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Energy-Efficient User Pairing and Power Allocation for Granted Uplink-NOMA in UAV Communication Systems

Seyyed Hadi Mostafavi-Amjad[1], Vahid Solouk[2], Hashem Kalbkhani[1*]

[1]. Faculty of Electrical Engineering, Urmia University of Technology, Urmia, Iran
[2]. Department of IT and Computer Engineering, Urmia University of Technology, Urmia, Iran

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Abstract
With the rapid deployment of users and increasing demands for mobile data, communication networks with high capacity are needed more than ever. Furthermore, there are several challenges, such as providing efficient coverage and reducing power consumption. To tackle these challenges, using unmanned aerial vehicles (UAVs) would be a good choice. This paper proposes a scheme for uplink non-orthogonal multiple access (NOMA) in UAV communication systems in the presence of granted and grant-free users. At first, the service area users, including granted and grant-free users, are partitioned into some clusters. We propose that the hover location for each cluster is determined considering the weighted mean of users' locations. We aim to allocate transmission power and form NOMA pairs to maximize the energy efficiency in each cluster subject to the constraints on spectral efficiency and total transmission power. To this end, the transmission powers of each possible pair are obtained, and then Hungarian matching is used to select the best pairs. Finally, finding the flight path of the UAV is modeled by the traveling salesman problem (TSP), and the genetic algorithm method obtains its solution. The results show that the increasing height of the UAV and density of users increases the spectral and energy efficiencies and reduces the outage probability. Also, considering the quality of service (QoS) of granted users for determining the UAV's hover location enhances the transmission's performance.

Keywords: Energy Efficiency; NOMA; Power Allocation, Unmanned Aerial Vehicle (UAV), Uplink, Users Pairing.

1- Introduction

1-1- Motivation

Nowadays, power consumption is an important challenge in wireless networks, and saving users' energy to achieve high performance is essential. Since users' quality of service (QoS) should be satisfied, energy-saving is more challenging in wireless networks. In future wireless communication networks, particularly in the 5th generation (5G) of wireless communications and beyond, the application of unmanned aerial vehicles (UAVs) is proposed for operating as moving aerial relay nodes or moving aerial base stations (ABSs). UAVs, known as drones in a common tongue, has been the subject of a bunch of research over the past few years [1-5]. If they are fine established and well-operated, UAVs can provide reliable and cost-effective wireless communication solutions for many kinds of real-world scenarios [6]. UAVs can operate better and flexibly than the traditional relay nodes in dense areas. Considering them as ABS has several challenges: power consumption, handover management, channel modeling, low-latency control, 3D localization, and interference management [6-9]. Batteries provide UAVs' power in most cases; therefore, power saving is a severe problem in UAV-assisted communications.

1-2- Contributions

This paper investigates the uplink NOMA communication between the ground users, including granted and grant-free and ABS. Our goal is to partition the users into clusters, form NOMA pairs in each cluster, and allocate power to maximize energy efficiency. Each NOMA pair includes one granted and one grant-free user. To this end, at first, UAV flies right into the communication area and simultaneously starts to send a signal periodically to the ground users to get information about their communication conditions that it needs in the next step to clustering the

✉ Hashem Kalbkhani
h.kalbkhani@uut.ac.ir

users. After that, power allocation for each possible pair in each cluster is performed to maximize energy efficiency, while the minimum QoS requirements of users should be satisfied. Finally, efficient pairs are the selection by the Hungarian algorithm. The hover locations for clusters are obtained considering the weighted mean of locations of granted users. Also, the flight path of UAV among different clusters is considered a traversal salesman problem (TSP), and its solution is obtained considering the genetic algorithm. In summary, the contributions of this work are as follows:

1) Introducing new ground-ABS uplink transmission scheme over the granted/grant-free ground users and UAV
2) Each NOMA group consists of one granted and one grant-free user to ensure the QoS of granted users
3) Problem formulation to maximize the energy-efficiency of the proposed transmission subject to the limitation on total transmit power and ensuring the QoS of the users in each NOMA group
4) Proposing weighted-mean based on the QoS of the users to determine the hover location of ABS
5) Proposing joint user groping and power allocation that first obtains the transmit power for each possible NOMA pair and then finds the optimal pairs by Hungarian matching algorithm
6) Considering the flight path of UAV as TSP and utilizing the genetic algorithm to solve it.

The rest of this paper is organized as follows. The previous works are reviewed in Section 2. The system model is described in Section 3. The proposed user clustering, NOMA pair forming, and power allocation is presented in Section 4. Simulation results are given in Section 5. Finally, conclusions remarks are provided in Section 6.

2- Previous Works

Here, we review the related researches which consider UAV-assisted wireless communication topics. In [10], a rotary-wing UAV performs the send and collect data task to/from multiple ground users. This research aimed to optimize the total UAV power consumption by minimizing propulsion and data transmission powers while satisfying each ground node's minimum quality-of-service (QoS) requirement in the uplink direction. Energy-efficient UAV communication with a ground terminal in the downlink direction via optimizing the UAV’s trajectory was studied in [11]. The authors aimed to design a new specimen that considers both the throughput and energy consumption of UAV together. Serving cell edge users by UAV and offloading the data from the base station in downlink direction by circle path for UAV was studied in [12]. The goal was to optimize UAVs' resource allocation, user partitioning, and trajectory by maximizing energy efficiency. A new modularity-based dynamic clustering relying on UAVs' modified Louvain method was studied in [13]. The authors aimed to save the transmitted power of mobile devices in the uplink direction by locating the UAVs on the user clusters' centroids. Resource allocation and trajectory design in downlink direction were formulated as an energy-efficient problem in [14], which jointly optimizes the transmit power, user scheduling, and trajectory and velocity of UAV. A real-time resource allocation algorithm for maximizing the energy efficiency in downlink direction by jointly optimizing the energy-harvesting time and power control for the considered device-to-device (D2D) communication embedded with UAV was proposed in [15].

The optimum establishing of UAV as a relay for maximizing the reliability was studied in [16]. The total power loss, outage, and error rate were considered as the reliability parameters, and optimum height was investigated for static and mobile UAVs. However, it would be better when they consider more than one user on the cell edge. In [17], the effective use of flight-time constrained UAVs as aerial ABSs was investigated to provide coverage for ground users. Notably, a novel framework was proposed for optimizing the average number of bits transmitted to users and UAVs’ hover duration. The authors in [18] proposed an optimum placement algorithm for UAVs that maximizes the number of covered users with minimum transmit power. They have detached the UAV located in the vertical dimension from the horizontal dimension, which simplifies the placement problem. The authors [19] characterized UAV-based communication's latency, reliability, and network availability of ultra-reliable and low-latency communications (URLLC). The height of UAVs and the bandwidth allocation were optimized to minimize the required total bandwidth of URLLC for a given density of UAVs. It was shown that the probability of the line-of-sight (LoS) path and the network availability is strictly concave for the distance between the ground user and UAV. The impact of the height of UAVs connected to the cellular network in uplink was studied in [19]. In [20, 21], a UAV was considered to collect data from a set of sensors with a fixed location. The goal was to minimize the UAV’s total flight time while each sensor could successfully upload its data using a given amount of energy. The problem of trajectory design for UAVs to maximize satisfied users was studied in [22].

Using non-orthogonal multiple access (NOMA) has its benefits and challenges in comparison with other multiple access techniques such as orthogonal-frequency-divisionmultiple-access (OFDMA) or orthogonal multiple access (OMA). Saving bandwidth by pairing strong and weak users in the same time slots is the most beneficial of NOMA. However, this pairing causes intra-time slot and intra-cell interference challenges. To tackle these challenges, the following works try to solve the problems. To facilitate the serving ground users in a cell, user clustering is a crucial element. Hence, dynamic user scheduling and power allocation problem was proposed in [23] to coordinate the intra-cell interference by minimizing the total power consumption. In [24], sum-rate maximization for uplink and downlink NOMA under the constraints of transmission power limitation, minimum rate requirements of users, and operation constraints were formulated. Machine learning-based user clustering and power allocation algorithms for mmWave-NOMA transmission were considered in [25]. Energy-efficient resource allocation for the uplink of hybrid NOMA and OMA transmission was considered in [26], obtained by jointly optimizing the user clustering, channel assignment, and power allocation. High-rate NOMA, where multiple users share a single zero-forcing beamforming vector, was proposed in [27]. The QoS of all clustered users was satisfied to maintain fairness among the users. In [28], ground-aerial uplink-NOMA of cellular networks was investigated, where ground base stations serve a UAV user and multiple ground users. They aimed to minimize the UAV mission completion time by jointly optimizing the UAV trajectory and association order while considering the UAV's interference to non-associated ground base stations. In [29], applying of NOMA technique to UAV to cellular BSs uplink communication, under the spectrum sharing with the existing ground users was investigated, and a new cooperative NOMA scheme was proposed to reduce the intense uplink interference due to the UAV's LoS channels with ground BSs in cellular-connected UAV communication. A combination of multi-UAV communication and NOMA was proposed in [30] to construct the high capacity uplink for the internet of things (IoT) which was achieved by jointly optimizing the sub-channel assignment, transmit power, and flying heights of UAVs. A novel framework for UAV networks with massive access capability supported by NOMA was proposed in [31].

User grouping into two sets to achieve low-latency access and reduce signaling overhead was investigated in [32], where the scheduled-access and random-access users are considered granted and grant-free users, respectively. In [33], NOMA-assisted semi-grant-free transmission was studied, which is investigated compromise between grant-free and grant-based users.

3- System Model

3-1- User Distribution and Transmission Model

As shown in Fig.1, it is assumed that N granted and $M > N$ grant-free terrestrial users are represented by $\boldsymbol{u} = \{u_1, u_2, \dots, u_N\}$ and $\boldsymbol{v} = \{v_1, v_2, \dots, v_M\}$,respectively. According to the spatial Poisson point process (SPPP) distribution with density λ_u, these users are distributed in the service area. The locations of the granted user u_i and grant-free user v_j in two-dimensional space are respectively denoted by (x_i, y_i) and $(\bar{x}_j, \bar{y}_j)$. These users are partitioned into n_c clusters $\{C_1, \dots, C_{n_C}\}$. The sets of granted and grant-free users belonging to the cluster C_k are given by $\boldsymbol{u}_k$ and $\boldsymbol{v}_k$, respectively. The number of granted and grant-free users in the cluster C_k is given by $N_c^{(k)}$ and $M_c^{(k)}$,respectively, therefore we have $\sum_{k=1}^{N_c} N_c^{(k)} = N$ and $\sum_{k=1}^{N_c} M_c^{(k)} = M$. Suppose that $\boldsymbol{S}$ is the binary matrices with the size of $(N + M) \times n_C$. If the granted user u_i belongs to the cluster C_k, we have $\boldsymbol{S}(i, k) = 1$, otherwise $\boldsymbol{S}(i, k) = 0$.On the other side, $\boldsymbol{S}(j + N, k) = 1$ denotes that grant-free user v_j is considered in the cluster C_k, else $\boldsymbol{S}(j + N, k) = 0$.

Considering Fig. 1, granted user u_i and grant-free user v_j belonging to cluster C_k form the two-user NOMA group (u_i, v_j) to transmit their data in uplink direction to ABS. The matrix $\boldsymbol{G}_k$, which presents the pairing of users in the cluster C_k, has the size of $N_c^{(k)} \times M_c^{(k)}$. If the granted user u_i and grant-free user v_j form the two-user NOMA group in the cluster C_k, then $\boldsymbol{G}_k(i, j) = 1$, otherwise $\boldsymbol{G}_k(i, j) = 0$.

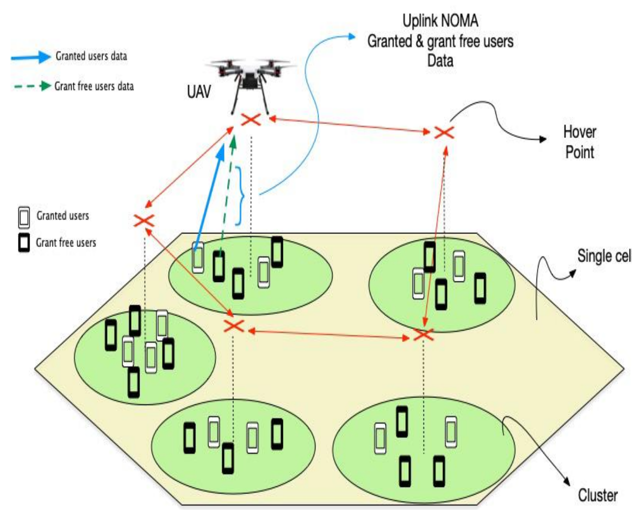

Fig. 1. The system and transmission model that considered in this paper.

The UAV has a hover for a specific time to collect data of the users of each cluster. Since the granted users have priority over the grant-free users, we propose that the hover location is determined based on the weighted mean of granted users in the cluster. Suppose that the hover location of UAV in three-dimensional space for the cluster C_k is denoted by $(\hat{x}_k, \hat{y}_k, \hat{h}_k)$, $k = 1, \ldots, n_C$, where $\hat{h}_k$ is the height of UAV, then we have

$$\hat{x}_k = \sum_{i=1}^{N} \alpha_{i,k} x_i \,;\, k = 1, \ldots, n_c \tag{1}$$

$$\hat{y}_k = \sum_{i=1}^{N} \alpha_{i,k} y_i \,;\, k = 1, \ldots, n_c \tag{2}$$

where $\alpha_{i,k}$ denotes the weight of the granted user u_i for the cluster c_k, which is obtained based on the normalized QoS of the user. Since each user only belongs to one cluster, $\alpha_{i,k} \neq 0$ only for one cluster, and it is zero for other clusters. The minimum rate requirement of the users is considered as QoS in this paper. Let $\boldsymbol{q} = \{q_1, q_2, \ldots, q_N\}$ and $\bar{\boldsymbol{q}} = \{\bar{q}_1, \bar{q}_2, \ldots, \bar{q}_M\}$ respectively denote the QoS of granted and grant-free users in terms of spectral efficiency in bit/sec/Hz. Then, the weight $\alpha_{i,k}$ is computed as:

$$\alpha_{i,k} = \frac{q_i}{\sum_{i=1}^{N} \mathcal{S}(i,k) q_i} \tag{3}$$

3-2- Channel Model

Given the granted user u_i located at (x_i, y_i) and the ABS located at $(\hat{x}_k, \hat{y}_k, \hat{h}_k)$, the path loss between the ABS and user u_i will be [34]:

$$l_{i,k} = 20\log_{10}\left(\frac{4\pi f_c d_{i,k}}{c}\right) + \vartheta_{i,k} \tag{4}$$

where f_c is the carrier frequency in Hz and c is the speed of light in m/s, and also $d_{i,k}$ is the Euclidean distance between UAV and user u_i in meter calculated as:

$$d_{i,k} = \sqrt{(x_i - \hat{x}_k)^2 + (y_i - \hat{y}_k)^2 + \hat{h}_k^2} \tag{5}$$

Also, $\vartheta_{i,k}$ is the normally distributed additional loss depending on environment conditions and distributed as $N(\mu_L, \sigma_L^2)$ and $N(\mu_{NL}, \sigma_{NL}^2)$ for the LoS and NLoS links, respectively. The probability of having an LoS link between the user u_i and ABS at hover location (x_k, y_k) is obtained as:

$$p_{i,k}^{L} = \frac{1}{1 + a\exp\left(-\frac{180}{\pi} b\left(\theta_{i,k} - a\right)\right)} \tag{6}$$

where a and b are constants, and they change depending on the environment and $\theta_{i,k} = \sin^{-1}\left(\hat{h}_k / d_{i,k}\right)$ is the elevation angle of ABS for the desired user u_i. Then, the probability of having an NLoS link is $p_{i,k}^{NL} = 1 - p_{i,k}^{L}$ [35]. Eventually, the total path loss from granted user u_i ABS to $L_{i,k}$, is obtained as

$$L_{i,k} = p_{i,k}^{L} l_{i,k}^{L} + p_{i,k}^{NL} l_{i,k}^{NL} \tag{7}$$

A similar procedure presented in equations (4)-(7) can be used to obtain the path loss of grant-free user v_j, i.e., $\bar{L}_{j,k}$.

3-3- Spectral and Energy Efficiency

In two-user NOMA transmission, the user with the higher channel gain is called the strong user, and another one is the weak user. The transmitted signal of these users experiences distinct channel gains. In uplink two-user NOMA, the received signal at location *k* of ABS due to the transmission of pair (u_i, v_j), i.e., $m_{k,i,j}^{r}$, can be obtained as [36]:

$$m_{i,j,k}^{r} = \sqrt{P_i} h_{i,k} m_i^t + \sqrt{\bar{P}_j} \bar{h}_{j,k} \bar{m}_j^t + n \tag{8}$$

where m_i^t and $\bar{m}_j^t$ denote the transmitted signal from u_i and v_j, respectively. P_i and $\bar{P}_j$ respectively signify the transmit power of granted user u_i and grant-free user v_j. $h_{i,k}$ and $\bar{h}_{j,k}$ represent the channel gain from u_i and v_j to ABS located at *k*th location, and n is the white noise with power spectral density P_{noise}. The results reported in [36] show that if there is enough separation between weak and strong users, the spectral efficiency of the strong user outperforms that of the weak user. Since satisfying the QoS of granted users has priority over grant-free users, granted users are considered strong users, and grant-free users transmit their data as weak users in each NOMA group.

Transmission of grant-free users interferes with the transmission of granted users and reduces the SNR of the granted user. On the other side, the transmission of the grant-free user receives zero interference from the transmission of the granted user during successive interference cancellation (SIC). Hence, the SINR of the transmission of pair (u_i, v_j) in ABS located in *k*th location is obtained as follows [36]:

$$\gamma_{i,k} = \frac{P_i L_{i,k}^{-1}}{P_j \bar{L}_{j,k}^{-1} + P_{noise}} \tag{9}$$

$$\bar{\gamma}_{j,k} = \frac{\bar{P}_j \bar{L}_{j,k}^{-1}}{P_{noise}} \tag{10}$$

Consequently, the SE of NOMA transmission of pair (u_i, v_j) at the *k*th location of ABS is obtained as:

$$\eta_{SE}^{i,j,k} = \log_2\left(1 + \gamma_{i,k}\right) + \log_2\left(1 + \hat{\gamma}_{i,k}\right) \text{ bits/sec/Hz} \tag{11}$$

With given the spectral efficiency of the pair (u_i, v_j), the energy efficiency is calculated as follows:

$$\eta_{EE} = \frac{\eta_{SE}}{P_{tot}}(1 - P_{out}) \quad \text{bits/sec/Hz/J} \tag{12}$$

where η_{SE} is the total spectral efficiency, P_{tot} is the total power consumption, which is the sum of transmit power (P_{Tx}), circuit powers of terrestrial users (P_{cir}), and power consumed by UAV (P_{ABS}), P_{out} denotes the outage probability. Eventually, P_{tot} described as follow:

$$P_{tot} = P_{Tx} + P_{cir} + P_{ABS} \tag{13}$$

The circuit power of ABS consists of two parts, including the circuit power of ABS in hovering ($P_{\square over}$) and flying times ($P_{flig\square t}$). The torque coefficient of UAV, q_c, is given as [10]:

$$q_c = \frac{\delta}{8} + (1+k)\frac{w^{1.5}}{\sqrt{2}\rho^{\frac{3}{2}}sA^{\frac{3}{2}}\Omega^3 R^3} \quad (14)$$

Therefore, the corresponding power consumption in hovering time of UAV can be described as [10]:

$$P_{\square over} = q_c \rho s A \Omega^3 R^3 \quad (15)$$

and by substitution of q_c in $P_{\square over}$, we have [10]:

$$P_{\square over} = \frac{\delta}{8}\rho s A \Omega^3 R^3 + (1+k)\frac{w^{1.5}}{\sqrt{2\rho A}} \quad (16)$$

The required power for the flight time of rotary-wing UAVs is more intricate than the fixed-wing peer. However, by some mild assumption, the pull coefficient of the blade area is constant, so the torque coefficient for the UAV in flight time with zero climbing angle and speed v_u is given as:

$$q_c = \frac{\delta}{8}(1+3\mu^2) + (1+k)\mu_i t_{cD} + \frac{1}{2}\hat{u}_u{}^3 d_0 \quad (17)$$

By substituting $\mu \approx \hat{v}_u = \frac{v_u}{\Omega R}$ and $t_{cD} = \frac{T}{\rho s A \Omega^2 R^2}$, q_c can be written as a function of forwarding speed v_u and rotor thrust T as follow:

$$q_c(v_u, T) = \frac{\delta}{8}\left(1 + \frac{3v_u^2}{\Omega^2 R^2}\right) + \frac{(1+k)T\lambda_i}{\rho s A \Omega^2 R^2} + \frac{1}{2} d_0 \frac{v_u^3}{\Omega^3 R^3} \quad (18)$$

Eventually, by definition of torque coefficient, the required power for flight time can be written as follow:

$$P_{flig\square t} = q_c \rho s A \Omega^3 R^3 \quad (19)$$

3-4- Outage Probability

Outage probability is defined as the probability that the SNR or spectral efficiency at the receiver becomes lower than the predefined (or threshold) value. Considering the SIC process, for the strong (or granted) user u_i, the outage probability is obtained as [37]:

$$P_{out}^{u_i} = 1 - P_C^{u_i} \quad (20)$$

where $P_C^{u_i}$ is the probability that the transmit message of the strong user u_i is correctly detected at the receiver, which is calculated as:

$$P_C^{u_i} = \Pr\{\gamma_{i,k} \geq q_i\} = \Pr\left\{\frac{P_i L_{i,k}^{-1}}{P_j \bar{L}_{i,j}^{-1} + P_{noise}} \geq q_i\right\} \quad (21)$$

Similarly, for weak (or grant-free) user v_j, we have:

$$P_{out}^{v_j} = 1 - P_C^{v_j} \quad (22)$$

where the probability of correct detection of the message of the grant-free user is calculated as [37]:

$$P_C^{v_j} = \Pr\{\gamma_{i,k} \geq q_i, \bar{\gamma}_{i,k} \geq \bar{q}_j\}$$
$$= \Pr\left\{\frac{P_i L_{i,k}^{-1}}{P_j \bar{L}_{i,j}^{-1} + P_{noise}} \geq q_i,\ \frac{P_j \bar{L}_{i,k}^{-1}}{P_{noise}} \geq \bar{q}_j\right\} \quad (23)$$

4- Proposed User Clustering, Power Allocation, and NOMA pair Forming

4-1- Problem Formulation

Over the past decades, energy efficiency has been studied from the information theory perspective. Due to the power limitation of ABS, it is worth considering the energy-efficient transmission scheme and maximizing energy efficiency. Therefore, the proposed scheme for users clustering and joint user pairing and power allocation can be formulated as follows:

$$(\mathbf{S}^*, \mathbf{G}^*, \mathbf{P}^*) = \operatorname{argmax}(\eta_{EE}) \quad (24)$$

subject to:

$$\begin{aligned}
&(S1) \quad \gamma_{i,k} \geq \gamma_i^{t\square} \\
&(S2) \quad \bar{\gamma}_{j,k} \geq \bar{\gamma}_j^{t\square} \\
&(S3) \quad P_i + \bar{P}_j \leq P_{max} \\
&(S4) \quad \sum_{k=1}^{n_C} \boldsymbol{C}(i,k) = 1, \forall i = 1, \dots, N \\
&(S5) \quad \sum_{k=1}^{n_C} \mathbf{G}(i,j) = 1, \forall i = 1, \dots, N \\
&(S6) \quad \sum_{i=1}^{n_C} \mathbf{G}(i,j) \leq 1, \forall j = 1, \dots, M
\end{aligned} \quad (25)$$

The constraints S1 and S2 respectively demonstrate that the QoS of granted and grant-free users should be satisfied, where $q_i = \log_2(1+\gamma_i^{th})$ and $\bar{q}_j = \log_2(1+\bar{\gamma}_j^{th})$. Furthermore, S3 determines the upper limit of transmit power of terrestrial users. Constraint S4 specifies that each terrestrial user must be included only in one cluster. According to S5, each granted user can pair with a grant-free user and transmit its data. While, according to S6, there is no guarantee for grant-free users to transmit data.

Considering the energy efficiency optimization problem and constraints given in equations (24)-(25), this problem is non-convex, and obtaining a solution requires vast computational complexity. Hence, we propose to partition it into two sub-problems to obtain its solution. First sub-problem partitions the terrestrial users into several clusters. After clustering, the joint user pairing and power allocation problem was formulated for each cluster to maximize the energy efficiency of each cluster.

4-2- Proposed Solution

The proposed solution for the problem given in equations (24)-(25) is explained in Algorithm 1. The proposed solution generally consists of three steps, including cluster forming, power allocation, and NOMA pair forming. In the following, each step is explained in detail.

Algorithm 1. The proposed solution for user clustering, power allocation, and NOMA pair forming

\\ ***Cluster forming and obtaining flight path***
1. UAV flights over the service area to partition the users to some clusters
2. Compute the hover location for each cluster considering equations (1)-(3)
3. Obtain the flight path by solving TSP via the genetic algorithm

\\ ***Power allocation and NOMA pair forming***
4. **for** each cluster, **do**
5. Perform power allocation for all possible pairs of granted and grant-free users using equations (32)-(33)
6. Compute energy efficiency of each pair using equation (34)
7. Select the best pairs using the Hungarian algorithm (Algorithm 2)
8. **end for**

4-2-1- User Clustering

In order to cluster the terrestrial users, the UAV starts to fly over the service area from a random location. UAV broadcasts the initialization signal and waits to receive the first acknowledgment signal from terrestrial users. This acknowledgment signal contains users' position, desired QoS, and type (granted or grant-free). When the UAV receives the first acknowledgment signal, it starts to create the first cluster. This process continues until the acknowledgment of the first signal is not received in the UAV. At this time, the first cluster is created, and all users whose acknowledgment signal was received are considered in the first cluster. Then, UAV continues to fly over the area to create the second cluster. This process will repeat until all users to be placed in one cluster.

After finishing the clustering process, the UAV computes the hover locations considering equations (1)-(2). In order to minimize the power consumption during fly and hover, the flight path should be minimized. We use TSP integer linear programming with the Dantzig-Fulkerson-Johnson formulation (DFJ) algorithm to obtain the shortest flight path. Suppose that the set $\{(\hat{x}_1, \hat{y}_1, \hat{\square}_1), \dots, (\hat{x}_{n_C}, \hat{y}_{n_C}, \hat{\square}_{n_C})\}$ contains the coordinates of hover locations. TSP solves the following problem:

$$min \sum_{i=1}^{n_C} \sum_{j=1, j\neq i}^{n_C} \beta_{ij} D_{i,j} \tag{26}$$

subject to:

$$\begin{aligned} &\beta_{ij} \in \{0,1\}, i,j = 1,\dots,n_C \\ &\sum_{i=1,i\neq j}^{n_C} \beta_{ij} = 1\,, \quad j = 1,\dots,n_C \\ &\sum_{i=1,i\neq j}^{n_C} \beta_{ij} = 1\,, \quad i = 1,\dots,n_C \\ &\sum_{i\in Q}^{n_C} \sum_{j\in Q}^{n_C} \beta_{ij} \leq |Q| - 1, \\ &\qquad \forall Q \subset \{1,\dots,n_C\}, |Q| \geq 2 \end{aligned} \tag{27}$$

where D_{ij} is the Euclidean distance between hover locations i and j and β_{ij} is a binary variable defined as:

$$\beta_{i,j} = \begin{cases} 1 & \text{UAV goes from point } i \text{ to point } j \\ 0 & \text{Otherwise} \end{cases} \tag{28}$$

The solution given in [38] is utilized to obtain the optimum flight path of the UAV.

4-2-2- Joint Power Allocation and User Pairing

After clustering the users, the user pairing and power allocation should be performed for each cluster. Hence, the problem demonstrated in equations (24)-(25) is simplified for cluster C_k as:

$$(\mathbf{G}_k^*, \mathbf{P}_k^*) = \text{argmax}\left(\eta_{EE}^{(k)}\right) \tag{29}$$

subject to:

$$\begin{aligned} &\text{(S1)} \quad \gamma_{i,k} \geq \gamma_i^{t\square} \\ &\text{(S2)} \quad \bar{\gamma}_{j,k} \geq \bar{\gamma}_j^{t\square} \\ &\text{(S3)} \quad P_i + \bar{P}_j \leq P_{max} \\ &\text{(S4)} \quad \sum_{k=1}^{M_c^{(k)}} \mathbf{G}_k(i,k) = 1, \forall i = 1,\dots,N_c^{(k)} \\ &\text{(S5)} \quad \sum_{i=1}^{N_c^{(k)}} \mathbf{G}_k(i,j) \leq 1, \forall j = 1,\dots,M_c^{(k)} \end{aligned} \tag{30}$$

where $\eta_{EE}^{(k)}$ is the energy efficiency of cluster C_k, which is computed as:

$$\eta_{EE}^{(k)} = \frac{\sum_{i=1}^{N_c^{(k)}} \left(\log_2(1+\gamma_{i,k}) + \log_2(1+\bar{\gamma}_{i,k})\right)}{\sum_{i=1}^{N_c^{(k)}} (P_i + \bar{P}_i) + 2N_c^{(k)} P_{cir,UE}} \tag{31}$$

where $P_{cir,UE}$ is the circuit power of each user. To solve this problem, at first, we perform power allocation for all possible pairs of granted and grant-free users, and then, the Hungarian algorithm is utilized to select the pairs that maximize the energy efficiency of the cluster.

Suppose that granted user u_i and grant-free user v_j form the two-user NOMA pair. We propose to minimize the power consumption to maximize energy efficiency. The transmit powers of them are calculated to satisfy the minimum QoS requirement of them as follows:

$$\bar{P}_j = \bar{\gamma}_{j,k} \bar{L}_{j,k} P_{noise} \tag{32}$$

$$P_i = \gamma_{i,k}\left(\bar{P}_j \bar{L}_{j,k}^{-1} + P_{noise}\right) L_{i,k} \tag{33}$$

After that, the energy efficiency of the pair (u_i, v_j) is computed as follows:

$$\eta_{EE}^{(k)}(i,j) = \frac{\log_2(1+\gamma_{i,k}) + \log_2(1+\bar{\gamma}_{j,k})}{P_i + \bar{P}_j + 2P_{cir,UE}} \tag{34}$$

Obtaining $\eta_{EE}^{(k)}(i,j)$ results in $N_c^{(k)} \times M_c^{(k)}$ the matrix for cluster C_k. The next step is to select the pairs from this matrix to maximize the energy efficiency of cluster C_k.
After forming the Hungarian matrix, which contains the select energy efficiency of different pairs of users, the best

pairs should be selected from them. There are two ways to solve this problem; adjacency matrix and bipartite graph. The bipartite graph can easily represent by an adjacency matrix. As an example, suppose seven users where the users in rows of the matrix belong to granted users and the columns belong to grant-free users, which is shown as follow:

$$\eta_{EE}^{(k)} = \begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 2 & 1 & 3 & 4 \\ u_2 & 8 & 4 & 2 & 6 \\ u_3 & 3 & 12 & 6 & 9 \end{matrix}$$

Note that the Hungarian method assigns a set of minimum optimal values of the matrix, and the energy efficiency problem must be maximized. Hence, we first convert all the arrays into the familiar form to get the maximized values from these minimum arrays as follow:

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 2 & 1 & 3 & 4 \\ u_2 & 8 & 4 & 2 & 6 \\ u_3 & 3 & 12 & 6 & 9 \end{matrix} \xrightarrow{\text{Inverse each elements}} \begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 0.50 & 1.0 & 0.33 & 0.25 \\ u_2 & 0.12 & 0.25 & 0.5.0 & 0.16 \\ u_3 & 0.33 & 0.08 & 0.16 & 0.11 \end{matrix}$$

It is essential to say that the Hungarian method is proper when the matrix is square. Therefore, if the assignment matrix is not square, we must turn it into square form by adding dummy rows or columns. The dummy arrays can be in two forms; they can be equal to the maximum matrix array or be a line with zero numbers; however, zero numbers are recommended. The solution for the Hungarian method is shown in Algorithm 2. The solution of the defined example with the Hungarian matrix method is shown step by step as follow:

(Step 1) Subtract the smallest value in each row from the other values in the row

(Step 2) Each column has zero, so no need to subtract the minimum value from each column.

(Step 1)

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 & \\ u_1 & 0.5 & 1 & 0.33 & 0.25 & -0.25 \\ u_2 & 0.12 & 0.25 & 0.5 & 0.16 & -0.12 \\ u_3 & 0.33 & 0.08 & 0.16 & 0.11 & -0.08 \\ Du & 0 & 0 & 0 & 0 & \end{matrix}$$

(Step 2)

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 0.25 & 0.75 & 0.08 & 0 \\ u_2 & 0 & 0.13 & 0.38 & 0.04 \\ u_3 & 0.25 & 0 & 0.08 & 0.03 \\ Du & 0 & 0 & 0 & 0 \end{matrix}$$

(Step 3) Draw lines through the row and columns that have the 0 entries such that the fewest possible lines are drawn. There are four lines drawn, which is equal to the matrix dimension, so there is the optimal number of zeroes.

Algorithm. 2. The Hungarian algorithm using an adjacency matrix

1. Convert all the arrays into the reciprocal form
2. **if** the number of rows and columns are not equal, **then**
3. Add dummy rows or columns to square the matrix
4. Subtract the smallest entry in each row from all the other entries in the row
5. **if** there is any column without zero, **then**
6. Subtract the smallest entry in each column from all the other entries in the column
7. Cover the rows and columns that have the 0 entries with the fewest lines possible are drawn
8. **if** there the number of lines drawn is equal to the number of rows, **then**
9. An optimal assignment of zeros is possible, and the algorithm is finished.
10. **else if** the number of lines is less than number of rows, **then**
11. The optimal number of zeroes is not yet reached.
12. **Go to** the next steps.
13. Find the smallest entry not covered by any line.
14. Subtract this entry from each row that is not crossed out,
15. Then add it to each column that is crossed out.
16. **end**

(Step 4) Highlight the selected zeros

(Step 3)

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 0.25 & 0.75 & 0.08 & 0 \\ u_2 & 0 & 0.13 & 0.38 & 0.04 \\ u_3 & 0.25 & 0 & 0.08 & 0.03 \\ & 0 & 0 & 0 & 0 \end{matrix}$$

(Step 4)

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 0.25 & 0.75 & 0.08 & \boxed{0} \\ u_2 & \boxed{0} & 0.13 & 0.38 & 0.04 \\ u_3 & 0.25 & \boxed{0} & 0.08 & 0.03 \\ & 0 & 0 & \boxed{0} & 0 \end{matrix}$$

(Step 5) Replace the original values. **(Step 6**) Replace the primary values of energy efficiency to get which users can be optimally pairs. As shown, there are four lines drawn, and it is equal to the dimension of the matrix, so the algorithm is finished optimally. However, if there are drawn lines less than the matrix dimension, it should follow the algorithm's rules. The Hungarian method, which is shown in Algorithm 2, forms pairs of users optimally. To the extent, one granted user should pair with a grant-free user, which are given as strong and weak users.

(Step 5)

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 0.5 & 1 & 0.33 & \boxed{0.25} \\ u_2 & \boxed{0.12} & 0.25 & 0.5 & 0.16 \\ u_3 & 0.33 & \boxed{0.08} & 0.16 & 0.11 \\ & 0 & 0 & \boxed{0} & 0 \end{matrix}$$

(Step 6)

$$\begin{matrix} & v_1 & v_2 & v_3 & v_4 \\ u_1 & 2 & 1 & 3 & \boxed{4} \\ u_2 & \boxed{8} & 4 & 2 & 6 \\ u_3 & 3 & \boxed{12} & 6 & 9 \\ & 0 & 0 & \boxed{0} & 0 \end{matrix}$$

5- Simulation Results

5-1- Simulation Setup

This section provides numerical results to evaluate the performance of the proposed user clustering, power allocation, and NOMA pair forming to maximize energy efficiency. The UAV acts as a flying ABS in the simulation area and serves the users randomly distributed according to SPPP with density λ_u. The parameters used in simulations are given in Table 1.

Table 1. Parameters used in simulations

Parameter	***Value***
Simulation area	5×5 km
Density of users	$(1\sim3)\times10^{-4}$
Height of ABS	100 ~ 800 m
Maximum total transmission power	23 dBm
The minimum acceptable received power	-90 dBm
Noise power	-130 dBm
Carrier frequency	1.2 GHz
Minimum acceptable SNR of granted users	[2 8] dB
Minimum acceptable SNR of grant-free users	[1 3] dB

Results in terms of spectral efficiency, energy efficiency, and outage probability are obtained for each pair of UAV height and density of users. For each pair, we run *Monte Carlo* simulations for 10^5 trials, and in each trial, the users' locations are generated using SPPP with specific density. Finally, results were averaged.

5-2- Spectral Efficiency

The spectral efficiency for different heights of UAV and density of users is given in Fig. 2 for the total transmission power of 23 dBm. It is observed that increasing the height of UAV and density of users increases the spectral efficiency. In traditional 2D wireless networks such as cellular networks, path loss increases as the distance of users from the base station increases. However, in UAV networks, increasing distance will not necessarily increase the path loss because the probability of the LoS link increases. Increasing the probability of LoS link reduces υ in path loss; hence, overall path loss reduces, SNR increases, and spectral efficiency increases. On the other side, increasing the density of users increases the number of users; therefore, there are more candidate users to form NOMA pairs with better channel conditions. As each pair transmits its data in a specific time slot, increasing the number of users does not increase the interference, and spectral efficiency increases. In summary, for the constant density of users, increasing the height of ABS enhances the spectral efficiency by reducing the path, resulting in higher SNR. For the constant height of ABS, increasing the density of users enhances the spectral efficiency by constructing the pairs with higher SNRs.

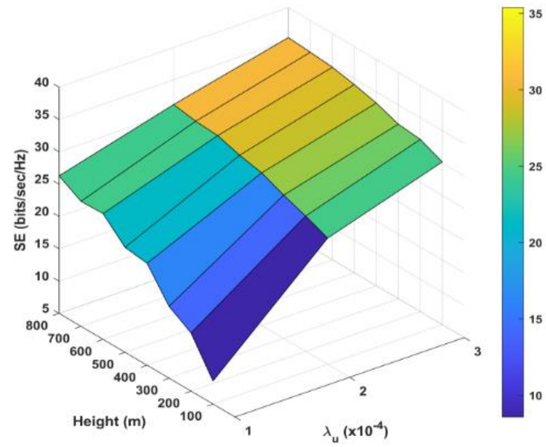

Fig. 2. Spectral efficiency for different densities of users and height of UAV.

Fig. 3 shows the impact of hover location on spectral efficiency. Three schemes are utilized to determine the hover location; 1) proposed weighted-mean (WM) of granted users, 2) equal-weight mean (EWM), where we simply consider the mean of the location of the granted user, and 3) random in which UAV randomly hover in the area of the cluster. It is observed that the proposed WM method achieves higher spectral efficiency than the other schemes. Proposed WM determines the hover location near granted users with higher QoS requirements, achieving higher spectral efficiency.

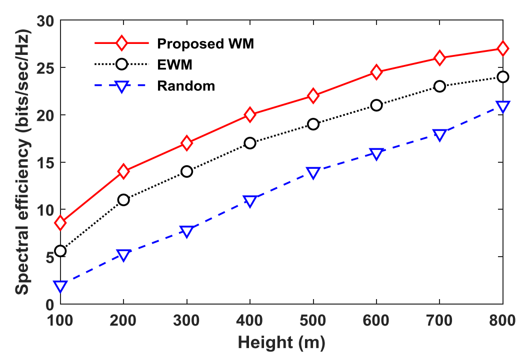

Fig. 3. The effect of hover location on the spectral efficiency

5-3- Energy Efficiency

In Fig. 4, the energy efficiency is given for several heights of UAV and the density of users. It is observed that similar to spectral efficiency, increasing the height of UAV and density of users increases the energy efficiency. Reducing path loss by increasing height reduces the transmit power to satisfy the spectral efficiency; hence energy efficiency increases. On the other side, increasing the density of users provides more candidates for NOMA pairs, which reduces the transmission power and increases energy efficiency. Also, Fig. 5 compares the energy efficiencies obtained for different hover locations. It is observed that the proposed WM scheme outperforms the other schemes considerably.

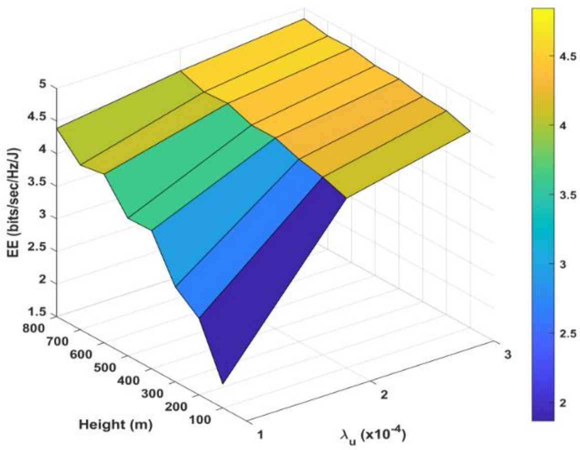

Fig. 4. Energy efficiency for different densities of users and heights of UAV.

5-4- Outage Probability

It was mentioned that increasing the height of the UAV enhances the uplink transmission by reducing the path loss; therefore, it is expected that outage probability reduces by increasing the height of the UAV, which is depicted in Fig. 6. As spectral and energy efficiencies, outage probability enhances by increasing the height of ABS location. Also, increasing the density of users reduces the outage probability. Fig. 7 compares the outage probability for different hover locations. As expected, the proposed WM scheme has the lowest outage probability since it determines the hover location of the UAV, considering the weighted mean of users' locations based on their QoS. This approach reduces UAV distance from the users with high QoS requirement and increases their SNR, which reduces the outage probability. Also, increasing the height of the UAV reduces the path loss by increasing the probability of LoS link resulting in lower outage probability.

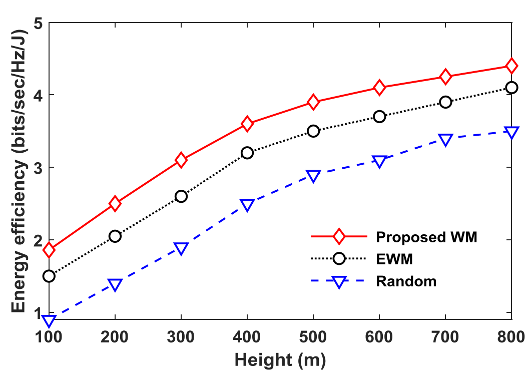

Fig. 5. The effect of hover location on the energy efficiency

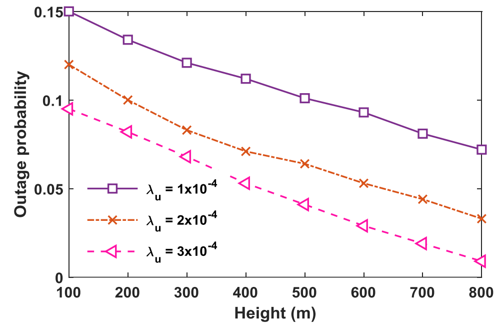

Fig. 6. Outage probability of network for UAV's height.

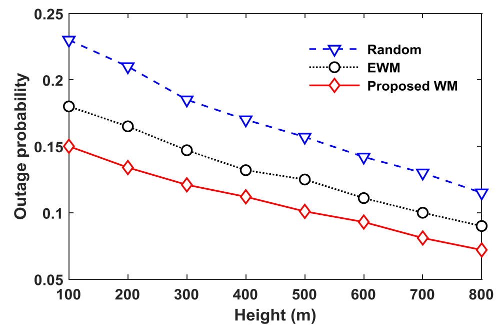

Fig. 7. The effect of hover location on the outage probability

5-5- Effect of Total Transmission Power

Fig. 8 demonstrates the effect of total transmission power on the energy and spectral efficiencies. As the maximum total power increases, the SNR of the links between ABS and ground users increases resulting in spectral efficiency enhancement. It is observed that increasing the total transmission power enhances spectral and energy efficiencies. As transmission power of granted and grant-free users increases, the SNR of links between them and ABS increases resulting in higher spectral efficiency values and lower outage probability values. Increasing the total transmission power increases the total power consumption. On the other side, the increase in spectral efficiency and $(1 - P_{out})$ is higher than the increase in total power consumption since most of the power consumption is related to flight and hover powers of ABS. Hence, increasing the total transmission power enhances energy efficiency.

5-6- Comparing Genetic Algorithm with PSO

Here we compare the performance of the genetic algorithm in finding the flight path of UAV with particle swarm optimization (PSO) and random approach, which selects the following hover location randomly among the possible locations. The flight path only affects the energy efficiency and does not affect spectral efficiency and outage probability since these metrics depend on the hover location, user pairing, and transmission power and are independent of the flight path. The genetic algorithm, PSO, and random approach performances on the energy efficiency are demonstrated in Fig. 9. As observed genetic algorithm outperforms the PSO and random approaches and has higher energy efficiency.

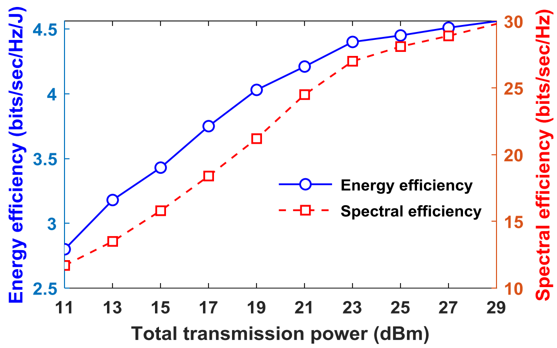

Fig. 8. Effect of total transmission power on energy and spectral efficiencies.

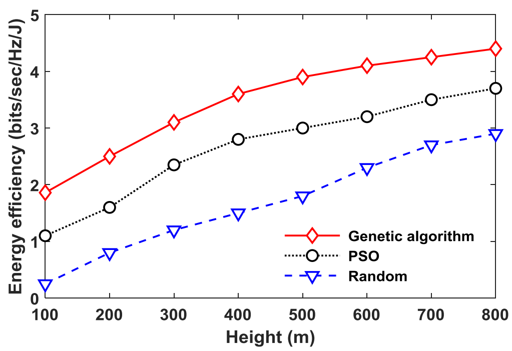

Fig. 9. The effect of the flight path on the energy efficiency

6- Conclusion

In this paper, the challenges of power allocation and NOMA form pairing in the uplink direction of UAV communication systems were investigated. Users in the UAV coverage area were divided into two classes: granted and grant-free, based on prioritizing the type of demands. Granted and grant-free users are respectively considered as strong and weak users in the NOMA pair. The main criterion for the stated challenges has been to maximize energy efficiency. The optimization problem was formulated to maximize the energy efficiency of transmission subject to the constraints on the minimum acceptable spectral efficiency and total transmission power. In order to solve the problem, at first, transmission powers were computed for each possible NOMA pair, and then, the Hungarian algorithm was employed to select the optimum pairs. The flight path of the UAV was modeled as TSP. The results demonstrated that increasing the height of ABS enhances spectral efficiency, energy efficiency, and outage probability by reducing path loss. Also, increasing the density of users enhances the performance metrics. We also demonstrate that the hover location greatly impacts the performance metrics, and the proposed weighted-mean location outperforms the random and equal-weight men locations.

As future work, we can consider the methods based on machine learning, such as deep belief networks (DBN) for power allocation and pair forming. We can also consider the NOMA clusters with more than two users to support grant-free users in each time slot. Considering different heights for each cluster can be considered as another future work.

Conflicts of Interest

All authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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