On Performance of Downlink Non-Orthogonal Multiple Access Wireless System Relying on UAV

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Abstract —Wireless communications relying on Unmanned Aerial Vehicles (UAVs) is a promising candidate in future communication systems. Compared with conventional terrestrial communications, UAV networks has some significant benefits including cost-effectiveness, mobility, fast deployment, higher probability of Line-of-Sight (LoS) links between UAV and ground terminals. Based on ideal conditions of high Signal-to-Noise Ratio (SNR), Non-Orthogonal Multiple Access (NOMA) with fixed power allocation factor is adopted to indicate performance of two users. These ground user from UAV is independent of channel and trajectory parameters is further evaluated under impact of imperfect channel state information (CSI). We drive the closed-form formula of outage probability for two ground users. Simulation results provide impacts of system parameters on outage behavior.

Index Terms—Unmanned Aerial Vehicles (UAV) Non-Orthogonal Multiple Access (NOMA) and outage probability

I. Introduction

To develop wireless access technique for the coming 5G era, Non-Orthogonal Multiple Access (NOMA) is introduced [1]–[8]. NOMA employs users' information is superposed in power domain along with non-orthogonal transmission at the transmitter to exhibit higher spectrum efficiency. In principle, NOMA can serve multiple users over the same resource block which is different with traditional Orthogonal Multiple Access (OMA). One of advantage of NOMA, it can effectively increase sum rate. To detect the users' information at the receiver, Successive Interference Cancellation (SIC) is required at receivers. Specifically, the user with the best channel condition is decoded its signal by considering other signal as interference. The authors in [8] presented analysis of NOMA and compared OMA and NOMA. One of benefits of NOMA, massive connections are provided by NOMA to implement 5G communication systems. non-orthogonal transmission and SIC lead to improvement of Spectrum Efficiency (SE). Rabie *et al*. [9] analyzed dual hop cooperative relaying by evaluating the average sum capacity performance of NOMA adopting relaying protocol to achieve a superior capacity performance. By implementing NOMA at both source and relay, a cooperative NOMA scheme was proposed in [10].

Recently, the cost of UAV is continuous decreasing to satisfy rapid development of wireless communication technology, innovation of UAV-based networks are attracted architecture. Therefore, the civilian market benefits from many new UAV applications. To setup temporary communication relay link, UAVs can rapidly be deployed for the communication infrastructure destroyed area or temporary hotspot area [11]. The fixed wing UAVs can be implemented as a relay for these scenarios by achieving the higher payload capacity and longer endurance [12]. The authors in [13], [14] introduced methods to improve the performance of UAV-enabled relay, such as time allocation, path planning. Recently, to enhance the system performance of NOMA has been applied in UAV communication system [18]–[20]. For example, multi-antenna UAV together with multiple input multiple output (MIMO) NOMA is studied in [19] by exploring outage performance and the sum rate.

In [21], the authors considered to apply NOMA technique in uplink communication from a UAV to cellular base stations relying spectrum sharing paradigm. By exploiting the existing backhaul links among base stations, a cooperative NOMA system was studied to mitigate the UAV's uplink interference and to significantly compromising its achievable rate. In the considered system, before sending the decoded signals to their backhaul-connected bases stations, some base stations with better channel conditions are decided to decode the UAV's signals first. In [22], a device-to-device (D2D)-enhanced UAV-NOMA network system was explored. The main goal is D2D is introduced to increase the file dispatching efficiency. In such D2D-enhanced UAV-NOMA system, the ground users (GUEs) are permitted to reuse the time-frequency resources assigned to NOMA links. The authors in [23] proposed a subslot allocation and UAV trajectory planning. They found uplink maximal sum rate of IoT terminals by synergistically planning UAV trajectory and subslot duration. In [24], the optimization of transmit power of the UAV was studied to obtain the minimum achievable rate requirements in NOMA-UAV system.

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Motivated by recent work [21]-[24], this paper evaluates outage performance of two user in UAV-assisted NOMA system.

II. System Model

Consider a UAV-aided NOMA downlink system as Fig. 1. Numerous users can be operated in a circular area with radius r. In particular, a UAV (denoted as S) is required to send information to ground users User 1 (U_1) and User 2 (U_2) relying on the NOMA transmission principle.

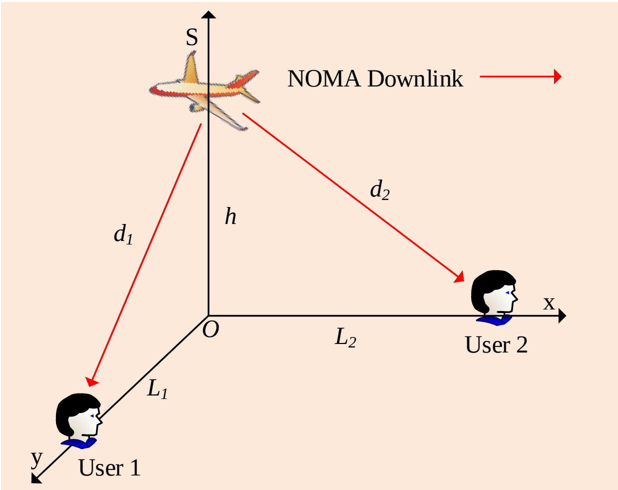

Fig. 1. System model of NOMA-assisted UAV network.

In this paper, we consider three-dimensional cartesian coordinates (x,y,z). First, the location of UAV(S) at (0,0,h). Then, we assume U1, U2 (User 1, User 2) are located at (0,L1,0) and (L2,0,0) respectively. Moreover, we can obtain the euclidean distance form S to U1 and U2 respectively as

$$d_i = \sqrt{h^2 + L_i^2} \tag{1}$$

We denote the channel between S and ground station Ui, ($i \in \{1,2\}$) as $h_i = g_i / \sqrt{d_i^\tau}, g_i \sim CN(\mu_i, 2\sigma^2)$ and τ is exponential pathloss factor. It is noted that the probability distribution function (PDF) of the unordered squared channel gain $|g_i|^2$ using non-central chi-square distribution with two degrees of freedom as

$$f_{|g_i|^2}(x) = \frac{(1+K_i)e^{-K_i}}{\Omega_i} e^{-\frac{(1+K_i)x}{\Omega_i}} I_0\left(2\sqrt{\frac{K_i(1+K_i)x}{\Omega_i}}\right) \tag{2}$$

where $I_0(x)$ is the zeroth-order modified Bessel function of the first kind and $K_i = \frac{|\mu_i|^2}{2\sigma^2}$ is the Rician factor. The corresponding cumulative distribution function (CDF) is formulated as

$$F_{|g_i|^2}(x) = 1 - Q\left(2\sqrt{K_i}, \sqrt{\frac{2(1+K_i)x}{\Omega_i}}\right) \tag{3}$$

where $Q(a,b)$ denotes the Marcum Q-function of first order [25].

In here, we consider the imperfect CSI especially as small scale fading between hovering UAVs and users is considered. The channel coefficients for the UAV to the user is shown as [26]

$$h_i = \hat{h}_i + \tilde{h}_i \tag{4}$$

where $\hat{h}_i$ is the estimated small-scale fading channel coefficient and $\tilde{h}_i$ is the channel estimated error with a complex Gaussian distribution that has zero-mean and variance $\tilde{\sigma}_i^2$.

Following the NOMA principle, the low channel gain user requires to be allocated more power i.e., $a_1 > a_2, a_1 + a_2 = 1$. Given the location of the channels are sorted e.g., $|h_2|^2 \ge |h_1|^2$. With the assumption that UAV has access to the flight control and location data, the order of the distances d_1 and d_2 can be known at S. The received signal at each ground user can be expressed by

$$\begin{aligned} y_i &= \left(\hat{h}_i + \tilde{h}_i\right)\sum_{i=1}^{2}\sqrt{a_i P_S}x_i + n_i \\ &= \hat{h}_i\sum_{i=1}^{2}\sqrt{a_i P_S}x_i + \underbrace{\tilde{h}_i\sum_{i=1}^{2}\sqrt{a_i P_S}x_i + n_i}_{\text{effective noise}} \end{aligned} \tag{5}$$

where P_S is the transmit power at S. Then, it can be expressed SNR at user U_1 to detect signal x_1 as

$$\gamma_{U_1 \to x_1} = \frac{a_1 \rho_S |\hat{h}_1|^2}{a_2 \rho_S |\hat{h}_1|^2 + \rho_S \tilde{\sigma}_1^2 + 1} \tag{6}$$

where $\rho_S = \frac{P_S}{\sigma^2}$ is transmit SNR at the source S. Similarly, SNR at user U_2 is given by

$$\gamma_{U_2 \to x_1} = \frac{a_1 \rho_S |\hat{h}_2|^2}{a_2 \rho_S |\hat{h}_2|^2 + \rho_S \tilde{\sigma}_2^2 + 1} \tag{7}$$

Using SIC, SNR is computed at user U_2 as

$$\gamma_{U_2 \to x_2} = \frac{a_2 \rho_S |\hat{h}_2|^2}{\rho_S \tilde{\sigma}_2^2 + 1} \tag{8}$$

III. Outage Probability Analysis

First, the achievable data rates at U_1 and U_2 with NOMA can be expressed respectively as

$$T_1 = \log\left(1 + \min\left(\gamma_{U_1 \to x_1}, \gamma_{U_2 \to x_1}\right)\right) \tag{9}$$

$$T_2 = \log\left(1 + \gamma_{U_2 \to x_2}\right) \tag{10}$$

For target rate R_i the outage probability (OP) at U1 can be computed by

$$OP_{x_1} = 1 - \Pr\left(\gamma_{U_1 \to x_1} > \gamma_1\right)\Pr\left(\gamma_{U_2 \to x_1} > \gamma_1\right) \quad (11)$$

where $\gamma_i = 2^{R_i} - 1$ is the threshold SNR. Then, the first term of outage probability of U_1 is expressed by

$$\Pr\left(\gamma_{U_1 \to x_1}^{NM} < \gamma_1\right) \triangleq \Xi_1 = 1 - \Pr\left(|g_1|^2 > \frac{d_1^\tau \gamma_1\left(\rho_S \tilde{\sigma}_1^2 + 1\right)}{\left(a_1 - \gamma_1 a_2\right)\rho_S}\right) \quad (12)$$

With the help (2) and [Eq. 8.447.1, 27] we have

$$\Xi_1 = 1 - \frac{(1+K_1)e^{-K_1}}{\Omega_1 (k_1!)^2} \sum_{k_1=0}^{\infty} \left(\frac{K_1(1+K_1)x}{\Omega_1}\right)^{k_1} \times \int_{\frac{d_1^\tau \gamma_1\left(\rho_S \tilde{\sigma}_1^2+1\right)}{(a_1-\gamma_1 a_2)\rho_S}}^{\infty} x^{k_1} e^{-\frac{(1+K_1)x}{\Omega_1}} dx \quad (13)$$

Based on [Eq. 3.351.2, 27], Ξ_1 can be obtained as

$$\Xi_1 = 1 - \sum_{k_1=0}^{\infty} \sum_{n_1=0}^{k_1} \frac{e^{-K_1} K_1^{k_1}}{k_1! n_1!} e^{-\frac{d_1^\tau \gamma_1\left(\rho_S \tilde{\sigma}_1^2+1\right)(1+K_1)}{(a_1-\gamma_1 a_2)\Omega_1 \rho_S}} \times \left(\frac{d_1^\tau \gamma_1\left(\rho_S \tilde{\sigma}_1^2+1\right)(1+K_1)}{(a_1-\gamma_1 a_2)\Omega_1 \rho_S}\right)^{n_1} \quad (14)$$

Similarly, the second term of (14) $\Pr\left(\gamma_{U_2 \to x_1} > \gamma_1\right) \triangleq \Xi_2$ is expressed as

$$\Xi_2 = 1 - \sum_{k_2=0}^{\infty} \sum_{n_2=0}^{k_2} \frac{e^{-K_2} K_2^{k_2}}{k_2! n_2!} e^{-\frac{d_2^\tau \gamma_1\left(\rho_S \tilde{\sigma}_2^2+1\right)(1+K_2)}{(a_1-\gamma_1 a_2)\Omega_2 \rho_S}} \times \left(\frac{d_2^\tau \gamma_1\left(\rho_S \tilde{\sigma}_2^2+1\right)(1+K_2)}{(a_1-\gamma_1 a_2)\Omega_2 \rho_S}\right)^{n_2} \quad (15)$$

Hence, $OP_{x_1}^{NM}$ is obtained by putting (17) and (18) into (14)

$$OP_{x_1}^{NM} = \begin{cases} 1 - \Xi_1 \times \Xi_2, & \text{if:} \gamma_1 > \frac{a_1}{a_2} \\ 1, & \text{otherwises} \end{cases} \quad (16)$$

The outage probability at U_2 can be written as

$$\begin{aligned} OP_{x_2}^{NM} &= 1 - \Pr\left(\gamma_{U_2 \to x_2} > \gamma_2\right) \\ &= 1 - \Pr\left(|\hat{g}_2|^2 > \frac{\gamma_2 d_2^\tau \left(\rho_S \tilde{\sigma}_2^2 + 1\right)}{a_2 \rho_S}\right) \end{aligned} \quad (17)$$

Similarly, we can obtain as

$$OP_{x_2}^{NM} = 1 - \sum_{k_2=0}^{\infty} \sum_{n_2=0}^{k_2} \frac{e^{-K_2} K_2^{k_2}}{k_2! n_2!} e^{-\frac{d_2^\tau \gamma_2\left(\rho_S \tilde{\sigma}_2^2+1\right)(1+K_2)}{a_2 \Omega_2 \rho_S}} \times \left(\frac{d_2^\tau \gamma_2\left(\rho_S \tilde{\sigma}_2^2+1\right)(1+K_2)}{a_2 \Omega_2 \rho_S}\right)^{n_2} \quad (18)$$

IV. Numerical Results

For numerical analysis, we set the system parameters as $\tilde{\sigma}^2 = \tilde{\sigma}_1^2 = \tilde{\sigma}_2^2 = 0.05$, $\Omega_1 = \Omega_2 = 1$, $K = K_1 = K_2 = 10$, $R_1 = R_2 = 1$, $L_1 = 2$, $L_2 = 1$, the path loss factor $\tau = 2$ and the normalized distances as $h = 1$

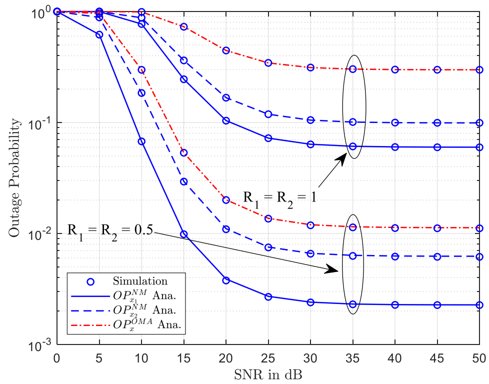

Fig. 2. Outage probability of U_1 and U_2 for different $R_1=R_2$ and compare NOMA, OMA.

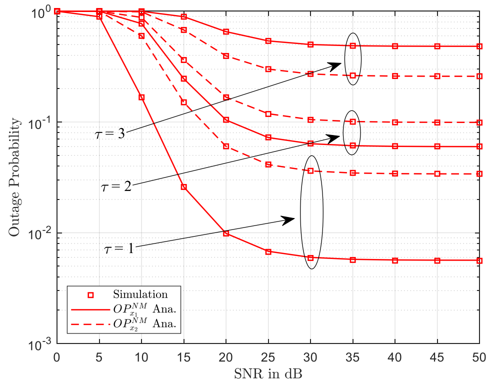

Fig. 3. Outage probability of U_1 and U_2 in NOMA for different τ .

In Fig. 2, outage performance of two users versus transmit SNR at UAV can be seen. The outage probability reduces significantly at high SNR regime. It is meaningful as analytical and simulation results are matched very tightly. In addition, outage performance would be better at lower target rates required. The User 1's outage probability exhibits better performance compared with another user. Especially, two NOMA users provide their superiority in term of outage probability compared with traditional OMA scheme.

We can see clearly the impact of pathloss factor on outage performance of two users in Fig. 3. It is worth noting that the outage probability keeps unchanged as SNR at the UAV is greater than 35 dB. There is the existence of performance gap among two users. It can be explained that different allocation power factors for two users lead to different SINR, and then there is difference in their outage probabilities.

Similarly Fig. 3, Fig. 4 plots outage performance of two users with varying level of noise terms. The reason is that, SINR will be changed under impact of parameter therein. It is worth noting that outage probability depends mainly on SINR, but in this figure noise term still contributes to the outage performance significantly.

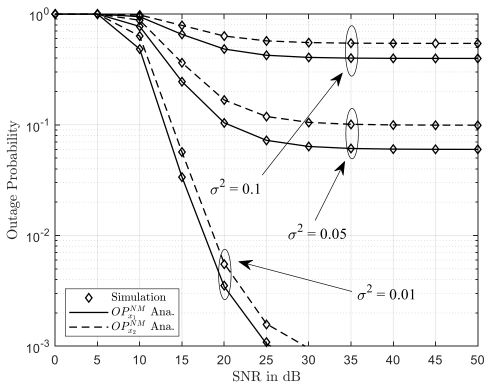

Fig. 4. Outage probability of U_1 and U_2 in NOMA for different σ^2.

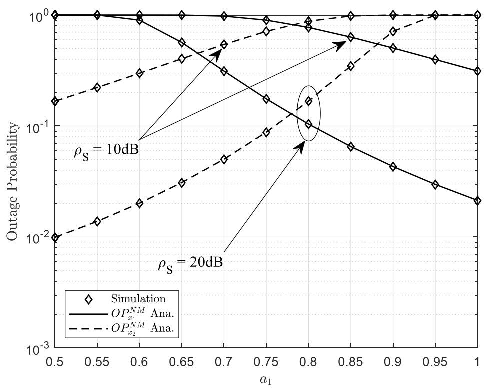

Fig. 5. Outage probability of U_1 and U_2 in NOMA varying a_1 for different ρ_S.

Fig. 5 plots the trends of outage probabilities of two users versus power allocation factor a_1. It can be explained that as increasing a_1 SINR in (6) will increase, then the outage probability would be better. It is noted higher a_1 results in lower a_2 and hence SINR in (8) changes. Therefore, outage performance of two users exhibit two different trends. It is noted that the transmit SNR at source always plays an important role to guarantee outage performance, regardless of any value of power allocation factor.

V. Conclusion

This paper investigated a UAV-enabled NOMA downlink wireless system to indicate different performance of two ground users. It is shown that in the center of a macro-cell the UAV flies in a circular trajectory with fixed height to provide ubiquitous coverage to the NOMA users which are located outside servicing area of the base station . The outage probability expressions are computed for both ground users under NOMA using model of Rician air-to-ground channels. Based on the OP expressions at high SNR, it is confirmed performance of considered system is better at high SNR. We observed that system performance can be controlled by varying other parameters such as placement of UAV and channel gain error.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A.-T. Le developed and performed analytical computations and then he coded to verify the computations. D.-T. Do, Le Cong Hieu provided ideas, developed mathematical formulation and wrote the paper. All authors had approved the final version.

References

[1] D. T. Do, A. T. Le, and B. M. Lee, "NOMA in cooperative underlay cognitive radio networks under imperfect SIC," *IEEE Access*, vol. 8, pp. 86180-86195, 2020.

[2] H. P. Dang, M. V. Nguyen, D. T. Do, H. L. Pham, B. Selim, and G. Kaddoum, "Joint relay selection, full-duplex and device-to-device transmission in wireless powered NOMA networks," *IEEE Access*, vol. 8, pp. 82442-82460, 2020.

[3] D. T. Do, C. B. Le, and A. T. Le, "Cooperative underlay cognitive radio assisted NOMA: Secondary network improvement and outage performance," *Telkomnika*, vol. 17, no. 5, pp. 2147-2154, 2019.

[4] D. T. Do and A. T. Le, "NOMA based cognitive relaying: Transceiver hardware impairments, relay selection policies and outage performance comparison," *Computer Communications*, vol. 146, pp. 144-154, 2019.

[5] C. Li, Q. Wang, H. Peng, H. Zhang, D. T. Do, K. M. Rabie, R. Kharel, and C. C. Cavalcante, "A unified framework for HS-UAV NOMA network: Performance analysis and location optimization" *IEEE Access*, vol. 8, pp. 13329-13340, 2020.

[6] D. T. Do and T. T. T. Nguyen, "Exact outage performance analysis of amplify-and forward-aware cooperative NOMA," *Telkomnika*, vol. 16, no. 5, pp. 1966-1973, 2018.

[7] D. T. Do and C. B. Le, "Exploiting outage performance of wireless powered NOMA," *Telkomnika*, vol. 16, no. 5, pp. 1907-1917, 2018.

[8] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, "Non-Orthogonal Multiple Access (NOMA) for cellular future radio access," in *Proc. IEEE 77th Vehicular Technology Conference (VTC Spring)*, Dresden, pp. 1-5, 2013.

[9] K. M. Rabie, B. Adebisi, E. H. Yousif, H. Gacanin, and A. M. Tonello, "A comparison between orthogonal and non-orthogonal multiple access in cooperative relaying power line communication systems," *IEEE Access*, vol. 5, pp. 10118–10129, 2017.

[10] K. M. Rabie, B. Adebisi, A. M. Tonello, S. Yarkan, and M. Ijaz, "Two-stage non-orthogonal multiple access over power line communication channels," *IEEE Access*, vol. 6, pp. 17368–17376, 2018.

[11] F. Ono, H. Ochiai, and R. Miura, "A wireless relay network based on unmanned aircraft system with rate optimization," *IEEE Trans. Wireless Commun.*, vol. 15, no. 11, pp. 7699-7708, Nov. 2016.
[12] Y. Zeng and R. Zhang, "Energy-efficient UAV communication with trajectory optimization," *IEEE Trans. Wireless Commun.*, vol. 16, no. 6, pp. 3747–3760, Jun. 2017.
[13] P. Zhan, K. Yu, and A. L. Swindlehurst, "Wireless relay communications with unmanned aerial vehicles: Performance and optimization," *IEEE Trans. on Aerosp. and Electron. Syst.*, vol. 47, no. 3, pp. 2068–2085, Jul. 2011.
[14] B. Pearre and T. X. Brown, "Model-free trajectory optimization for wireless data ferries among multiple sources," in *Proc. IEEE Global. Commun. Conf. (GLOBECOM)*, Miami, FL, USA, Dec. 2010, pp. 1793–1798.
[15] Z. Xiao, P. Xia, and X. G. Xia, "Enabling UAV cellular with millimeterwave communication: Potentials and approaches," *IEEE Commun. Mag.*, vol. 54, no. 5, pp. 66–73, May 2016.
[16] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, "Unmanned aerial vehicle with underlaid device-to-device communications: Performance and tradeoffs," *IEEE Trans. on Wireless Commun.*, vol. 15, no. 6, pp. 3949–3963, Feb. 2016.
[17] V. Sharma, M. Bennis, and R. Kumar, "UAV-assisted heterogeneous networks for capacity enhancement," *IEEE Commun. Lett.*, vol. 20, no. 6, pp. 1207–1210, Apr. 2016.
[18] M. F. Sohail, C. Y. Leow, and S. Won, "Non-orthogonal multiple access for unmanned aerial vehicle assisted communication," *IEEE Access*, vol. 6, pp. 22 716–22 727, Apr. 2018.
[19] T. Hou, Y. Liu, Z. Song, X. Sun, and Y. Chen, "Multiple antenna aided NOMA in UAV networks: A stochastic geometry approach," *IEEE Trans. on Commun.*, vol. 67, no. 2, pp. 1031-1044, Feb. 2019.
[20] P. K. Sharma and D. I. Kim, "UAV-enabled downlink wireless system with non-orthogonal multiple access," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Dec. 2017, pp. 1–6.
[21] W. Mei and R. Zhang, "Uplink cooperative NOMA for cellular-connected UAV," *IEEE Journal of Selected Topics in Signal Processing*, vol. 13, no. 3, pp. 644-656, June 2019.
[22] B. Wang, *et al*., "Graph-Based file dispatching protocol with D2D-Enhanced UAV-NOMA communications in large-scale networks," *IEEE Internet of Things Journal*, vol. 7, no. 9, pp. 8615-8630, Sept. 2020.
[23] Z. Na, Y. Liu, J. Shi, C. Liu, and Z. Gao, "UAV-supported clustered NOMA for 6G-enabled internet of things: Trajectory planning and resource allocation," *IEEE Internet of Things Journal*, 2020.
[24] D. Hu, Q. Zhang, Q. Li and J. Qin, "Joint position, decoding order, and power allocation optimization in UAV-Based NOMA downlink communications," *IEEE Systems Journal*, vol. 14, no. 2, pp. 2949-2960, June 2020.
[25] M. K. Simon and M. S. Alouini, *Digital Communication over Fading Channels*, 2nd ed. New York: Wiley, 2005.
[26] H. Zhang, J. Zhang, and K. Long, "Energy efficiency optimization for NOMA UAV network with imperfect CSI," *IEEE Journal on Selected Areas in Commu.*
[27] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*, Academic Press, 2014.

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