NOMA-Enabled CoMP-Transmission in Satellite-Aerial-Terrestrial Networks

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***Abstract*—In this paper, we consider a non-orthogonal multiple access (NOMA)-enabled satellite-aerial-terrestrial network, where a batch of unmanned-aerial-vehicles (UAVS) act as decode-and-forward (DF) relays to simultaneously serve ground user equipments (UEs). The UAVs employ joint-transmission coordinated multi-point (JT-CoMP) to cooperatively provide coverage to a cluster of UEs utilizing the same resource block (RB), in a low signal-to-interference-plus-noise-ratio (SINR) setting. Our main objective is to increase the quality-of-service (QoS) of the UEs by maximizing the system sum-rate, which is accomplished by presenting a relay selection and a power allocation scheme, under limited available transmission power at the satellite and UAVs, QoS of UEs, and decoding order of UEs constraints. We first present an optimal UAV relays selection scheme which selects a group of UAVs satisfying the rate and decoding order constraints, and then sequentially solve the power allocation optimization problem for the two stages of transmission using Lagrange multipliers method and Karush-Kuhn-Tucker (KKT) conditions. Simulation results prove the effectiveness of our proposed system in successfully increasing the sum-rate of the network compared to baseline schemes, hence amplifying spectral efficiency.**

***Index Terms*—Non-orthogonal multiple access (NOMA), coordinated multi-point (CoMP), satellite-aerial-terrestrial.**

I. INTRODUCTION

The prospective deployment of the fifth generation (5G) and the forthcoming sixth generation (6G) networks is anticipated to generate manifold increase in network applications, active devices, energy-efficiency and spectral-efficiency [1]. Because of its considerable spectral-efficiency enhancement, non-orthogonal multiple access (NOMA) has been regarded as a promising technology for the future wireless networks [2]. NOMA serves multiple users simultaneously within a given resource block (RB), by utilizing superposition coding (SC) at the transmitter, and successive interference cancellation (SIC) at the receiver, providing a balanced trade-off between system throughput and user fairness [3].

Recent trends have also involved the use of coordinated multi-point (CoMP) transmission and reception, which allows geographically distributed nodes to cooperatively transmit or decode information at symbol level. As a result, the reliability and throughput of the system can be considerably enhanced, especially for cell edge users [4]. Considerable research efforts have been devoted to integrating NOMA and CoMP in recent years. The authors in [5] proposed a network NOMA-CoMP technique, where multiple base stations (BS) cooperate to serve a user pair with a common CoMP user, using the same RB. The authors used a stochastic geometry approach to derive expressions for the outage probabilities and ergodic rates. In [6], the authors formulated a dynamic power allocation problem for downlink CoMP-NOMA, and analyzed the performance gap between NOMA and orthogonal multiple access (OMA). A joint optimization of BS clustering and power control for NOMA-enabled CoMP transmission was investigated in [7], and the authors employed an alternating optimization (AO)-based method to maximize the system sum-rate for dense cellular networks.

Furthermore, in [8], the authors analyzed CoMP-NOMA for simultaneous wireless information and power transfer (SWIPT), and studied analytical expressions for the outage probabilities of two proposed CoMP-NOMA schemes, i.e., Alamouti-NOMA (A-NOMA), and joint transmission-NOMA (JT-NOMA). The authors in [9] designed centralized and distributed algorithms to optimize power allocation for cell edge users in a two cell network, using coordinated transmission techniques. A joint beamforming and power allocation design for multi-cell multi-user multiple-input multiple-output (MIMO) network was presented in [10], and the authors maximized the sum-rate of the system using successive convex approximation (SCA). The authors in [11] proposed a relay-aided multiple access (RAMA) scheme based on network coding, and studied the trade-off between NOMA and RAMA under different conditions. The authors then presented an adaptive NOMA-RAMA scheme, and proposed a power allocation and user clustering scheme, using branch and bound (BB), and greedy algorithm, respectively.

Recently, unmanned aerial vehicles (UAVs) have also received considerable interest in recent years due to their enticing features such as line-of-sight (LoS) communication, high mobility and flexibility etc, to extend the connectivity to isolated users. In [12], the authors considered an overloaded BS in a two-cell NOMA-CoMP network, which is supported by a UAV, and the authors studied the UAV placement strategies to benefit from interference cancellation, enhancing system throughput.

The authors in [13] proposed a UAV-aided cognitive satellite-terrestrial network, with the objective of maximizing the terrestrial user's achievable rate. The formulated optimization problem was decoupled into two sub-problems of power allocation and UAV trajectory optimization, and the authors approached the solution using block coordinate descent method. Moreover, in [14], the authors presented an uplink communication scenario in a multi-UAV-enabled multi-user system, and derived analytical expressions for UAV placement and movement for CoMP. Additionally, a relay selection scheme for satellite communication was proposed in [15], where UAVs were used as relays to serve a ground user pair. The authors investigated the outage probability and the sum-rate of the system under relay selection strategies.

Although terrestrial networks are able to provide efficient quality-of-experience (QoE) to users in most cases, they rely heavily on communication infrastructure placed in close proximity to the user equipments (UEs). This arises as an arduous task in remote areas with complex terrains such as mountains, deserts, and isolated highways, where timely maintenance and active performance is difficult to accomplish. Moreover, network coverage in such areas is limited and scarce, and vulnerable to natural disasters, consequently, the UEs may be unable to form reliable network connections. This motivates us to employ a satellite-aided UAV network, utilizing CoMP-NOMA scheme to provide diverse services in network-deprived areas to increase QoS of UEs. Different from the aforementioned works, which mainly focus on cell edge users in either terrestrial or aerial scenario, we propose a JT-CoMP scheme to simultaneously provide services to a cluster of isolated users for a satellite-aerial-terrestrial network, and aim to maximize system throughput by optimizing power allocation and relay selection. The major contributions of this work are summarized as follows.

- We propose a NOMA-enabled CoMP scheme for a satellite-aerial-terrestrial network, where multiple UAVs act as decode-and-forward (DF) relays to extend services to isolated users through joint transmission.
- We present an optimal relay selection scheme and a power allocation scheme, under limited available transmission power at the satellite and UAVs, QoS of UEs, and decoding order of UE constraints, in order to maximize system throughput. We obtain the optimal power allocation strategies using Lagrange multipliers method and Karush-Kuhn-Tucker (KKT) conditions.
- The results show that the optimal power allocation and relay selection strategies, can significantly enhance the sum-rate of the system, and can help in improving spectral-efficiency.

The rest of the paper is organized as follows. Section II proposes the system model, including the channel and transmission model. Section III presents the optimal relays selection and the power allocation optimization for maximizing system sum-rate. The simulation results are provided in Section IV, and finally we conclude the paper in Section V with emphasis on future work.

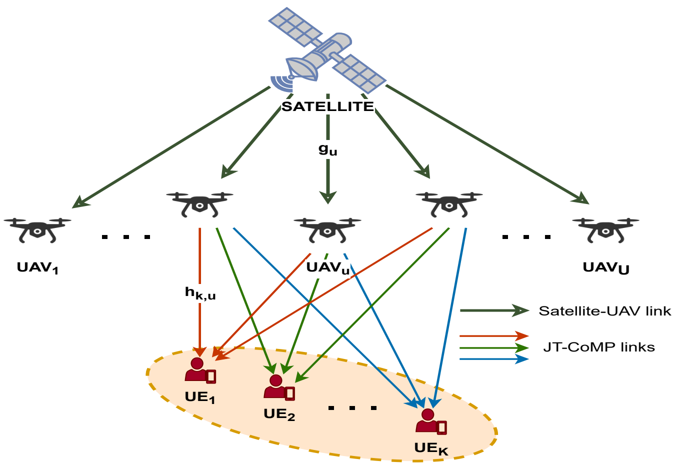

Fig. 1. Illustration of a JT-CoMP-NOMA satellite-aerial-terrestrial network model, with K UEs and U UAVs.

II. System Model

In this paper, we consider a satellite-aerial-terrestrial cooperative communication model as illustrated in Fig. 1, where a group of UAVs fly over a serving area, and act as decode-and-forward (DF) relays to help transmit messages from the satellite to several ground user equipment (UEs), simultaneously. We assume that the satellite is unable to transmit messages directly to UEs, owing to extremely high path loss and shadowing etc. Therefore, the UAVs act as half-duplex (HD) relays to extend coverage to the UEs. We denote the set of UAVs and UEs in the network as $\mathcal{U} = \{1, 2, ..., U\}$ and $\mathcal{K} = \{1, 2, ..., K\}$, respectively. The satellite, UAVs and UEs are all equipped with a single antenna and are located in fixed positions, denoted by $w_u = (x_u, y_u, z_u)$, and $w_k = (x_k, y_k, z_k)$, respectively. The communication between the satellite and UEs takes place in two time-slots. In the first time-slot, the satellite broadcasts the messages of the UEs to the UAVs, which are then decoded and re-transmitted to the UEs during the second time-slot. The UAVs employ JT-CoMP scheme, where a set of UAVs are coordinated to transmit the data to UEs, and the UEs are further formed into a cluster, for NOMA transmission over the same RB.

A. Channel Model

The channel between the satellite and the UAVs is given by [16]

$$g_u = \frac{\lambda\sqrt{G_u G_{s,u}(\theta)}}{4\pi d_{s,u}} \hat{g_u}, \tag{1}$$

where λ is the wavelength, G_u is the antenna gain of the uth UAV, $d_{s,u} = \sqrt{(x_s - x_u)^2 + (y_s - y_u)^2 + (z_s - z_u)^2}$ is the distance between the satellite and the uth UAV. $G_{s,u}(\theta)$ is the typical satellite antenna gain to the uth UAV, which is represented by [17]

$$G_{s,u}(\theta) = G_{\max}\left(\frac{J_1(r_u)}{2r_u} + 36\frac{J_3(r_u)}{r_u^3}\right)^2, \tag{2}$$

where $J(\cdot)$ is the Bessel function, G_{max} is the maximum satellite antenna gain, and

$$r_u = 2.07123 \frac{\sin(\phi_u)}{\sin(\phi_{3\text{dB}})}, \tag{3}$$

where ϕ_u is the angle between the beam center and the corresponding UAV, and $\phi_{3\text{dB}}$ is the 3dB angle. Moreover, in (1), $\hat{g}$ follows Rician distribution which is given by

$$\hat{g}_u = \sqrt{\frac{B}{B+1}} \psi^{\text{LoS}} + \sqrt{\frac{1}{B+1}} \psi^{\text{NLoS}}, \tag{4}$$

where ψ^{LoS} and ψ^{NLoS} represent the deterministic line-of-sight (LoS) component and the non-line-of-sight (NLoS) small scale-fading components, respectively, and B represents the Rician factor, where the channel becomes completely LoS as $B \to \infty$. Also, the channel gain between the uth UAV and kth UE follows a free space path loss model with perfect compensation of Doppler effect at the UEs, and is given by

$$h_{k,u} = \frac{\beta_0}{(\sqrt{(x_u - x_k)^2 + (y_u - y_k)^2 + (z_u - z_k)^2})^{\frac{\kappa}{2}}}, \tag{5}$$

where β_0 is the reference channel gain at a distance of 1m, and κ is the path loss exponent.

B. Transmission Model

In the first time-slot, the satellite broadcasts the signal s to the UAVs, which is given by

$$s = \sum_{u=1}^{U} \sqrt{\eta_u P_S} s_u, \tag{6}$$

where s_u is the signal intended for the uth UAV, η_u is the power allocation coefficient for the uth UAV, and P_S is the total power available at the satellite. We also assume that an efficient multi-user detection (MUD) scheme (e.g., SIC) is employed at the BS, for which the users in a NOMA cluster need to be ordered based on their channel gains as

$$|g_1|^2 < |g_2|^2 < ... < |g_K|^2, \tag{7}$$

The received signal at the uth UAV is consequently given as

$$y_u = g_u \sqrt{\eta_u P_S} s_u + g_u \sum_{i=u+1}^{U} \sqrt{\eta_i P_S} s_i + n_u, \tag{8}$$

where the first term is the desired signal of the UAV, and the second term is the inter-UAV interference after the SIC process. In addition, n_u denotes the additive white Gaussian noise, which follows complex Gaussian distribution with zero mean and variance of σ_u^2 (i.e., $n_u \sim \mathcal{CN}(0, \sigma_u^2)$). Accordingly, the achievable capacity of the satellite to the uth UAV is given by

$$R_u = \frac{1}{2} \log_2 \left(1 + \frac{\eta_u P_S |g_u|^2}{|g_u|^2 \sum_{i=u+1}^{U} \eta_i P_S + \sigma_u^2} \right). \tag{9}$$

In the second time-slot, a set of UAVs for CoMP, $\mathcal{V}$, are selected, which are used to transmit the signals to the users by employing JT-CoMP-NOMA. Consequently, the received signal at the kth UE is given by

$$y_k = \sum_{u \in \mathcal{V}} h_{k,u} \sqrt{\alpha_{k,u} P_u} s_{k,u} + \sum_{u \in \mathcal{V}} h_{k,u} \sum_{j=k+1}^{K} \sqrt{\alpha_{j,u} P_u} s_{j,u} + n_k, \tag{10}$$

where P_u is the total power available at the uth UAV, and $\alpha_{k,u}$ is the power allocation coefficient from uth UAV to the kth UE. Consequently, the achievable capacity of the kth UE is

$$R_k = \frac{1}{2} \log_2 \left(1 + \frac{\sum_{u \in \mathcal{V}} \alpha_{k,u} P_u |h_{k,u}|^2}{\sum_{u \in \mathcal{V}} |h_{k,u}|^2 \sum_{j=k+1}^{K} \alpha_{j,u} P_u + \sigma_k^2} \right). \tag{11}$$

III. Relay Selection and Power Allocation

A. Relay Selection

In order to improve system performance, a relays selection strategy needs to be formulated. A set of relays, $\mathcal{W}$, maximizing the system sum rate is selected and used to perform JT-CoMP-NOMA. This is accomplished by comparing the received data rate at the uth UAV to its threshold data rate, which can be expressed as

$$\mathcal{W} = \{u | R_u \geq R_u^{\text{th}}, \forall u \in \mathcal{U}\} \tag{12}$$

where R_u^{th} is the threshold data rate of the uth UAV to successfully decode its data. However, in JT-CoMP-NOMA, the UEs receive multiple streams of the same data simultaneously. Therefore, it is vital that the decoding orders remain the same, and only those UAVs are selected which have the same decoding order for all UEs, to cater for inter-user interference. Therefore a subset, $\mathcal{V}$, of UAVs from $\mathcal{W}$ is selected, in which all the UEs have the same decoding order.

$$\mathcal{V} = \{u | \Delta_u = \Delta_{u'}, \forall u \in \mathcal{W}, \forall u' \in \mathcal{W}\}, \tag{13}$$

where Δ_u is the decoding order of the users for the uth UAV. In case the decoding order of all UAVs is different, the UAV with the strongest channel gain is selected only.

B. Power Allocation

We decouple the power allocation over two time-slots into two different sub-problems. The first sub-problem optimizes the power allocation coefficients for the first time-slot under the constraints of maximum power available at the satellite. This problem is convex and can be efficiently solved using the method in [18]. The sum-rate maximization problem for the second time-slot is expressed as

$$\begin{aligned}
\underset{\alpha_{k,u}}{\text{maximize}} \quad & \sum_{k=1}^{K} \frac{1}{2}\log_2\left(1+\frac{\sum_{u\in\mathcal{V}}\alpha_{k,u}\gamma_{k,u}}{\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1}\right)\\
\text{subject to} \quad & C1: \log_2\left(1+\frac{\sum_{u\in\mathcal{V}}\alpha_{k,u}\gamma_{k,u}}{\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1}\right)\\
\geq R_k^{\text{th}}, \forall k,&\\
& C2: \sum_{k=1}^{K}\alpha_{k,u}\leq 1, \forall u\in\mathcal{V},\\
& C3: \sum_{u\in\mathcal{V}}(\alpha_{k,u}-\sum_{r=k+1}^{K}\alpha_{r,u})\gamma_{k+1,u}\geq P_\theta
\end{aligned}$$

In the above problem, $\gamma_{k,u}=\frac{P_u|h_{k,u}|^2}{\sigma_k^2}$, and $C1$ indicates that the received data rate at the kth UE must satisfy the QoS requirements. $C2$ ensures that the transmission power at the UAV cannot exceed the maximum power available, i.e., P_u. Whereas, $C3$ specifies the SIC constraint at the UEs.The objective function of problem (14) is generally non-convex because of the interference terms with dependent variables in the denominator of the SINR, which causes the function to oscillate between convexity and concavity. The objective function can be rearranged as

$$R_{\text{sum}}=\sum_{k=1}^{K}\frac{1}{2}\log_2\left(\frac{\sum_{u\in\mathcal{V}}\gamma_{k,u}(\alpha_{k,u}+\sum_{j=k+1}^{K}\alpha_{j,u})+1}{\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1}\right). \tag{14}$$

Let

$$p(k)=\sum_{u\in\mathcal{V}}\gamma_{k,u}(\alpha_{k,u}+\sum_{j=k+1}^{K}\alpha_{j,u}), \tag{15}$$

and

$$q(k)=\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}. \tag{16}$$

The objective function can be equivalently re-written as

$$R_{\text{sum}}=\sum_{k=1}^{K}\frac{1}{2}\left[\log_2\left(p(k)+1\right)+\log_2\left(\frac{1}{q(k)+1}\right)\right]. \tag{17}$$

In (17), it is evident that the first term in the summation is monotonically increasing, whereas the second term in the summation is monotonically decreasing, which makes them concave and convex functions, respectively. However, due to the addition of constraint $C3$, the degree of convexity of the second term will always be greater than the degree of concavity of the first term, as noted by [19], which would make their sum strictly convex, hence R_{sum} is convex.

Also, constraint $C1$ can be rearranged as

$$\frac{\sum_{u\in\mathcal{V}}\alpha_{k,u}\gamma_{k,u}}{\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1}\geq 2^{R_k^{\text{th}}}-1. \tag{18}$$

This is converted into

$$\sum_{u\in\mathcal{V}}\alpha_{k,u}\gamma_{k,u}-(2^{R_k^{th}}-1)(\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1)\geq 0, \tag{19}$$

which is an affine function.

Since the objective function of the formulated problem is convex and the constraints $C1-C3$ are affine, the formulated optimization problem is a convex optimization problem. This motivates us to employ the Lagrange multipliers method for a low-complexity solution to the problem. The Lagrange function for the problem is expressed as

$$\begin{aligned}
&\mathcal{L}(\alpha,\mu,,\Gamma,\chi)=\\
&\sum_{k=1}^{K}\frac{1}{2}\log_2\left(1+\frac{\sum_{u\in\mathcal{V}}\alpha_{k,u}\gamma_{k,u}}{\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1}\right)\\
&+\sum_{k=1}^{K}\mu_k\left[\sum_{u\in\mathcal{V}}\left(\alpha_{k,u}-\Omega_k(\sum_{j=k+1}^{K}\alpha_{j,u})\right)\gamma_{k,u}-\Omega_k\right]\\
&+\sum_{k=1}^{K-1}\Gamma_i\left[\left(P_\theta-\sum_{u\in\mathcal{V}}(\alpha_{k,u}-\sum_{r=k+1}^{K}\alpha_{r,u})\gamma_{k+1,u}\right)\right]\\
&+\sum_{u\in\mathcal{V}}\chi(1-\sum_{k=1}^{K}\alpha_{k,u})
\end{aligned} \tag{20}$$

where $\Omega=2^{R_k^{\text{th}}}-1$. Using KKT conditions, we have

$$\begin{aligned}
\frac{\partial\mathcal{L}}{\partial\alpha_{k,u}}=&\frac{\xi_k^u}{2\ln(2)\left(1+\sum_{u\in\mathcal{V}}\alpha_{k,u}\xi_k^u\right)}+\mu_k\gamma_{k,u}-\Gamma_k\gamma_{k+1,u}\\
&-\chi_u,
\end{aligned} \tag{21}$$

where

$$\xi_k^u=\frac{\gamma_{k,u}}{\sum_{u\in\mathcal{V}}\gamma_{k,u}\sum_{j=k+1}^{K}\alpha_{j,u}+1}. \tag{22}$$

By setting $\frac{\partial\mathcal{L}}{\partial\alpha_{k,u}}=0$, the optimal power allocation coefficient is obtained as

$$\begin{aligned}
&\alpha_{k,u}^*=\\
&\left[\frac{1}{\ln(2)\left(\chi_u+\Gamma_k\gamma_{k+1,u}-\mu_k\gamma_{k,u}\right)}-\frac{1+\sum_{i\in\mathcal{V}/\{u\}}\alpha_{k,i}\xi_k^i}{\xi_k^u}\right]^+
\end{aligned} \tag{23}$$

where $[\zeta]^+=\max(0,\zeta)$. We iteratively update the Lagrange multipliers, μ,χ, and Γ, using sub-gradient methods as

$$\begin{aligned}
&\mu_k(s+1)=\Bigg[\mu_k(s)-\\
&\omega(s)\left[\sum_{u\in\mathcal{V}}\left(\alpha_{k,u}-\Omega_k(\sum_{j=k+1}^{K}\alpha_{j,u})\right)\gamma_{k,u}-\Omega_k\right]\Bigg]^+
\end{aligned} \tag{24}$$

$$\begin{aligned}
&\Gamma_k(s+1)=\\
&\left[\Gamma_k(s)-\omega(s)\left(P_\theta-\sum_{u\in\mathcal{V}}(\alpha_{k,u}-\sum_{r=k+1}^{K}\alpha_{r,u})\gamma_{k+1,u}\right)\right]^+
\end{aligned} \tag{25}$$

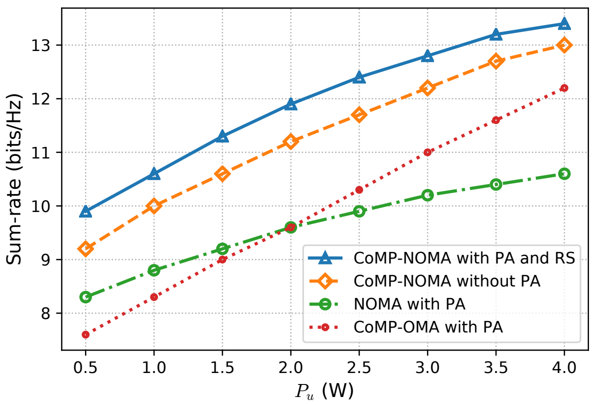

Fig. 2. Sum-rate of the system against P_u, with $K = 5$ and $U = 4$.

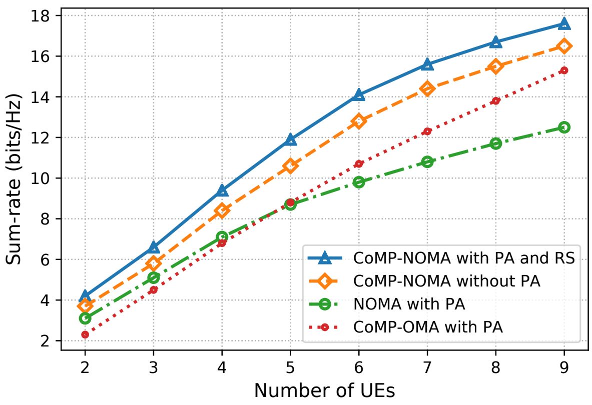

Fig. 3. Sum-rate of the system against K, with $U = 4$.

$$\chi_u(s+1) = \left[\chi_u(s) - \omega(s)\left(1 - \sum_{k=1}^{K} \alpha_{k,u}\right)\right]^+, \tag{26}$$

where $\omega(s) = \frac{s}{2s+1}$ is the positive step size, and s denotes the iteration number. At each iteration s, μ_k, Γ_k and χ_u, are updated using the optimal value of the power allocation coefficient, $\alpha^*_{k,u}$, and the obtained values of μ_k, Γ_k and χ_u are used to update the optimal $\alpha^*_{k,u}$ in the next iteration. The process continues until the difference between any two consecutive values of Langrange multipliers falls below ϵ, which is a very small value to signify convergence.

IV. Simulation Results

In this section, we present the simulation results to evaluate the performance of the relay selection and power allocation scheme for the proposed JT-CoMP-NOMA-based satellite-aerial-terrestrial network. We assume that the UEs and UAVs are uniformly distributed horizontally in an area of 400 m $\times$ 400 m, with vertical heights of 1 m and 50 m, respectively. We initially assume that there are 5 UEs and 4 UAVs in the system, and vary the numbers to study the effects on the system later on in this section. The total power available at the satellite, P_S, is 80 W, and the total power budget of each UAV, P_u, is set to 2 W initially. The noise power is set to $\sigma_k^2 = \sigma_u^2 = -110$ dBm, and $R_u^{\text{th}} = R_k^{\text{th}} = 0.5$ bits/s, and the Rician factors for the channel gains, $B = 10$ dB. We also fix $\beta_0 = -30$ dB and $\kappa = 3$. Moreover, the SIC sensitivity, $P_\theta = 1$ dBm, 3 dB angle, $\phi_{3\text{dB}} = 0.4°$, the carrier frequency is set to 2 GHz, the UAV antenna gain, $G_u = 16$ dBi, and the maximum satellite antenna gain, $G_{\max} = 52$ dBi.

The proposed solution is compared against three baseline methods as follows

- CoMP-NOMA with relay selection (RS), and without optimal power allocation (PA).
- NOMA with optimal PA, where one UAV is selected to relay information to the UEs.
- OMA with RS and PA.

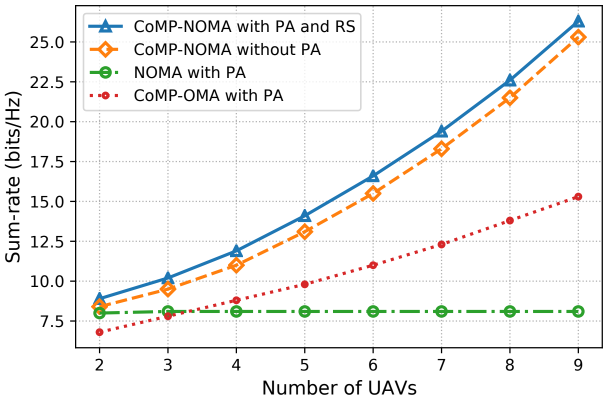

Fig. 4. Sum-rate of the system against U, with $K = 5$.

Fig. 2 depicts the sum-rate of the system relative to the maximum transmission power available at the UAVs, P_u, with $K = 5$ and $U = 4$. As depicted in the figure, the sum-rate of the system increases with an increase in P_u. The proposed JT-CoMP-NOMA scheme with optimal PA and RS, considerably performs better than the other baseline schemes, which shows its potential in increasing spectral-efficiency of the system. It can also be seen that although the NOMA without CoMP scheme performs better than the OMA-CoMP scheme in the low power region, it performs worse in the high power region due to increased inter-user interference, which is more noticeable in the no CoMP case.

We next evaluate the sum-rate performance of the system on varying the number of UEs in the system in Fig. 3. The sum-rate of the system increases with an increase in the number of UEs in the system. The proposed optimal JT-CoMP-NOMA scheme outperforms the baseline schemes, but the sum-rate increases at a decreasing rate because of increased inter-user interference, which is less pronounced in the OMA-CoMP scheme. However, the OMA-CoMP scheme uses more frequency resources than NOMA. We further compare the sum-rate performance of the system on increasing the number of UAVs in the system in

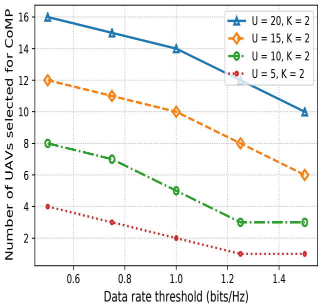

Fig. 5. Number of UAVs used for CoMP against threshold rate.

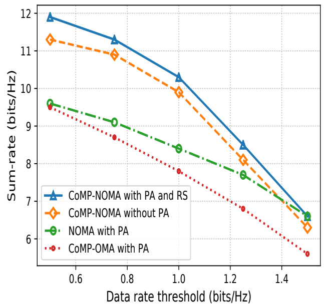

Fig. 6. Sum-rate of the system against threshold rate.

Fig. 4. As expected, the sum-rate increases with an increase in the number of UAVs, except for the NOMA without CoMP scenario, which employs just one UAV for transmission of data. The sum-rate of the sytem for the proposed JT-CoMP-NOMA scheme increases at an increasing rate because more UAVs can be selected which have the same decoding order for the users, and are able to overcome the rate thresholds. The increase for the OMA-CoMP scheme is fairly constant because the selection of the UAVs does not depend on the corresponding decoding order of the UEs, as in the case of NOMA-based schemes.

Finally, we evaluate the effect of increasing the UAV and the UE data rate threshold, $R_u^{\text{th}} = R_k^{\text{th}}$, on the number of UAVs selected for CoMP, and the sum-rate of the system, in Fig. 5 and Fig. 6, respectively. An increase in the data rate threshold leads to a decrease in the number of UAVs selected for CoMP. As a consequence, the sum-rate of the system decreases for all CoMP schemes, but decreases at a higher rate for CoMP-NOMA schemes, since the selection of the UAVs also depends on the decoding order of the UEs.

V. Conclusion

In this paper, we have proposed a JT-CoMP-NOMA-enabled satellite-aerial-terrestrial network, with the objective of increasing the sum-rate of the system. We formulated a relay selection and power allocation scheme, where the relays were selected according to the decoding order of the connected UEs, and the data rate thresholds, and the power allocation problem was solved using using Langrange multipliers method, and KKT conditions, for a low complexity implementation. Extensive simulation results exhibit the effectiveness of the proposed scheme, and prove that the proposed network model is able to effectively increase the system performance and spectral-efficiency of the system. Future extensions of this work can include incorporation of MIMO scheme into the system to reap benefits from signal diversity from multiple antennae. Moreover, a NOMA clustering scheme can be employed to increase the coverage capacity of the system.

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References

[1] F. Tariq, M. R. A. Khandaker, K.-K. Wong, M. A. Imran, M. Bennis, and M. Debbah, “A speculative study on 6g,” *IEEE Wireless Communications*, vol. 27, no. 4, pp. 118–125, 2020.

[2] Y. Liu, Z. Qin, M. Elkashlan, Z. Ding, A. Nallanathan, and L. Hanzo, “Nonorthogonal multiple access for 5g and beyond,” *Proceedings of the IEEE*, vol. 105, no. 12, pp. 2347–2381, 2017.

[3] S. Qureshi, S. A. Hassan, and D. N. K. Jayakody, “Divide-and-allocate: An uplink successive bandwidth division noma system,” *Transactions on Emerging Telecommunications Technologies*, vol. 29, no. 1, p. e3216, 2018, e3216 ett.3216. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/ett.3216

[4] R. Irmer, H. Droste, P. Marsch, M. Grieger, G. Fettweis, S. Brueck, H.-P. Mayer, L. Thiele, and V. Jungnickel, “Coordinated multipoint: Concepts, performance, and field trial results,” *IEEE Communications Magazine*, vol. 49, no. 2, pp. 102–111, 2011.

[5] Y. Sun, Z. Ding, X. Dai, and O. A. Dobre, “On the performance of network noma in uplink comp systems: A stochastic geometry approach,” *IEEE Transactions on Communications*, vol. 67, no. 7, pp. 5084–5098, 2019.

[6] M. S. Ali, E. Hossain, A. Al-Dweik, and D. I. Kim, “Downlink power allocation for comp-noma in multi-cell networks,” *IEEE Transactions on Communications*, vol. 66, no. 9, pp. 3982–3998, 2018.

[7] Y. Dai, J. Liu, M. Sheng, N. Cheng, and X. Shen, “Joint optimization of bs clustering and power control for noma-enabled comp transmission in dense cellular networks,” *IEEE Transactions on Vehicular Technology*, vol. 70, no. 2, pp. 1924–1937, 2021.

[8] M. Hedayati and I.-M. Kim, “Comp-noma in the swipt networks,” *IEEE Transactions on Wireless Communications*, vol. 19, no. 7, pp. 4549–4562, 2020.

[9] Q. Guo, C. W. Sung, Y. Chen, and C. S. Chen, “Power control for coordinated noma downlink with cell-edge users,” in *2018 IEEE Wireless Communications and Networking Conference (WCNC)*, 2018, pp. 1–6.

[10] X. Sun, N. Yang, S. Yan, Z. Ding, D. W. K. Ng, C. Shen, and Z. Zhong, “Joint beamforming and power allocation in downlink noma multiuser mimo networks,” *IEEE Transactions on Wireless Communications*, vol. 17, no. 8, pp. 5367–5381, 2018.

[11] Q. Zhou, Y. Ma, L. Bai, J. Choi, and Y.-C. Liang, “Relay-aided multiple access scheme in two-point joint transmission,” *IEEE Transactions on Vehicular Technology*, vol. 68, no. 6, pp. 5629–5641, 2019.

[12] A. Kilzi, J. Farah, C. A. Nour, and C. Douillard, “Analysis of drone placement strategies for complete interference cancellation in two-cell noma comp systems,” *IEEE Access*, vol. 8, pp. 179 055–179 069, 2020.

[13] M. Hua, Y. Wang, M. Lin, C. Li, Y. Huang, and L. Yang, “Joint comp transmission for uav-aided cognitive satellite terrestrial networks,” *IEEE Access*, vol. 7, pp. 14 959–14 968, 2019.

[14] L. Liu, S. Zhang, and R. Zhang, “Comp in the sky: Uav placement and movement optimization for multi-user communications,” *IEEE Transactions on Communications*, vol. 67, no. 8, pp. 5645–5658, 2019.

[15] S. Mirbolouk, M. A. Choukali, M. Valizadeh, and M. C. Amirani, “Relay selection for comp-noma transmission in satellite and uav cooperative networks,” in *2020 28th Iranian Conference on Electrical Engineering (ICEE)*, 2020, pp. 1–5.

[16] X. Liu, M. Lin, Q. Huang, J.-Y. Wang, and J. Ouyang, “Performance analysis for multi-user integrated satellite and uav cooperative networks,” *Physical Communication*, vol. 36, p. 100762, 07 2019.

[17] G. Zheng, S. Chatzinotas, and B. Ottersten, “Generic optimization of linear precoding in multibeam satellite systems,” *IEEE Transactions on Wireless Communications*, vol. 11, no. 6, pp. 2308–2320, 2012.

[18] M. S. Ali, H. Tabassum, and E. Hossain, “Dynamic user clustering and power allocation for uplink and downlink non-orthogonal multiple access (noma) systems,” *IEEE Access*, vol. 4, pp. 6325–6343, 2016.

[19] Y. Al-Eryani, E. Hossain, and D. I. Kim, “Generalized coordinated multipoint (gcomp)-enabled noma: Outage, capacity, and power allocation,” *IEEE Transactions on Communications*, vol. 67, no. 11, pp. 7923–7936, 2019.