Resource Allocation for Sum-Rate Maximization in Multi-UAV SCMA Networks

Saumya Chaturvedi, Vivek Ashok Bohara, Zilong Liu, Anand Srivastava, Pei Xiao

***Abstract*—This work investigates a sparse code multiple access (SCMA) assisted multiple unmanned aerial vehicles (UAVs) downlink communication network for improved data services to multiple ground users. Our objective is to maximize the sum-rate of the multi-UAV SCMA network by optimizing the SCMA factor graph matrix used for resource allocation, considering the inter-UAV and intra-UAV interference components. The formulated problem is non-convex in nature and is subject to the SCMA codebook constraints. We propose a factor graph matrix assignment algorithm to solve this optimization problem. Our simulation results demonstrate the superiority of the proposed scheme in terms of rate performance over the benchmark schemes. Thus, compared with orthogonal multiple access strategies, SCMA emerge as a promising candidate for next generation multiple access (NGMA) techniques.**

***Index Terms*—Factor Graph Matrix Assignment, Probabilistic LoS channel model, Sparse Code Multiple Access (SCMA), Unmanned Aerial Vehicles (UAV) communications.**

I. Introduction

With the advent of 6G research for the next generation mobile communication systems across the world, various wireless techniques have been studied to provide improved quality-of-service (QoS), such as lower latency, higher spectrum efficiency, and massive connectivity [1]. Recently, unmanned aerial vehicles (UAVs) are being utilized in several scenarios, such as disaster, medical, search and rescue, etc [2]. UAVs are also expected to play a critical role in the next-generation wireless applications (e.g., communication recovery after disasters or traffic offloading) [3]. Thanks to their maneuvering capability and agile nature, UAVs can also maintain the line-of-sight (LoS) connection with most of the ground devices and can also be used in tough geographical conditions [2]. Thus, UAVs can be deployed as mobile base stations (BSs) for enhanced on-demand coverage.

With increasing demand in connectivity of devices, advanced multiple access techniques are required. Conventional orthogonal multiple access (OMA) schemes, such as time division multiple access (TDMA), frequency-division multiple access (FDMA), may not be able to fulfill the requirements of 6G wireless systems. To solve this problem, non-orthogonal multiple access (NOMA) has been extensively studied in providing massive connectivity and higher spectral efficiency compared to OMA [4].

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In NOMA, multiple users are served with limited number of resource elements (REs) using distinct power levels or codebooks (CBs). NOMA schemes are mainly classified into two groups: code-domain NOMA (CD-NOMA) and power-domain NOMA (PD-NOMA). In PD-NOMA, multiple users are served using the same REs by assigning a different power level to each user [4]. One of the popular CD-NOMA techniques is sparse code multiple access (SCMA), in which several bits of each user is mapped to a codeword, which is extracted from its associated codebook (CB). As studied in the literature, SCMA outperforms PD-NOMA in respect of bit error rate (BER) and sum-rate [5], [6]. For practical SCMA system design, a number of low-complexity detectors have been studied [7]. Driven by the growing demand for higher data rates and massive connectivity in future wireless applications, SCMA emerge as a next generation multiple access (NGMA) technique, which is capable of providing required QoSs in a complexity and resource efficient manner than existing multiple access techniques [8].

A. Related Works

In the literature, most of the UAV-assisted network applications use UAVs as mobile BSs or relays. In [9], the 3D UAVs placement and resource allocation in an IoT network were studied considering the inter-UAV interference. [10] proposed a distributed algorithm to learn the UAV-BSs optimal 3-D locations and user association to maximize the network's sum rate. In [11], the UAV-BS 3D placement and user association problem was solved for a multi-UAV network for a LoS link. Moreover, in [9] and [11], each user was accredited with a single subchannel. In [12], the sum-rate maximization was done in a UAV-assisted NOMA system, and UAV altitude and transmit power were optimized. In [13], multiple antennas assisted UAV-NOMA system was investigated in both LoS and non-LoS environments. In [14], the sum-rate was maximized for a multi-UAV NOMA system by optimizing the subchannel allocation, UAVs' attitude and transmit power. In [15], the aim was to maximize the user minimum data rate by optimizing the UAV power allocation, user association, and trajectory in the NOMA system. In [16], two secure transmission schemes were proposed for UAV-NOMA networks.

Majority of the aforementioned works studied the integration of PD-NOMA with UAV. On the other side, this work studies the integration of multiple UAVs with SCMA. Inspired by the benefits of UAVs and SCMA, the multi-UAV SCMA network can be a potential candidate for delivering improved QoSs for future wireless applications under limited resources.

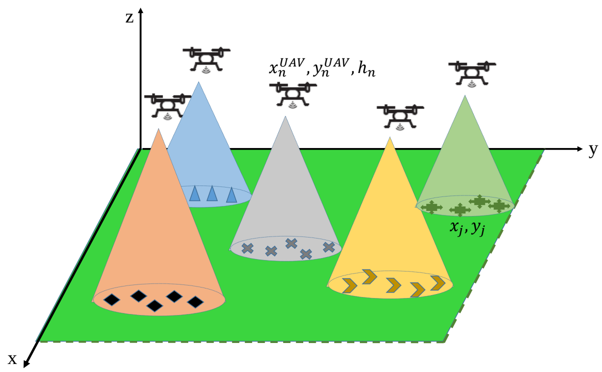

Fig. 1. Multi-UAV SCMA-assisted Network Model.

To efficiently utilize the inherent characteristics of SCMA, proper resource allocation optimization needs to be conducted depending on the application [17]. However, most of the works on resource optimization in SCMA have focused on the terrestrial networks. On the other hand, UAV-BSs have different characteristics, and also the UAV-user channel model varies significantly from the terrestrial channel.

We focus on the optimization of the SCMA resource allocation matrix in order to maximize the system sum-rate in a downlink multi-UAV SCMA network. To the best of our knowledge, the sum-rate maximization problem subject to the intra-UAV interference and inter-UAV interference in the multi-UAV networks for SCMA has not been studied before. Also, we consider a probabilistic LoS channel model, which includes both LoS and non-LoS (NLoS) components, which is more close to the practical environment [18]. The major challenge lies in solving the above problem with low computational complexity. We show that the formulated optimization problem is a non convex non-linear integer programming problem problem. In the proposed method, we allocate the resources to the users based on the available instantaneous channel state information (CSI) and received signal to interference plus noise ratio (SINR) strength. The remaining of the paper is outlined as follows. Section II discusses the multi-UAV SCMA network. Section III presents the formulated optimization problem and the proposed solution. The results are presented and discussed in Section IV. Finally, the concluding remarks are drawn in Section V.

II. System Model

A. System Model

We study a downlink multi-UAV SCMA network, where N rotary-wing single-antenna UAVs are working as mobile BSs to serve N user groups (as shown in Fig. 1). There are a total of J users served with K REs, with $J > K$ in SCMA. The users are presumed to be static or have low mobility, and the location of jth user is $[x_j, y_j] \in \mathbb{R}^{1\times 2}$. The nth UAV location is given as $\mathbf{q}_n = [x_n, y_n, z_n]$. The association between UAVs and users is done using K-means algorithm [9].

Thanks to UAV-BS's flexible and mobile nature, LoS connection can be kept for most devices. However, the blockages may affect the UAV-to-ground device links, especially in urban scenarios. Therefore, we consider a probabilistic LoS channel model, which includes both the LoS and NLoS components, dependent on the UAV deployment environment [3], [12]. The LoS link probability between nth UAV-BS and jth user is:

$$Pr_j^{\text{LoS}}[n] = \frac{1}{1 + ae^{-b(\theta_j[n]-a)}}, \tag{1}$$

where a and b are the constants depending on the carrier frequency f_c and environmental conditions, respectively [19]. Here, θ_j denotes the elevation angle in degrees from the jth user to the UAV-BS, and is given as $\theta_j[n] = (\frac{180}{\pi})\tan^{-1}(\frac{z[n]}{r_j[n]})$, where $r_j[n]$ denotes the 2D distance between nth UAV-BS and jth user. Correspondingly, the NLoS probability is $Pr^j_{\text{NLoS}}[n] = 1 - Pr^j_{\text{LoS}}[n]$. Next, the path loss is computed as [20]

$$L_j^{\text{LoS}}[n] = \left(\frac{4\pi f_c d_j[n]}{c}\right)^{\alpha} \eta_{\text{LoS}}, \tag{2}$$

$$L_j^{\text{NLoS}}[n] = \left(\frac{4\pi f_c d_j[n]}{c}\right)^{\alpha} \eta_{\text{NLoS}}, \tag{3}$$

where α is the path loss exponent, c is the speed of light, η_{LoS} and η_{NLoS} are the path loss coefficients for LoS and NLoS paths, respectively. The average channel gain between the jth user and nth UAV is

$$G_j[n] = \frac{1}{Pr_j^{\text{LoS}}[n]L_j^{\text{LoS}}[n] + Pr_j^{\text{NLoS}}[n]L_j^{\text{NLoS}}[n]}.$$

B. SCMA

One of the significant features of SCMA that distinguishes it from other schemes is the sparse CBs. In SCMA, a bipartite factor graph is a way to represent the RE-user association. In this paper, we consider a regular factor graph for each cluster. It means that each user node (UN) communicates via d_v number of REs or resource nodes (RNs), and d_f number of users' data is superimposed on each RE. Fig. 2 shows the association between user-RE for a 4×6 SCMA block using a factor graph. The RE-users association can also be represented using a factor graph matrix, $\mathbf{F}$. Let $\mathbf{F}$ be a binary matrix of size $K \times M_n$, called the factor graph matrix with element $f_{k,j}$. One example of a factor graph matrix for a 4×6 SCMA block is

$$\mathbf{F}_{4\times 6} = \begin{bmatrix} 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix}. \tag{4}$$

Let $h_{n,k,j}$ denotes the channel between UAV-BS n and user j at RE k. The channel components are assumed to be independent complex Gaussian random variables. It is

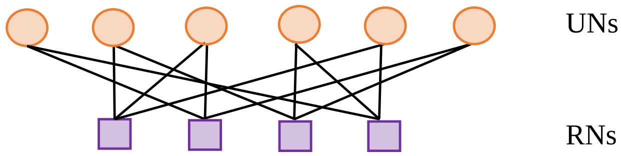

Fig. 2. The factor graph corresponding to (4) with $d_v = 2$ and $d_f = 3$.

assumed that UAV-BSs has the perfect CSI available to it. Thus, the signal received at the jth user of the nth cluster is

$$y_{n,j} = \underbrace{\sum_{k=1}^{K} h_{n,k,j} f_{n,k,j} x_{n,k,j}}_{\text{Desired signal}} + \underbrace{\sum_{k=1}^{K} \sum_{\substack{i \in M_n \\ i \neq j}} h_{n,k,i} f_{n,k,i} x_{n,k,i}}_{\text{Intra-group interference}} + \underbrace{\sum_{\substack{m \in \mathcal{N} \\ m \neq n}} \sum_{k=1}^{K} \sum_{i=1}^{M_m} h_{m,k,i} f_{m,k,i} x_{m,k,i}}_{\text{Inter-group interference}} + \underbrace{w_{n,j}}_{\text{noise}}, \tag{5}$$

where $f_{n,k,j} = 1$ indicates that there is active transmission between jth user of nth cluster and the nth UAV at RE k, $x_{n,k,j}$ represent the codeword element of the jth user of the nth cluster on the kth RE, and $w_{n,j} \sim \mathcal{CN}(\mathbf{0}, \sigma^2)$ denotes the additive white Gaussian noise (AWGN) at the (n, j)th user. The (n, j)th user suffers two types of interference: the intra-group interference because of all the other users of the same group and the inter-group interference caused by the users of the other groups. Thus, the decoding SINR of user (n, j) is given as:

$$\gamma_{n,k,j} = \frac{|h_{n,k,j}|^2 p_{n,k,j}}{I^{\text{intra}}_{n,k,j} + I^{\text{inter}}_{n,k,j} + \sigma^2}, \tag{6}$$

where $I^{\text{intra}}_{n,k,j} = \sum_{\substack{i \in M_n \\ i \neq j}} |h_{n,k,i}|^2 f_{n,k,i} p_{n,k,i}$, $I^{\text{inter}}_{n,k,j} = \sum_{\substack{m \in \mathcal{N} \\ m \neq n}} \sum_{i=1}^{M_m} |h_{m,k,i}|^2 f_{m,k,i} p_{m,k,i}$, and $p_{n,k,j}$ denotes the power allocated to the codeword element of the (n, j)th user on the kth RE. The achievable rate of (n, j)th user is $R_{n,j} = \sum_{k=1}^{K} \log_2(\gamma_{n,k,j})$.

III. Problem Formulation and Proposed Solution

In this section, we formulate an optimization problem, in which the aim is to maximize the sum-rate for the overall multi-UAV SCMA network, and optimize the factor graph matrix subject to the SCMA CB constraints. The formulated sum-rate optimization problem is as follows:

Algorithm 1 The $\mathbf{F}$ assignment algorithm for multi-UAV SCMA network

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Inputs:
J, M_n K, d_f, d_v, $\mathbf{H}_{K \times M_n}$: Channel gain matrix of nth cluster.
Output:
$\mathbf{F}_{\text{joint}} = [\mathbf{F}_1, \cdots, \mathbf{F}_n, \cdots, \mathbf{F}_N]$: Binary Factor graph matrix of all clusters.

1: **for** $n = 1 : N$ **do**
2: Initialize $\mathbf{F}_{\text{ini}}$ as an all-ones matrix, and $\mathbf{F}$ as a zero matrix of size $K \times M_n$.
3: Calculate the SINR matrix $\mathbf{S}_{K \times n * M_n}$ with each element equal to $\gamma_{k,j}$, $\forall\ 1 \leq k \leq K, 1 \leq j \leq n * M_n$.
4: Calculate the average RMS value, $\mathbf{r}$ from $\mathbf{S}$ for each user of nth cluster .
5: Sort the RMS values in the descending order.
6: **for** $i = 1 : M_n$ **do**
7: **if** $\sum_{j=1}^{M_n} \mathbf{F}_{k,j} \leq d_f$, $\forall\ 1 \leq k \leq K$ or $\mathbf{F}_{n,i} \neq \mathbf{F}_{n,j}$ **then**
8: Find the largest d_v number of values from the $\mathbf{S}$ column with index $\mathbf{r}(n, i)$.
9: For the chosen d_v number of values in Step 5, set the corresponding indices in $\mathbf{F}_n$ equal to one.
10: For the $\mathbf{r}(i)$ column in $\mathbf{S}$, set the d_v largest value equal to zero.
11: **else**
12: Follow the similar Steps 8-10 for the indices of the next d_v largest values.
13: **end if**
14: **end for**
15: **end for**

$$\mathcal{P}(\text{A}): \ \max_{\mathbf{F}_n} \ \sum_{k=1}^{K} \sum_{j=1}^{M_n} \sum_{n=1}^{N} R_{n,k,j} \tag{7a}$$

$$\text{s.t.} \quad \sum_{j=1}^{M_n} f_{n,k,j} \leq d_f, \quad \forall\ k \in \mathcal{K},\ n \in \mathcal{N}, \tag{7b}$$

$$\sum_{k=1}^{K} f_{n,k,j} \leq d_v, \quad \forall\ j \in \mathcal{J},\ n \in \mathcal{N} \tag{7c}$$

$$\mathbf{F}_{n,j} \neq \mathbf{F}_{n,j'},\ \forall\ 1 \leq j \neq j' \leq M_n, n \in \mathcal{N} \tag{7d}$$

$$f_{n,k,j} \in \{0, 1\},\ \forall\ n \in \mathcal{N},\ k \in \mathcal{K}, j \in \mathcal{J}, \tag{7e}$$

where constraint (7b) determines the maximum number of signals superimposed on each RE, constraint (7c) denotes that a user can communicate over a maximum d_v number of REs, and constraint (7d) represent that no two columns of the factor graph matrix of a cluster are same, and constraint (7e) represents that each element of the $\mathbf{F}$ is either zero or one. The above optimization problem is a non convex non-linear integer programming problem, which makes it difficult to compute the global optimal solution [21].

A. Proposed Solution

To solve the optimization problem, we need to design the factor graph matrix and allocate the REs to each user in such a manner to reduce both inter-UAV interference and intra-UAV interference. To solve the problem $\mathcal{P}(\text{A})$, the factor graph matrix is computed using the proposed factor graph matrix assignment algorithm, as described in **Algorithm 1**.

In **Algorithm 1**, we start with the group which is at the corner of the overall area. The number of users in each group is $M_n = J/N$. First, a factor graph matrix as an all-ones matrix of size $K \times M_n$ is considered, and the SINR values are calculated taking into consideration the intra-UAV interference from the users of this group, $\forall\ 1 \le k \le K, 1 \le j \le M_n$. The SINR matrix is denoted as $\mathbf{S}$ of size $K \times M_n$, and its kth row, jth element is denoted by $\gamma_{k,j}$. Next, the root mean square (RMS) value of all the users SINR is calculated and is sorted in the descending order. The RE allotment starts with the user having the highest RMS value. For this user, d_v number of REs with the highest SINR values are chosen and these REs are assigned to the corresponding user. A similar procedure is repeated for all the users of this group sequentially with decreasing RMS values. Let the resultant factor graph matrix be denoted as $\mathbf{F}_1$.

Once the factor graph matrix is designed for this group, we choose one of the adjacent groups of the previous group. Consider again a factor graph matrix as an all-ones matrix $\mathbf{F}_{ini} = K \times M_n$. This matrix is concatenated with previously designed $\mathbf{F}_1$. The resultant matrix is of size $2 \times K \times M_n$. Next, the SINR values are calculated for the current group, considering the intra-UAV interference from the users of same group and inter-UAV interference from the users of other group. Next, the root mean square (RMS) value of the current group users is calculated and sorted in the descending order. Now, the resource allocation is performed in a similar manner as that for the previous group. Once the factor graph matrix of the current group is designed, it is stored for the designing of the factor graph matrix for next group. In this manner, the $\mathbf{F}$ matrix is designed, which provides the resource allocation for all the users of the network. This algorithm provides a regular factor graph matrix, which denotes the association between users and the REs, considering the constraints shown in (7b, 7c, 7d). The complexity of **Algorithm 1** for factor graph matrix assignment is dependent on the number of users and on the channel conditions. In **Algorithm 1**, d_v REs with best channel conditions are chosen for one user, which will be indexed with value one for that user. Let a_3 denote the complexity of choosing d_v REs for each user with best channel conditions. Thus, every time the indexes match with any other user, the complexity increases by $O(a_3)$. Thus, the overall complexity is constant value times the number of users, and is proportional to $O(J)$.

IV. Results and Discussion

In this section, the performance of the proposed algorithm for maximizing the sum-rate for multi-UAV SCMA system is evaluated. The simulation setup consists of five UAVs working as aerial BSs each serving 20 ground users, as shown in Fig. 1. The simulation parameters are: $a = 11.95$, $b = 0.136$, $\alpha = 2.5$, $\eta_{\text{LoS}} = 3$ dB, $\eta_{\text{NLoS}} = 23$ dB, $d_v = 2$ and $d_f = 4$. The size of $\mathbf{F}_n$ is $K \times M_n$, i.e., 10×20, resulting in $\mathbf{F}_{\text{joint}}$ of size $5 \times 10 \times 20$. We assume that UAVs are located at the centroid of associated users, and power is uniformly divided among all users. We consider two benchmark schemes for comparison: 1) OMA and 2) Interference free (IF). In OMA, all UAVs are assumed to share the same subchannels and serve the users in orthogonal time slots, resulting in inter-uav interference. In IF, all UAVs are assumed to be allocated orthogonal subchannels and serve the users time slots.

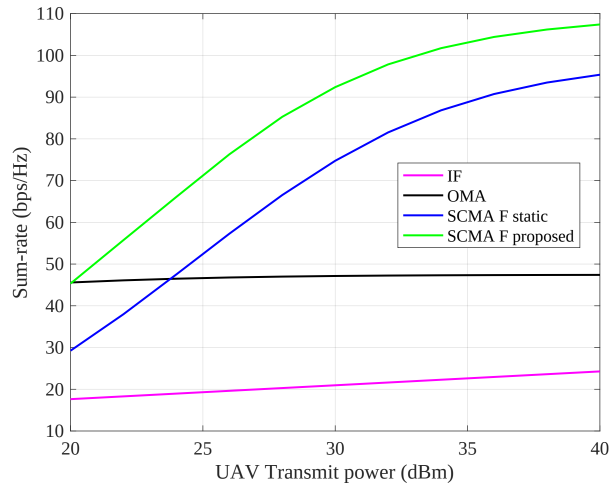

Fig. 3. Sum-rate versus transmit power for multi-UAV network.

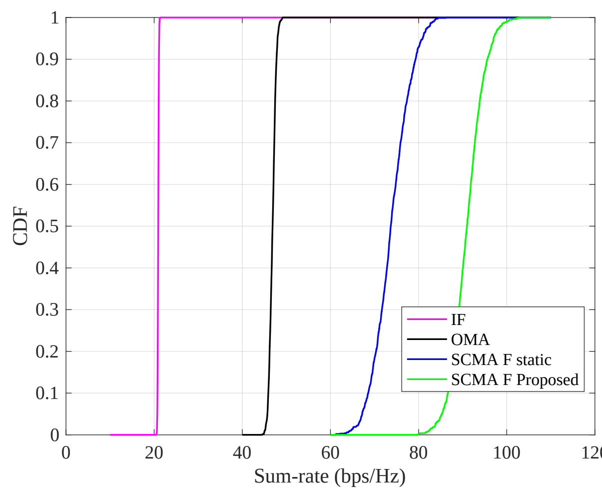

Fig. 4. CDF curves for SCMA, static and proposed $\mathbf{F}_{\text{joint}}$, OMA and IF with UAV transmit power of 30 dBm for multi-UAV network.

Fig. 3 shows the sum-rate performance of the SCMA, OMA and Interference free (IF) with respect to the total transmit power of each UAV, when all the UAVs are at a height of 100 m. In case of SCMA, we have shown the sum-rate performance for static $\mathbf{F}$ and proposed $\mathbf{F}$, as generated from **Algorithm 1**. With the assignment of $\mathbf{F}$, the association between the user and REs is decided based on the CSI. As shown in Fig. 3, the sum-rate performance of all schemes increases with increase in power. But in case of OMA, the interference is dominating, because of which there is a saturation in its performance very early. However, it is evident that among all the multiple access techniques, the sum-rate of SCMA with proposed $\mathbf{F}$ is significantly higher as the transmit power increases.

Fig. 4 shows the cumulative distribution function (CDF)

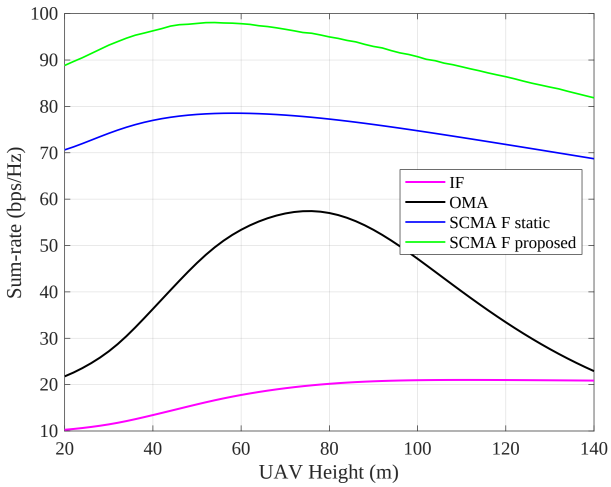

Fig. 5. Sum-rate versus UAVs height for multi-UAV network at UAV transmit power of 30 dBm.

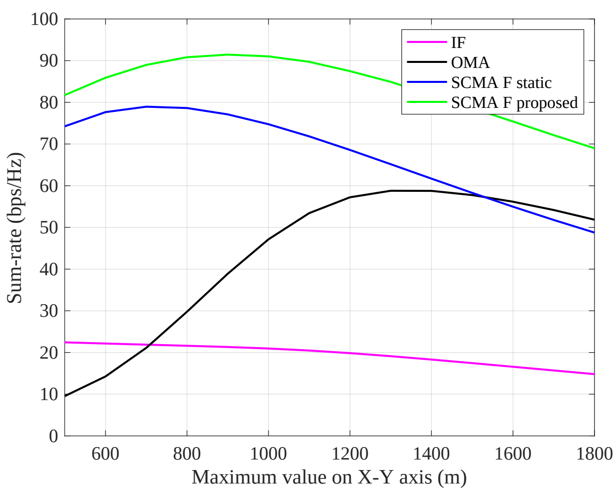

Fig. 6. Sum-rate performance for changing the difference between initial and final X-Y coordinate users for multi-UAV network at UAV transmit power of 30 dBm and UAVs height of 100m.

of the sum-rate corresponding to all the schemes. Note that the gains of the proposed method are stable, and the curves are consistent with their counterparts in Fig. 3. Fig. 5 shows the sum-rate performance with respect to the UAVs height. It is shown that the proposed factor graph matrix assignment outperforms the static **F** matrix and other baseline schemes. Next, we have changed the difference between initial and final X-Y coordinate from 500 m to 1800 m for UAV height to be 100 m. Fig. 6 shows the sum-rate performance with respect to changing maximum value of X-Y axis. Here, for OMA as users are more far, interference decreases, and correspondingly sum-rate increases. Among all, SCMA with proposed **F** outperforms all the schemes.

V. Conclusion

This work has investigated the sum-rate in a multi-UAV SCMA-assisted downlink network. Our aim is to maximize the sum-rate and optimize the joint factor graph matrix, subject to the SCMA constraints. The formulated optimization problem is a non convex non-linear integer programming problem which is difficult to solve. Thus, we have proposed a factor graph matrix assignment algorithm based on available channel state information to solve the optimization problem, considering the inter-UAV and intra-UAV interference. The simulation results verified the system sum-rate improvement for the proposed factor graph matrix assignment algorithm over the benchmark schemes. It is envisaged that the proposed method can assist the UAV systems for on-demand applications, such as providing service in densely populated events, remote areas, etc.

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References

[1] M. Noor-A-Rahim et al., “6G for vehicle-to-everything (V2X) communications: Enabling technologies, challenges, and opportunities,” *Proc. IEEE*, vol. 110, no. 6, pp. 712–734, Jun. 2022.

[2] Y. Zeng, R. Zhang, and T. J. Lim, “Wireless communications with unmanned aerial vehicles: opportunities and challenges,” *IEEE Commun. Mag.*, vol. 54, no. 5, pp. 36–42, 2016.

[3] M. Mozaffari, W. Saad, M. Bennis, Y. Nam, and M. Debbah, “A tutorial on UAVs for wireless networks: Applications, challenges, and open problems,” *IEEE Commun. Surveys Tuts.*, vol. 21, no. 3, pp. 2334–2360, 3rd Quart., 2019.

[4] Y. Liu, Z. Qin, M. Elkashlan, Z. Ding, A. Nallanathan, and L. Hanzo, “Non-orthogonal multiple access for 5G and beyond,” *Proc. IEEE*, vol. 105, no. 12, pp. 2347–2381, Dec. 2017.

[5] M. Moltafet, N. M. Yamchi, M. R. Javan, and P. Azmi, “Comparison study between PD-NOMA and SCMA,” *IEEE Trans.Veh. Technol.*, vol. 67, no. 2, pp. 1830–1834, Feb. 2018.

[6] Q. Luo et al., “An error rate comparison of power domain non-orthogonal multiple access and sparse code multiple access,” *IEEE Open J. Commun. Soc.*, vol. 2, pp. 500–511, 2021.

[7] S. Chaturvedi, Z. Liu, V. A. Bohara, A. Srivastava and P. Xiao, ”A Tutorial on Decoding Techniques of Sparse Code Multiple Access,” *IEEE Access*, vol. 10, pp. 58503-58524, 2022.

[8] Y. Liu et al., “Evolution of NOMA toward next generation multiple access (NGMA) for 6G,” *IEEE J. Sel. Areas Commun.*, vol. 40, no. 4, pp. 1037–1071, Apr. 2022.

[9] Y. Liu, K. Liu, J. Han, L. Zhu, Z. Xiao, and X.-G. Xia, “Resource allocation and 3-d placement for uav-enabled energy-efficient iot communications,” *IEEE Internet of Things Journal*, vol. 8, no. 3, pp. 1322–1333, 2021.

[10] H. El Hammouti, M. Benjillali, B. Shihada, and M.-S. Alouini, “Learnas-you-fly: A distributed algorithm for joint 3D placement and user association in multi-UAVs networks,” *IEEE Trans. Wireless Commun.*, vol. 18, no. 12, pp. 5831–5844, Dec. 2019

[11] O. Esrafilian and D. Gesbert, "Simultaneous user association and placement in multi-UAV enabled wireless networks," in *Proc. 22nd Int. ITG Workshop Smart Antennas (WSA)*, 2018, pp. 1–5.

[12] M. F. Sohail, C.Y. Leow, and S.Won, "Non-orthogonal multiple access for unmanned aerial vehicle assisted communication," *IEEE Access*, vol. 6, pp. 22 716–22727, 2018.

[13] T. Hou, Y. Liu, Z. Song, X. Sun, and Y. Chen, "Multiple antenna aided NOMA in UAV networks: A stochastic geometry approach," *IEEE Trans. Commun.*, vol. 67, no. 2, pp. 1031–1044, Feb. 2019.

[14] R. Duan, J. Wang, C. Jiang, H. Yao, Y. Ren, and Y. Qian, "Resource allocation for multi-UAV aided IoT NOMA uplink transmission systems," *IEEE Internet Things J.*, vol. 6, no. 4, pp. 7025–7037, Aug. 2019.

[15] F. Cui, Y. Cai, Z. Qin, M. Zhao, and G. Y. Li, "Multiple access for mobile- UAV enabled networks: Joint trajectory design and resource allocation," *IEEE Trans. Commun.*, vol. 67, no. 7, pp. 4980–4994, Jul. 2019.

[16] N. Zhao et al., "Security enhancement for NOMA-UAV networks," *IEEE Trans. Veh. Technol.*, vol. 69, no. 4, pp. 3994–4005, Apr. 2020.

[17] J. V. C. Evangelista, Z. Sattar, G. Kaddoum, and A. Chaaban, "Fairness and sum-rate maximization via joint subcarrier and power allocation in uplink scma transmission," *IEEE Trans. Wireless Commun.*, vol. 18, no. 12, pp. 5855–5867, Dec. 2019.

[18] N. Gupta, S. Agarwal, and D. Mishra, "Trajectory design for throughputmaximization in UAV-assisted communication system," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 3, pp. 1319–1332, Sep. 2021.

[19] K. Zhu, X. Xu, and S. Han, "Energy-efficient uav trajectory planning for data collection and computation in mmtc networks," in *2018 IEEE Globecom Workshops (GC Wkshps)*, 2018, pp. 1–6.

[20] A. Al-Hourani, S. Kandeepan, and S. Lardner, "Optimal lap altitude for maximum coverage," *IEEE Wireless Commun. Lett.*, vol. 3, no. 6, pp. 569–572, 2014.

[21] J. Hartmanis, "Computers and intractability: a guide to the theory of NP-completeness (michael r. garey and david s. johnson)," *Siam Review*, vol. 24, no. 1, p. 90, 1982.