Yong, Lim, & Teng, et al. (2016). Wireless communications with unmanned aerial vehicles: opportunities and challenges. IEEE Communications Magazine Articles News & Events of Interest to Communications Engineers.
[9] Hourani, A., Kandeepan, S., & Lardner, S. (2014). Optimal lap altitude for maximum coverage. IEEE Wireless Communication Letters, 3(6), 569-572.
[10] Chen, Y., Zhao, N., Ding, Z., & Alouini, M. S. (2018). Multiple uavs as relays: multi-hop single link versus multiple dual-hop links. IEEE Transactions on Wireless Communications, 1-1.
[11] Pan, C., Ren, H., Deng, Y., Elkashlan, M., & Nallanathan, A. (2019). Joint blocklength and location optimization for urlc-enabled uav relay systems. IEEE Communications Letters.
[12] Ren, H., Pan, C., Wang, K., Xu, W., Elkashlan, M., & Nallanathan, A. (2020). Joint transmit power and placement optimization for urlc-enabled uav relay systems. IEEE Transactions on Vehicular Technology.
[13] Dan, Z., Wu, X., Zhu, S., Zhuang, T., & Wang, J. Y. (2019). On the Outage Performance of Dual-Hop UAV Relaying with Multiple Sources. 2019 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC).
[14] Khuwaja, A. A., Chen, Y., & Zheng, G. (2019). Effect of user mobility and channel fading on the outage performance of uav communications. IEEE Wireless Communication Letters, PP(99), 1-1.
[15] Deng, D., & Zhu, M. (2021). Joint uav trajectory and power allocation optimization for noma in cognitive radio network. Physical Communication, 46(6), 101328.
[16] Jz, A., Xz, A., Gpb, C., & Yx, A. (2020). On secrecy analysis of uav-enabled relaying noma systems. Physical Communication, 45.

[17] Chen, X., Yang, Z., Zhao, N., Chen, Y., & Yu, R. (2020). Secure transmission via power allocation in noma-uav networks with circular trajectory. IEEE Transactions on Vehicular Technology, PP(99), 1-1.

[18] X Sun, Yang, W., & Cai, Y. (2019). Secure communication in noma assisted millimeter wave swipt uav networks. IEEE Internet of Things Journal, PP(99), 1-1.

[19] Zhao, N., Li, Y., Zhang, S., Chen, Y., & Wang, X. (2020). Security enhancement for noma-uav networks. IEEE Transactions on Vehicular Technology, PP(99).

[20] Liu, Hongwu, Yoo, Sang-Jo, Kwak, & Sup, K. (2018). Opportunistic relaying for low-altitude uav swarm secure communications with multiple eavesdroppers. Journal of Communications and Networks.

[21] Ye, J., Zhang, C., H Lei, Pan, G., & Ding, Z. (2019). Secure uav-to-uav systems with spatially random uavs. Wireless Communications Letters, IEEE, 8(2), 564-567.

[22] H Lei, Wang, D., Park, K. H., Ansari, I. S., Pan, G., & Alouini, M. S. (2019). On Secure UAV Communication Systems with Randomly Located Eavesdroppers. 2019 IEEE/CIC International Conference on Communications in China (ICCC). IEEE.

[23] Ma, R., Yang, W., Zhang, Y., Liu, J., & Shi, H. (2019). Secure mmWave communication using uav-enabled relay and cooperative jammer. IEEE Access, PP(99), 1-1.

[24] Li, X., Wang, Q., Liu, Y., Tsiftsis, T. A., Ding, Z., & Nallanathan, A. (2020). Uav-aided multi-way noma networks with residual hardware impairments.

[25] Hu, Z., Yuan, C., F Zhu, & F Gao. (2016). Weighted sum transmit power minimization for full-duplex system with swipt and self-energy recycling. IEEE Access, 4, 4874-4881.

[26] Fang, F., Xu, Y., Ding, Z., Shen, C., & Karagiannidis, G. K. (2020). Optimal resource allocation for delay minimization in noma-mec networks. IEEE Transactions on Communications, PP(99), 1-1.