Throughput Maximization for Multi-Cluster NOMA-UAV Networks

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***Abstract*—Combining non-orthogonal multiple access (NOMA) and unmanned aerial vehicles (UAVs) can achieve better performance for wireless networks. In this paper, we propose an effective scheme for NOMA-UAV network with multiple clusters. Due to the limited resource, the user clustering and optimal routing are first developed by the K-means algorithm and genetic algorithm, respectively. Then, the sum throughput is maximized by jointly optimizing the transmission power, hovering locations and transmission duration of UAV. To solve this non-convex problem with coupled variables, we decompose it into three subproblems. Among them, the non-convex subproblems can be transformed into convex ones by successive convex approximation. Then, we propose an iterative algorithm to solve these three subproblems alternately. Finally, simulation results are presented to show the effectiveness of the proposed scheme.**

***Index Terms*—Genetic algorithm, K-means, non-orthogonal multiple access, resource allocation, unmanned aerial vehicle.**

I. Introduction

Unmanned aerial vehicle (UAV) assisted communication has become an important supplement to the terrestrial networks due to its high mobility, flexible configuration and low cost [1]. Owing to these advantages, UAV-assisted communications have attracted great attentions from both academia and industry [2], [3]. In [2], Zhao *et al.* established a framework of UAV-assisted emergency networks in response to disasters. In [3], Zeng *et al.* introduced how to integrate UAVs into the fifth-generation and future wireless networks. However, due to the finite onboard energy, how to allocate the resource reasonably still remains a great challenge for UAV-assisted communications. In [4], Wang *et al.* proposed an effective algorithm to improve the throughput by jointly optimizing the transmission power and trajectory.

On the other hand, non-orthogonal multiple access (NOMA) is becoming a promising solution to satisfy the requirements of super-high rate, ultra-reliability and massive connectivity [5]. In [6], Chen *et al.* proved that NOMA can always achieve better performance than orthogonal multiple access (OMA) when both have the optimal resource allocation policies. However, there exists serious interference between users because they share the same resource block. Thus, the power allocation is extremely significant for NOMA systems [7]. In [7], Xiao *et al.* maximized the sum rate for millimeter-wave NOMA communications by jointly optimizing the transmission power and beamforming.

Due to their own advantages, it is natural to adopt NOMA in UAV-assisted communications to further improve the performance. In [8], the sum rate was maximized by Zhang *et al.* through jointly optimizing the location of UAV and the transmission power for NOMA-UAV networks. Furthermore, the decoding order was considered to improve performance. However, to the best of our knowledge, the resource allocation design for NOMA-UAV networks with multiple clusters has not been fully investigated [9], [10]. In [9], the sum rate was maximized by Feng *et al.* through jointly adjusting the three-dimensional locations of UAV, beam pattern and transmission power, where the optimal UAV routing was obtained by the branch and bound algorithm. In [10], Katwe *et al.* deployed multiple UAVs to improve the sum rate of the NOMA-UAV system by dynamic user clustering, optimal UAV placement and power allocation, where each cluster was served by a single UAV.

Different from the above works with given clusters or multi-UAV service, in this paper, we propose a scheme to maximize the sum throughput for multi-cluster NOMA-UAV networks, where the user clustering and UAV routing are both taken into account. The NOMA clusters and optimal routing are first determined by the K-means algorithm and genetic algorithm (GA), respectively. Based on the optimized user clustering and UAV routing, the sum throughput maximization problem is decomposed into three subproblems of transmission power, hovering locations and transmission duration, which can be transformed into convex ones by successive convex approximation (SCA). Then, we propose an iterative algorithm to solve these subproblems alternately.

II. System Model and Problem Formulation

A. System Model

Consider a NOMA-UAV network where a UAV is deployed as the mobile base station (BS) with a single antenna to serve K single-antenna ground users as shown in Fig. 1. The users

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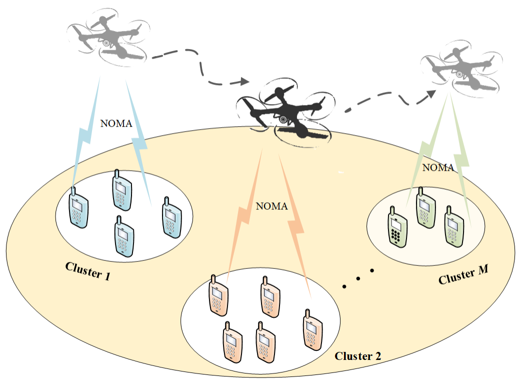

Fig. 1. A K-user NOMA-UAV network with M clusters.

are assumed to be divided into M clusters. Define the set of clusters as $\mathbf{\Lambda} = \{1, 2, ..., M\}$. There are N_m users in the m-th cluster. The set of users in the m-th cluster is defined as $\mathbf{\Gamma_m} = \{1, 2, ..., N_m\}, m \in \mathbf{\Lambda}$.

The UAV takes off from the initial point, and sequentially flies to the hovering point of each cluster according to the predefined trajectory. The transmission is performed only when hovering to avoid the Doppler effect. Meanwhile, to achieve high spectrum efficiency and massive connections, the UAV serves the users in each cluster via NOMA.

The whole duration T_0 can be divided into the flying duration T_S and the transmission duration. The transmission duration for the m-th cluster is denoted as τ_m. Thus, we have

$$\sum_{m=1}^{M} \tau_m + T_S \leq T_0. \tag{1}$$

Denote the n-th user in the m-th cluster as $U_{m,n}$. The distance from the UAV to $U_{m,n}$ when connected can be represented by $d_{m,n}$. Assume that the UAV is flying at the altitude H_0. Define the horizontal hovering coordinate of the UAV for the m-th cluster as $\mathbf{L}_m = [A_m, B_m] \in \mathbb{R}^{1\times 2}$, and the position of $U_{m,n}$ as $\mathbf{q}_{m,n} = [a_{m,n}, b_{m,n}] \in \mathbb{R}^{1\times 2}$. Therefore, $d_{m,n}$ can be calculated as

$$d_{m,n} = \sqrt{H_0^2 + \parallel \mathbf{q}_{m,n} - \mathbf{L}_m \parallel^2}, n \in \mathbf{\Gamma_m}, m \in \mathbf{\Lambda}. \tag{2}$$

Without loss of generality, in the m-th cluster, we assume

$$d_{m,1} \leq d_{m,2} \leq \cdots \leq d_{m,N_m}. \tag{3}$$

Define $h_{m,n}$ as the channel coefficient from the UAV to $U_{m,n}$. According to [11], the LoS probability is almost 1 when the UAV is higher than a suitable altitude, e.g., 120 m. Thus, the air-ground channels can be approximated as LoS, which is expressed as

$$\mid h_{m,n} \mid^2 = \rho_0 d_{m,n}^{-2}, \tag{4}$$

where ρ_0 is the reference channel coefficient of the unit distance 1 m.

According to NOMA, the user with weaker channel will be compensated for more transmission power. Define $P_{m,n}$ as the transmission power for $U_{m,n}$. Thus, according to the distance order in (3), $P_{m,n}$ should satisfy

$$0 < P_{m,1} \leq P_{m,2} \leq ... \leq P_{m,N_m}. \tag{5}$$

Meanwhile, the sum transmission power for all the users in each cluster should not exceed the power limit of UAV P_{sum}, and we have

$$\sum_{n=1}^{N_m} P_{m,n} \leq P_{sum}. \tag{6}$$

Therefore, the received signal at $U_{m,i}$ can be expressed as

$$y_{m,i} = h_{m,i} \sum_{j=1}^{N_m} \sqrt{P_{m,j}} x_{m,j} + n_{m,i}, \tag{7}$$

where $n_{m,i}$ represents the additive white Gaussian noise (AWGN) with variance σ^2 and zero mean at $U_{m,i}$, and $x_{m,j}$ denotes the message of $U_{m,j}$ with the unit power of $|x_{m,j}|^2 = 1$.

In NOMA, each user first decodes the stronger signals and removes them from the superposed signal before decoding its own. Thus, according to (3), the signal-to-interference-plus-noise ratio (SINR) for $U_{m,n}$ can be denoted as

$$\mathrm{SINR}_{m,n} = \frac{|h_{m,n}|^2 P_{m,n}}{|h_{m,n}|^2 \sum\limits_{j=1}^{n-1} P_{m,j} + \sigma^2}, n \in N_m. \tag{8}$$

In addition, the messages from weaker users should be also correctly decoded at the receiver with better channel. Thus, we have the constraint as

$$\mathrm{SINR}_{m,n}^{min} = \min\{\mathrm{SINR}_{m,n}^1, \cdots, \mathrm{SINR}_{m,n}^n\} \geq \eta_{m,n}, \tag{9}$$

where $\eta_{m,n}$ is the QoS requirement of $U_{m,n}$. Define $\mathrm{SINR}_{m,n}^w, \{w \leq n \in \mathbf{\Gamma_m}\}$ as the SINR when the signal of $U_{m,n}$ is decoded at the receiver $U_{m,w}$, which can be expressed as

$$\mathrm{SINR}_{m,n}^w = \frac{|h_{m,w}|^2 P_{m,n}}{|h_{m,w}|^2 \sum\limits_{j=1}^{n-1} P_{m,j} + \sigma^2}, w \leq n. \tag{10}$$

Accordingly, the downlink achievable rate of $U_{m,n}$ can be denoted as

$$R_{m,n} = \log_2(1 + \mathrm{SINR}_{m,n}^{min}). \tag{11}$$

B. Problem Formulation

As the available resource of UAV is limited, we first utilize the K-means algorithm to group all users into M clusters. Then, GA is adopted to obtain the optimal UAV routing and the shortest distance S_{min}, which can decrease the computational complexity. The index number of the initial point is set as 0, which locates at $\mathbf{L}_0 = (0, 0)$. Thus, the optimal routing can be denoted by $\mathbf{G}$, which is an array including the initial point and the cluster numbers from 1 to M.

Based on the optimized user clustering and UAV routing, to take the full advantage of the resource, we aim at maximizing the system throughput by jointly optimizing the transmission power $\mathbf{P}=\{P_{m,n}|n\in\mathbf{\Gamma_m}, m\in\mathbf{\Lambda}\}$, the UAV hovering locations $\mathbf{L}=\{\mathbf{L}_m|m\in\mathbf{\Lambda}\}$ and the transmission duration allocation $\mathbf{T}=\{\tau_m|m\in\mathbf{\Lambda}\}$. Thus, the optimization problem can be formulated as

$$
\begin{aligned}
(\mathrm{P1}):\max_{\mathbf{P},\mathbf{L},\mathbf{T}} & \sum_{m=1}^{M}\sum_{n=1}^{N_m} R_{m,n}\tau_m \\
& s.t. R_{m,n}\tau_m \geq \delta_{m,n}, && (12a)\\
& \sum_{i=1}^{M}\|\mathbf{L}_{\mathbf{G}(i+1)}-\mathbf{L}_{\mathbf{G}(i)}\|\leq S_{min}. && (12b)\\
& (1),(5),(6),(9). && (12c)
\end{aligned}
$$

In (P1), (12a) ensures that the throughput for $U_{m,n}$ should exceed a threshold $\delta_{m,n}$. (12b) ensures that the flying distance cannot ascend with the change of hovering locations.

(P1) is a non-convex problem with $\mathbf{P},\mathbf{L}$ and $\mathbf{T}$ coupled, which is difficult to solve directly. Thus, we propose an effective algorithm to solve the resource allocation iteratively in next section.

III. Resource Allocation

In this section, to simplify (P1), we first decompose it into three subproblems of the transmit power optimization, the hovering location optimization and the duration optimization. In the end, an effective algorithm is proposed to solve the subproblems alternately.

A. Transmission Power Optimization

For any given UAV location $\mathbf{L}$ and transmission duration $\mathbf{T}$, (P1) can be decomposed as

$$
\begin{aligned}
\max_{\mathbf{P}} & \sum_{m=1}^{M}\sum_{n=1}^{N_m} R_{m,n}\tau_m \\
s.t.\ & R_{m,n}\tau_m \geq \delta_{m,n}, && (13a)\\
& \mathrm{SINR}_{m,n}^{min} \geq \eta_{m,n}, && (13b)\\
& (5),(6). && (13c)
\end{aligned}
$$

which is intractable due to the non-convex objective function and the constraints (13a) and (13b). Thus, SCA is adopted to approximate them as convex ones.

For the objective function and the constraints (13a), we have

$$
\begin{aligned}
R_{m,n} &= \log_2\left(1+\mathrm{SINR}_{m,n}^{min}\right) && (14)\\
&= \log_2\left(1+\min\{\mathrm{SINR}_{m,n}^{w}\}\right), w\leq n\in\mathbf{\Gamma_m}, && (15)
\end{aligned}
$$

where $\mathrm{SINR}_{m,n}^{w}$ can be rewritten as

$$
\mathrm{SINR}_{m,n}^{w} = \frac{P_{m,n}}{\sum\limits_{j=1}^{n-1}P_{m,j}+\frac{\sigma^2}{|h_{m,w}|^2}}. \tag{16}
$$

$\mathrm{SINR}_{m,n}^{w}$ increases with $|h_{m,w}|^2$. According to the distance order in (3), we have $\mathrm{SINR}_{m,n}^{min}=\mathrm{SINR}_{m,n}^{n}=\mathrm{SINR}_{m,n}$.

Substituting $\mathrm{SINR}_{m,n}^{min}$ by $\mathrm{SINR}_{m,n}$ in $R_{m,n}$, we can obtain

$$
\begin{aligned}
R_{m,n} &= \log_2\left(1+\frac{|h_{m,n}|^2P_{m,n}}{|h_{m,n}|^2\sum\limits_{j=1}^{n-1}P_{m,j}+\sigma^2}\right)\\
&= \log_2\left(|h_{m,n}|^2\sum_{j=1}^{n}P_{m,j}+\sigma^2\right)\\
&\quad -\log_2\left(|h_{m,n}|^2\sum_{j=1}^{n-1}P_{m,j}+\sigma^2\right)\\
&= \widetilde{R}_{m,n}-\overline{R}_{m,n}.
\end{aligned} \tag{17}
$$

$R_{m,n}$ is a non-concave function with respect to $\mathbf{P}$ due to $\overline{R}_{m,n}$. To perform the approximate transformations, we introduce Lemma 1.

Lemma 1: If a function $f(x)$ is concave and its derivative exists, $f(x)$ can be expanded at $x=a$ by the first-order Taylor expansion as

$$
f(x)\leq f(a)+\triangledown f(a)^{\dagger}(x-a), \tag{18}
$$

where $\triangledown f(a)^{\dagger}$ is the transpose of the gradient function for $f(x)$ at $x=a$.

If $f(x)$ is convex, it can be expanded as

$$
f(x)\geq f(a)+\triangledown f(a)^{\dagger}(x-a). \tag{19}
$$

When $x=a$, the equality holds. ■

Define $P_{m,n}^{r}$ as the transmission power of $U_{m,n}$ in the r-th iteration. According to Lemma 1, the first-order Taylor expansion of $\overline{R}_{m,n}$ at $P_{m,n}^{r}$ can be deduced as

$$
\begin{aligned}
\overline{R}_{m,n} \leq & \sum_{j=1}^{n-1}\frac{|h_{m,n}|^2\log_2(e)}{|h_{m,n}|^2\sum\limits_{j=1}^{n-1}P_{m,j}^{r}+\sigma^2}\left(P_{m,j}-P_{m,j}^{r}\right)\\
& +\log_2\left(|h_{m,n}|^2\sum_{j=1}^{n-1}P_{m,j}^{r}+\sigma^2\right)\triangleq\overline{R}_{m,n}^{[e]},
\end{aligned} \tag{20}
$$

which is approximated to a concave function. (13a) can be rewritten as

$$
R_{m,n}\tau_m\geq\left(\widetilde{R}_{m,n}-\overline{R}_{m,n}^{[e]}\right)\tau_m\geq\delta_{m,n}, 2\leq n\leq N_m. \tag{21}
$$

In particular, when $n=1$, $R_{m,1}$ needs to satisfy

$$
R_{m,1}\tau_m=\log_2\left(1+\frac{|h_{m,1}|^2P_{m,1}}{\sigma^2}\right)\tau_m\geq\delta_{m,1}, \tag{22}
$$

which is a concave constraint.

Then, (13b) can be transformed as

$$
\frac{|h_{m,n}|^2P_{m,n}}{|h_{m,n}|^2\sum\limits_{j=1}^{n-1}P_{m,j}+\sigma^2}\geq\eta_{m,n}, \tag{23}
$$

which can be rewritten into a convex constraint as

$$P_{m,n} - \eta_{m,n} \sum_{j=1}^{n-1} P_{m,j} \geq \frac{\sigma^2 \eta_{m,n}}{|h_{m,n}|^2}. \quad (24)$$

As a result, the problem (13) can be approximated as

$$\begin{aligned}
(\text{P2}): \max_{\mathbf{P}} & \sum_{m=1}^{M} \sum_{n=1}^{N_m} \left(\widetilde{R}_{m,n} - \overline{R}_{m,n}^{[e]} \right) \tau_m \\
s.t. & \left(\widetilde{R}_{m,n} - \overline{R}_{m,n}^{[e]} \right) \tau_m \geq \delta_{m,n}, && (25a) \\
& P_{m,n} - \eta_{m,n} \sum_{j=1}^{n-1} P_{m,j} \geq \frac{\sigma^2 \eta_{m,n}}{|h_{m,n}|^2}, && (25b) \\
& (5), (6), && (25c)
\end{aligned}$$

which is convex and can be solved by CVX.

B. Location Optimization

Then, with the fixed transmission power $\mathbf{P}$ and duration $\mathbf{T}$, the hovering location can be optimized as

$$\begin{aligned}
\max_{\mathbf{L}} \quad & \sum_{m=1}^{M} \sum_{n=1}^{N_m} R_{m,n} \tau_m \\
s.t. \; & \text{SINR}_{m,n}^{min} \geq \eta_{m,n}, && (26a) \\
& R_{m,n} \tau_m \geq \delta_{m,n}, n \in \boldsymbol{\Gamma_m}, m \in \boldsymbol{\Lambda}, && (26b) \\
& \sum_{i=1}^{M} \| \mathbf{L}_{\mathbf{G}(i+1)} - \mathbf{L}_{\mathbf{G}(i)} \| \leq S_{min}. && (26c)
\end{aligned}$$

The objective function, (26a) and (26b) are non-convex with respect to $\mathbf{L}$. First, for (26a), we introduce Proposition 1 to further handle it.

Proposition 1: (26a) can be transformed as

$$\| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2 \leq \rho_0 \frac{P_{m,n} - \eta_{m,n} \sum_{j=1}^{n-1} P_{m,j}}{\eta_{m,n} \sigma^2} - H_0^2, w \leq n, \quad (27)$$

which is convex and can be solved directly.

Proof: $\text{SINR}_{m,n}^{min}$ can be calculated as

$$\text{SINR}_{m,n}^{min} = \min\{\text{SINR}_{m,n}^{1}, \cdots, \text{SINR}_{m,n}^{n}\}. \quad (28)$$

To achieve (26a), we have

$$\text{SINR}_{m,n}^{w} \geq \eta_{m,n}, \forall w \leq n \in \boldsymbol{\Gamma_m}, \quad (29)$$

which can be rewritten as

$$\frac{\dfrac{\rho_0}{H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2} P_{m,n}}{\dfrac{\rho_0}{H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2} \sum_{j=1}^{n-1} P_{m,j} + \sigma^2} \geq \eta_{m,n}, w \leq n, \quad (30)$$

Accordingly, (27) can be derived. ■

Then, for $R_{m,n}$, we have

$$\begin{aligned}
R_{m,n} &= \log_2 \left(1 + \min\{\text{SINR}_{m,n}^{w}\} \right), \forall w \leq n \in \boldsymbol{\Gamma_m} \\
&= \min\{\log_2 \left(1 + \text{SINR}_{m,n}^{w} \right)\} \triangleq \min\{R_{m,n}^{w}\}, \quad (31)
\end{aligned}$$

which is non-concave. To perform the approximation, we rewrite $R_{m,n}^{w}$ as

$$\begin{aligned}
R_{m,n}^{w} = & \log_2 \left(\frac{\rho_0}{H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2} \sum_{j=1}^{n} P_{m,j} + \sigma^2 \right), \\
& - \log_2 \left(\frac{\rho_0}{H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2} \sum_{j=1}^{n-1} P_{m,j} + \sigma^2 \right). \\
\triangleq & \hat{R}_{m,n}^{w} - \check{R}_{m,n}^{w}, w \leq n, m \in \boldsymbol{\Lambda}, \quad (32)
\end{aligned}$$

Regarding $\| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2$ as a variable, we have that both $\hat{R}_{m,n}^{w}$ and $\check{R}_{m,n}^{w}$ are convex. Thus, we need to first transform $\hat{R}_{m,n}^{w}$ into a concave one. Define L_m^r as the hovering location in the r-th iteration. We can obtain the first-order expansion of $\hat{R}_{m,n}^{w}$ at $\| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2$ by Lemma 1 as

$$\begin{aligned}
\hat{R}_{m,n}^{w} \geq & -C_{m,n}^{w} \left(\| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2 - \| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2 \right) \\
& + \log_2 \left(\frac{\rho_0}{H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2} \sum_{j=1}^{n} P_{m,j} + \sigma^2 \right) \triangleq \dot{R}_{m,n}^{w}, \quad (33)
\end{aligned}$$

which is concave with respect to $\mathbf{L}$. $C_{m,n}^{w}$ can be expressed as

$$C_{m,n}^{w} = \frac{\dfrac{\rho_0 \log_2(e)}{(H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2)^2} \sum_{j=1}^{n} P_{m,j}}{\dfrac{\rho_0}{H_0^2 + \| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2} \sum_{j=1}^{n} P_{m,j} + \sigma^2}. \quad (34)$$

However, $R_{m,n}^{w}$ is still non-concave with respect to $\mathbf{L}$ due to $\check{R}_{m,n}^{w}$. Therefore, we introduce the slack variable $V_{m,w}$, which satisfies

$$V_{m,w} \leq \| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2, w \in \boldsymbol{\Gamma_m}, m \in \boldsymbol{\Lambda}. \quad (35)$$

This is a non-convex constraint due to $\| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2$. Thus, we approximate it through Lemma 1 at L_m^r as

$$\| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2 \geq \| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2 + 2(\mathbf{q}_{m,w} - \mathbf{L}_m^r)(\mathbf{L}_m^r - \mathbf{L}_m)^{\dagger}. \quad (36)$$

As a result, for (35) we have

$$V_{m,w} \leq \| \mathbf{q}_{m,w} - \mathbf{L}_m^r \|^2 + 2(\mathbf{q}_{m,w} - \mathbf{L}_m^r)(\mathbf{L}_m^r - \mathbf{L}_m)^{\dagger}. \quad (37)$$

Substituting $\| \mathbf{q}_{m,w} - \mathbf{L}_m \|^2$ by $V_{m,w}$, $\check{R}_{m,n}$ can be reformulated as

$$\check{R}_{m,n}^{w} \leq \log_2 \left(\frac{\rho_0}{H_0^2 + V_{m,w}} \sum_{j=1}^{n-1} P_{m,j} + \sigma^2 \right) \triangleq \ddot{R}_{m,n}^{w}, \quad (38)$$

which is convex.

Finally, $R_{m,n}^{w}$ can be approximated to a concave function, which satisfies

$$R_{m,n}^{w} \tau_m \geq \left(\dot{R}_{m,n}^{w} - \ddot{R}_{m,n}^{w} \right) \tau_m \geq \delta_{m,n}, w \leq n \in \boldsymbol{\Gamma_m}. \quad (39)$$

From the above derivation, all the constraints have been transformed into convex ones. Thus, the location optimization can be transformed as

$$(\mathrm{P3}): \max_{\mathbf{L},\mathrm{V}_{\mathrm{m,w}}} \sum_{m=1}^{M}\sum_{n=1}^{N_m}\min\{\dot{R}_{m,n}^{1}-\ddot{R}_{m,n}^{1},\cdots,\dot{R}_{m,n}^{n}-\ddot{R}_{m,n}^{n}\}\tau_m$$

$$s.t. \sum_{i=1}^{M}\parallel \mathbf{L}_{\mathbf{G}(i+1)}-\mathbf{L}_{\mathbf{G}(i)}\parallel \leq S_{min}, \tag{40a}$$

$$(27),(37),(39), \tag{40b}$$

which is convex and can be solved via CVX. Meanwhile, the decoding order should be updated according to the results.

C. Duration Optimization

The transmission duration $\mathbf{T}$ is optimized with $\mathbf{P}$ and $\mathbf{L}$ obtained by solving (P2) and (P3). Thus, we have

$$(\mathrm{P4}): \max_{\mathbf{T}} \sum_{m=1}^{M}\sum_{n=1}^{N} R_{m,n}\tau_m$$

$$s.t. \sum_{m=1}^{M}\tau_m \leq T_0 - T_S, \tag{41a}$$

$$R_{m,n}\tau_m \geq \delta_{m,n}, n \in \boldsymbol{\Gamma_m}, m \in \boldsymbol{\Lambda}. \tag{41b}$$

To obtain the flying duration T_S, assume that the maximum speed of UAV is ν. During the flight, the UAV first accelerates to reach the maximum speed, then keeps the constant velocity motion, and finally decelerates to the next hovering location. Thus, the flying duration of UAV T_S can be calculated as

$$T_S = \frac{S_{min} - 2M\cdot\dfrac{\nu^2}{2\alpha}}{\nu} + 2M\cdot\frac{\nu}{\alpha}, \tag{42}$$

where α is the acceleration during the accelerating and decelerating. Meanwhile, S_{min} can be updated in each iteration according to the optimized locations. As a result, for (41a), we have

$$\sum_{m=1}^{M}\tau_m \leq T_0 - \frac{S_{min}}{\nu} - \frac{M\cdot\nu}{\alpha}. \tag{43}$$

Thus, (P4) is a standard linear programming, which can be solved by CVX directly.

D. Proposed Algorithm

Accordingly, the problem (P1) have been divided into three subproblems, which are transformed into convex ones. Thus, we propose an iterative algorithm to solve the problem, summarized as Algorithm 1.

Since the resource is limited, the throughput has a specific upper bound, and cannot always decrease in each iteration. Therefore, Algorithm 1 is convergent. Furthermore, both (P2) and (P3) have K variables, the computational complexity of which can be denoted as $\mathcal{O}\left(K^3\right)$ in each inner iteration [12]. Meanwhile, (P4) is a linear programming, whose computational complexity can be denoted as $\mathcal{O}\left(M\left(K+1\right)^2\right)$ in each outer iteration.

Algorithm 1 - Alternating Optimization Algorithm for (P1)

Initialization: The initial transmission duration of UAV in each cluster τ_m^0 is set to $(T_0-T_S)/M$. Set the initial index of iterations as $k=0$.
Repeat
  Set the initial index of iterations as $r=0$.
  Repeat
    Solve (P2), and obtain the optimal power P^{r+1}.
    Solve (P3), and obtain the optimal location L^{r+1}.
    Adjust the decoding order in each cluster via L^{r+1}.
    Update: $r=r+1$.
  Until P and **L** are convergent.
  Solve (P4), obtain the optimized duration T^{k+1}.
  Update: $k=k+1$.
Until convergence.
Output: **P**, **L**, **T** and the throughput.

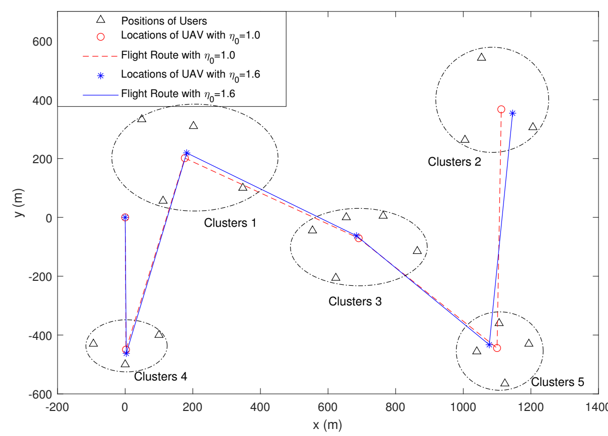

Fig. 2. Optimal routing and hovering locations of UAV with different QoS requirements.

IV. Simulation Results and Discussion

In the simulation, the power of AWGN σ^2 is set as -110 dBm. In addition, we set the reference channel coefficient ρ_0 as -60 dB. The number of ground users is set to 19. Assume that all the users have the same QoS requirement and throughput threshold, i.e., $\eta_{m,n}=\eta_0, \delta_{m,n}=\delta_0=3$ bit/Hz, $n \in \boldsymbol{\Gamma_m}, m \in \boldsymbol{\Lambda}$. To establish LoS links, the altitude of UAV H_0 is set to 150 m. Meanwhile, the maximum speed and acceleration of UAV are set as $\nu=8$ m/s and $\alpha=4$ m/s^2, respectively. To guarantee that the UAV can complete all the tasks, the whole duration T_0 is set as 415 s.

Fig. 2 shows the optimal routing and hovering locations of UAV with different QoS requirements. All users are organized into 5 clusters by the K-means algorithm, and the optimal routing is obtained as shown in Fig. 2 by GA. The total transmission power P_{sum} of UAV is set as 0.2 W. From the results, we can see that the UAV routing and locations can be effectively optimized. Furthermore, we find that the optimal UAV locations get closer to the users with better channels when the QoS threshold of users η_0 increases. This is because

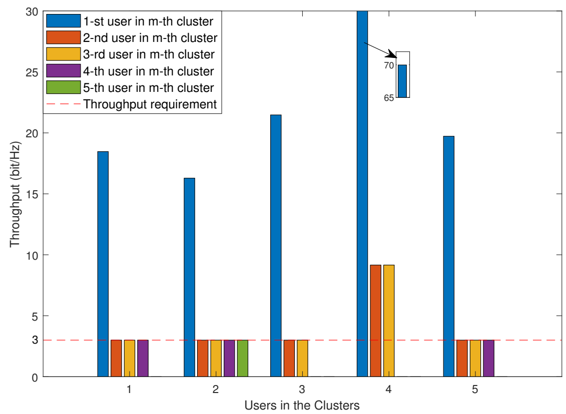

Fig. 3. Throughput of each user with $\eta_0 = 1.0$ when there are 19 users in the network.

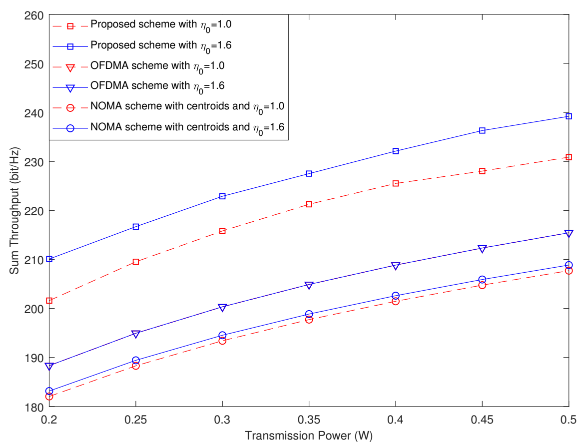

Fig. 4. Sum throughput of the proposed scheme and benchmarks with different the transmission power.

the users with worse channels will be allocated more power to achieve higher QoS. Due to the limited power, the users with better channels will be allocated less. Therefore, the locations of UAV get closer to the users with better channels to compensate for their transmission power.

In Fig. 3, we show the throughput of each user. The QoS threshold η_0 is set as 1.0. We can find that the throughput requirement of each user can be satisfied by the proposed scheme. From the result, we can find that more resource trends to be allocated to the user with the best channel in each cluster to maximize the sum throughput.

The sum throughput of the proposed scheme is compared with benchmarks in Fig. 4. The first benchmark is the OFDMA scheme. The second benchmark is the NOMA scheme, where the hovering locations are the centroids of clusters determined by the method in [13]. The results show that the proposed scheme has much better performance than both the two benchmarks. Furthermore, in the two schemes with NOMA, the sum throughput is higher with stricter QoS requirement. This is because higher QoS means higher achievable rate, and less transmission duration is needed for the clusters with worse channels. In this way, more transmission duration can be allocated to the clusters with the better channels, and the sum throughput can be improved.

V. Conclusion

In this paper, we have proposed a scheme resource allocation to maximize the sum throughput of the multi-cluster NOMA-UAV network. We first adopt the K-means algorithm and GA to group the users and obtain the optimal routing, respectively. Based on the optimal clusters and routing, we jointly optimize the transmission power, hovering locations and transmission duration to maximize the sum throughput, which is non-convex. We divide it into three subproblems including two non-convex subproblems and a linear programming one. Thus, we adopt SCA to transform the non-convex subproblems into convex ones. Finally, an iterative algorithm is proposed to solve the resource allocation problem. Simulation results show that the proposed scheme is effective and has better performance than the benchmarks.

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