

Performance Evaluation of UAV-based NOMA for 5G and Beyond

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Abstract— The use of Unmanned Aerial Vehicles (UAVs) as flying Base Stations (BSs) is an efficient way to enhance wireless communication throughput and coverage, especially in Line-of-Sight (LoS) networks. Both military and civilian applications have shown interest in studying communication aided by UAVs. Utilizing UAVs as BSs to expand the range of current cellular networks is widely discussed, and Non-Orthogonal Multiple Access (NOMA) is a potential approach for UAV communications. This paper investigates the use of NOMA for upcoming 5G radio access and beyond, focusing on a multiuser communication system in which a UAV-BS with a single antenna communicates with ground users via NOMA. Simulation results show that NOMA outperforms Orthogonal Multiple Access (OMA) in terms of rates, Energy Efficiency (EE), Spectral Efficiency (SE), and Signal to Noise Ratio (SNR). The main objective is to develop a MATLAB platform for NOMA-related systems at the system-level analysis. NOMA's SE performance is significantly higher than other potential 6G options. The paper provides a NOMA system for two or more users, and the system-level analyses include scenarios with three cells, seven cells, and 19 cells.

Keywords—6G, EE, NOMA, OMA, UAV, SE, SNR.

I. INTRODUCTION

UAVs have an inclusive range of uses in the civilian and commercial sectors in addition to carrying out combat operations, including cargo delivery, traffic control, aerial imaging, and other tasks. UAVs are now used in communication systems for wireless broadcasting, data collection, and relaying. Due to their flexibility and mobility, UAVs are used as aerial BSs which can offer ubiquity coverage and meet customers' diverse requirements. UAVs can be deployed more flexibly than standard terrestrial communication devices, which are often fixed once deployed.

The use of UAVs and advanced communication technologies have garnered much interest from academic and business circles. In the past few years, the application of UAVs in civil and military sectors, such as cargo delivery, search and rescue, and precision agriculture, has rapidly increased. Moreover, the use of UAVs for communication purposes is expected to provide faster deployment options, increased mobility, and reliable line-of-sight connections in comparison to traditional ground-based communication methods. Therefore, UAVs are poised to play a significant role in the forthcoming communication networks.

However, due to the increasing density of equipment and frequency reuse, the amount of resources available for UAVs is diminishing rapidly. To address this issue, NOMA has been recognized as a promising technique that allows UAVs to reuse the spectrum assigned to terrestrial BSs or users. By implementing Successive Interference Cancellation (SIC) at

receivers and Superposition Coding (SC) at transmitters, NOMA can enhance network performance, support more users, and improve SE, EE, and SNR. Several studies have explored the integration of NOMA into UAV communication systems. This paper focuses on a new NOMA-based framework for UAV networks and investigates uplink NOMA transmission in UAV communication networks that are connected to cellular networks.

This paper explores a method for improving spectrum utilization by using a UAV system with NOMA technology to connect two ground users. The challenges faced by wireless networks operating on 5G and beyond 5G (B5G) are significant, with high SE requirements and connection rates causing damage to BSs and making reliable service provision difficult, particularly in disaster zones where IoT devices are located. UAVs offer flexibility and mobility to quickly provide wireless coverage in such areas, and NOMA is a strong contender for enhancing SE and enabling IoT device connection by sharing physical resources such as time, frequency, and code among multiple users, in contrast to the traditional OMA method.

An emergency communications system for a NOMA-UAV network is established in this paper. During exceptional events, such as natural disasters, clogged roadways, concerts, athletic events, war situations, etc., UAVs can serve as flying BSs to supplement traditional communication networks and manage traffic. By acting as temporary hotspots, UAVs can establish links between a safe location and areas affected by the tragedy. UAV-BSs will provide LoS air-to-ground connectivity to ground users, enabling various wireless communications. Researchers have recently shown significant interest in UAV-enabled communication, and numerous studies have been conducted on the subject.

The optimal choice for UAV communication is a UAV with a single antenna due to the poor transmission reliability of downlink communication with UAVs. However, a single UAV cannot offer the same transmission bandwidth to multiple users concurrently. Typically, each user is assigned their own bandwidth channel, and the available rate substantially depends on the number of users sharing the bandwidth. By splitting users in the power domain, NOMA can effectively serve numerous clients with non-orthogonal resources simultaneously. NOMA can enhance the obtainable rate for remote users by enabling close users to receive the information intended for faraway users who face weaker received signals.

II. SYSTEM MODEL

Let us assume that a single-antenna UAV, like the one shown in Fig. 1, is used to provide coverage for a certain outdoor venue (such as a stadium, traffic jam, concert, etc.). Assuming there are M ground users in the area $m \in \{1, \dots, M/2\}$, we will refer to those as "near users" or "cell-centered users" because they are situated closer to the UAV (in terms of Euclidean distance) than the other users. The remaining $M/2$ users $m \in \{M/2+1, \dots, M\}$ are known as "far users" or "cell-edge users" since they are situated comparatively further away from one another. Each close user can be paired with a far user by the UAV using NOMA.

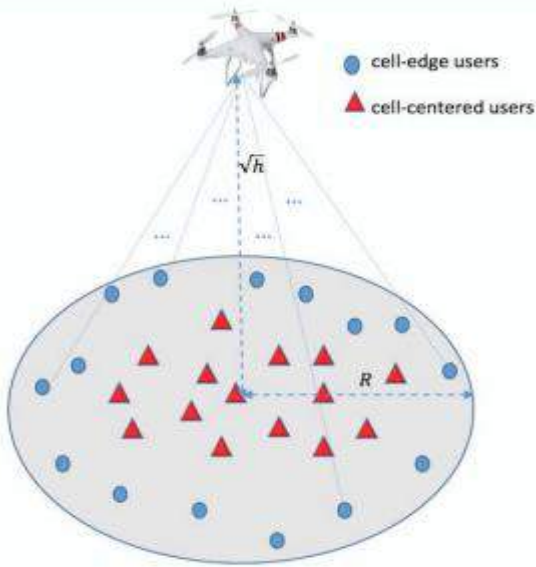


Fig. 1. UAV-NOMA system

We propose a system with a UAV that can speak to two NOMA users, U1 and U2, through the system. Such a UAV maintains a circular trajectory with a constant velocity U_v , a circular trajectory of radius U_r , and an altitude U_h while flying. The location of the UAV is represented as, $UAV(U_r \cos \phi, U_r \sin \phi, U_h)$ where ϕ is the angle of the UAV position in the UAV circle. As a result, the following equation can be used to determine the Euclidean distance between users U1 and U2 and the UAV.

$$\overline{U_{d1}} = \sqrt{U_h^2 + U_r^2 + U_L^2 - 2U_r U_L \cos \phi} \quad (1)$$

$$\overline{U_{d2}} = \sqrt{U_h^2 + U_r^2 + U_L^2 + 2U_r U_L \cos \phi} \quad (2)$$

Finally, $P_{LOS}(\theta_m)$ and $P_{NLOS}(\theta_m) = 1 - P_{LOS}(\theta_m)$ denote the probability of LOS and NLOS respectively. These final two numbers are derived using the formula below.

$$P_{LOS}(\theta_m) = \frac{1}{1 + pe^{-q(\theta_m - p)}}, m \in \{1, 2\} \quad (3)$$

Where $\theta_m = \arcsin\left(\frac{H}{d_m}\right)$ is elevation angle of the UAV with respect to each user, and p and q are constant values based on the surroundings. Denote $U_{u,m}$ as the serving indicator. $U_{u,m} = 1$ indicates that the UAV 'u' is serving the user 'm', $U_{u,m} = 0$ if otherwise. So, here is the transmitting signal from UAV 'u' to user 'm' can be expressed as,

$$i^u(t) = \sum_{m=1}^M U_{u,m}(t) \sqrt{P_m^u(t)} i_m^u(t) \quad (4)$$

Where $i_m^u(t)$ is the transmitting signal of UAV 'u', $P_m^u(t)$ represents the assigned power of user 'm', may be used to express the superposition. Equation (4) has the result that the signals received at the user 'm' are

$$z_m^u(t) = g_m^u(t) i^u(t) + I_{inter,m}^u(t) + I_{intra,m}^u(t) + \sigma_m^u(t) \quad (5)$$

Where $\sigma_m^u(t)$ denotes the AWGN, $I_{intra,m}^u(t)$ denotes the intra-cluster interference, and $I_{inter,m}^u(t)$ denotes the cumulative inter-cluster interference to user 'm' from all other UAVs other than UAV 'u'.

The composition of $I_{inter,m}^u(t)$ can be expressed as

$$I_{inter,m}^u(t) = \sum_{r=1, r \neq u}^U g_m^r(t) \sqrt{P^r(t)} i^r(t) \quad (6)$$

Where $P^r(t)$ represents the total power consumed by the UAV $r \neq u$, which is represented by,

$$P^r(t) = \sum_{m=1}^M U_{u,m}(t) P_m^r(t) \quad (7)$$

and $P^r(t)$ denotes channel gain between the UAV and user 'm'.

In order to eliminate some of the intra-cell interference at the receiver side, the NOMA protocol employs SIC. Successfully identifying interference depends on identifying the optimal decoding sequence for SIC. Since the channel gain and inter-cell interference of each user may fluctuate due to movement, a dynamic decoding order must be utilized. To this end, the auxiliary term $A_m^u(t)$ specified in equation (8) functions as a decoding order criterion and represents the comparable channel gain.

$$A_m^u(t) = \frac{U_{u,m}(t) g_m^u(t)}{\sum_{r=1, r \neq u}^U g_m^r(t) P^r(t) + \sigma_m^u(t)^2} \quad (8)$$

The user's data rate when linked to a UAV u can be computed using the formula

$$\mathcal{R}_{\pi(m)}^u(t) = B \log_2 \left(1 + \gamma_{\pi(m)}^u(t) \right) \quad (9)$$

where B is the UAV's bandwidth. As a result, the sum data rate at time 't' can be determined as

$$\mathcal{R}(t) = \sum_{u=1}^U \sum_{m=1}^M \mathcal{R}_{\pi(m)}^u(t) \quad (10)$$

As a result, the throughput is

$$\mathcal{R} = \sum_{t=0}^T \mathcal{R}(t) \quad (11)$$

III. SIMULATION RESULTS

The study revealed a significant problem faced by users in multi-cell applications. Our models featuring 3, 7, and 19 cells discovered interference from the cells in the first or second tier with the core cell. Inter-cell interference was calculated using a distance-based method, where the interference was a function of the distance between the cell centre BS and the nearby BS. To assess system-level NOMA simulator capabilities, we examined three scenarios with randomly distributed users within each cell: the 3-cell, 7-cell, and 19-cell scenarios. Each cell's interference model was considered, incorporating the link performance model. For

example, Fig. 2(a) illustrates the boundary shared by three cells, where the core cell is surrounded by two cells. In this situation, the interference caused by a user's two neighbouring cells is considered in the link performance model. Figure 2(b) shows a boundary shared by seven cells, and the link performance model accounts for the interference caused by a user's six neighbouring cells. Finally, Fig. 2(c) displays a scenario with 19 cells sharing a border, and the link measurement model determines intercell interference, SNR, and user capacity based on the interference caused by each of the cell's 18 adjacent cells on its users.

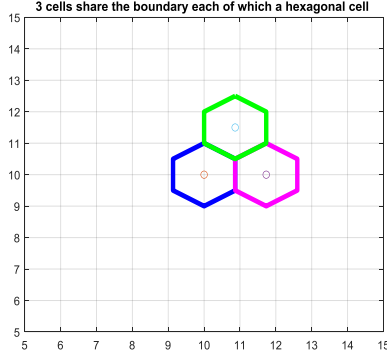


Fig. 2. (a) Three-Cell Scenario

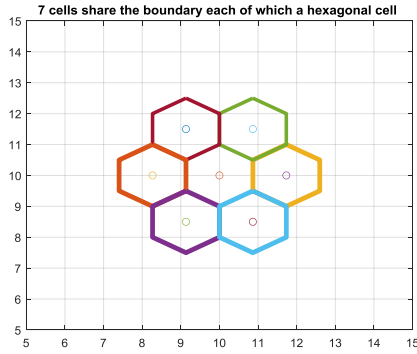


Fig. 2. (b) Seven-Cell Scenario

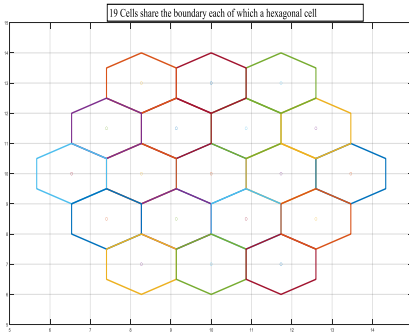


Fig. 2. (c) Nineteen-Cell Scenario

In this paper, a comparison is made between user 1 and user 2 rates at different heights of UAVs (100, 150, and 250 meters) in three environments - rural, urban, and suburban as shown in Figure 3-8. The performance of NOMA and OMA is assessed on the basis of SE and EE graphs at various UAV heights and in different scenarios. Fig. 3 illustrates the bit rates of users 1 and 2 in rural areas considering all UAV heights, indicating that NOMA performs better than OMA in

all scenarios. Similarly, Figure 4 shows the SE versus EE performance in rural areas, again confirming the superiority of NOMA over OMA. The comparison between user 1 and user 2 rates in bits per second is shown in Figure 5 for the suburban area, while Figure 6 plots the SE versus EE for the same area, resulting in the same conclusion of NOMA outperforming OMA. In the urban area, Figures 7 and 8 show that NOMA is consistently better than OMA in terms of user rates and SE versus EE performance.

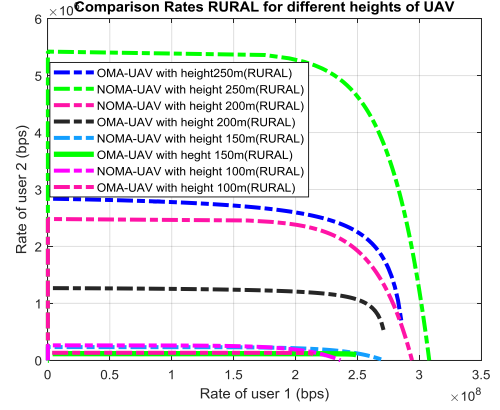


Fig. 3. Rate comparison of Rural area for different heights of UAV

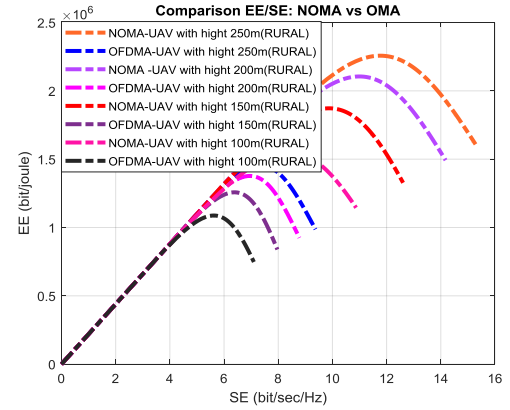


Fig. 4. Comparison of SE vs EE in a rural area for different heights of UAV

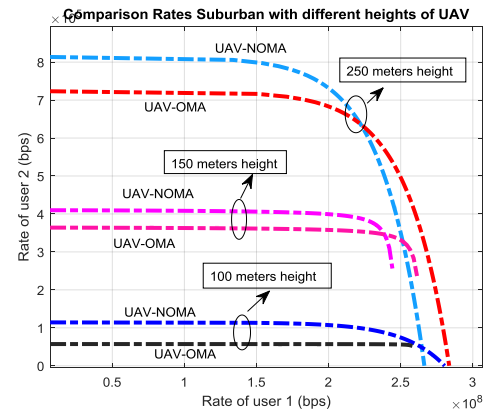


Fig. 5. Rate comparison of Sub-Urban area for different heights of UAV

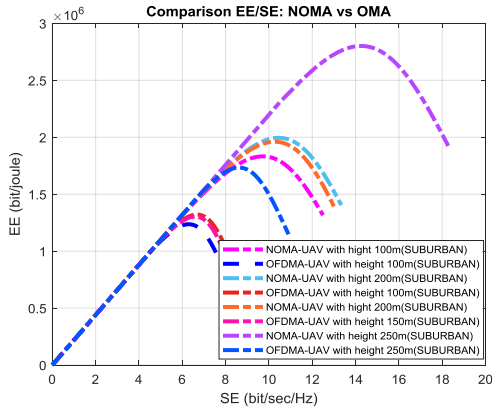


Fig. 6. Comparison of SE vs EE in Sub-Urban area for different heights of UAV

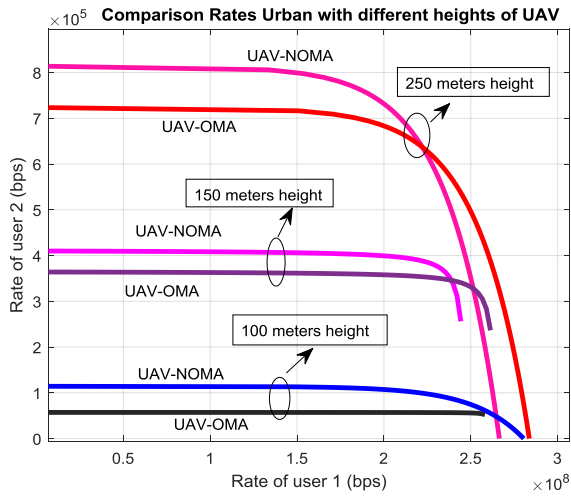


Fig. 7. Rate comparison of Urban area for different heights of UAV

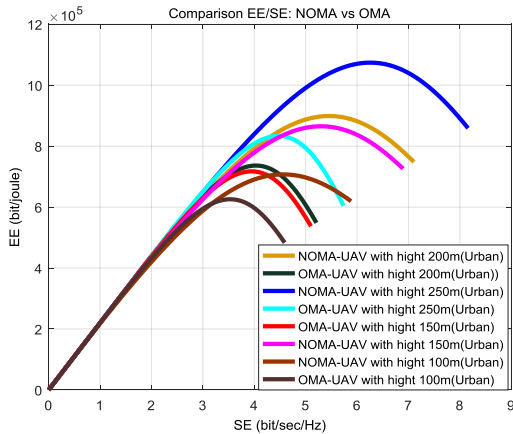


Fig. 8. Comparison of SE vs EE in Urban area for 250m UAV height

IV. CONCLUSION

This paper provided a thorough comparative analysis of altitude-fixed UAV-NOMA and UAV-OMA systems in terms of their performance and efficiency. MATLAB is used to evaluate the performance for both systems UAV-OMA and UAV-NOMA and conducted a comprehensive examination of various scenarios, including 3-cell, 7-cell, and 19-cell setups. One significant contribution of the paper was the inclusion of multi-user scenarios, which extended

beyond the typical analysis limited to two users in NOMA-related publications. By considering more than two users in a cell, the paper provided insights into the practical implications and performance of NOMA in real-world scenarios. Furthermore, the paper addressed the impact of inter-cell interference in multi-cell scenarios. This aspect is crucial for assessing the scalability and performance of UAV-NOMA and UAV-OMA systems, as interference between neighboring cells can have a significant impact on system-level analysis. Overall, the paper's findings contribute to the understanding of SE and EE UAV-NOMA and UAV-OMA systems, shedding light on their performance, efficiency, and practical implications. The thorough examination of different scenarios and considerations, such as multi-user setups and inter-cell interference, enhances the applicability and relevance of the study in real-world deployments.

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