UAV-enabled communications using NOMA for 5G and beyond: research challenges and opportunities

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ABSTRACT

Future wireless networks are expected to provide ubiquitous connectivity to a wide range of devices with varying traffic patterns, wherever and whenever it is required. Unmanned aerial vehicles (UAVs) are also considered a potential technique for accommodating massive connections and providing seamless coverage. They can be used as flying base stations (BSs) to take advantage of line-of-sight (LoS) connections and effectively support wireless communication coverage and throughput for 5G and beyond. However, the use of highly mobile and energy-constrained UAVs for wireless communications brings plenty of new challenges. 5G wireless networks require non-orthogonal multiple access (NOMA) to be able to meet heterogeneous requirements for low latency, high dependability, massive connection, better fairness, and high throughput. This paper presents an overview of NOMA-based UAV enabled communications by introducing the background of UAV communication and NOMA schemes. Power allocation schemes are also explored as they are critical controlling mechanisms for performance optimization of NOMA-UAV systems. We also categorize UAV-enabled communication applications for usage in both routine professional settings and emergency scenarios. Finally, we address several open research questions that need to be solved for NOMA, as well as new opportunities and future research trends to be exploited.

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1. INTRODUCTION

Wireless networks are dependable technologies that make communication in daily life simple. The computer systems and mobile nodes can be connected using this technology without the need for any established infrastructure. With promised services available anywhere, anytime, and with this digital revolution, computers and communication have undergone fundamental transformations [1]. Nowadays, unmanned aerial vehicle (UAVs) or drones have been widely accepted as disruptive technology which can serve multitude of civil operations such as smart farming, delivery service, and surveillance. In fact, UAV can be used to provide communication access to ground users where communication is not possible at certain places due to natural disasters or non-availability of communication towers. Tang *et al.* [2] mentions that coverage blind zones are an inevitable result of the absence of communication infrastructure in the ocean. Even building several terrestrial base stations (TBSs) alongside the coast is not enough in order to keep the enormous ocean connected. The density of 5G wireless network base stations (BSs) is significantly higher than that of 3G and 4G due to the utilization of the high frequency band and the widespread application of heterogeneous network architecture. As a result, most of the expense of building a 5G wireless network is related to base station installation. In order to lower the cost of network development and implement 5G technology effectively, wireless network operators must figure out how to reduce the number of BSs while maintaining the quality of network service [3]. This is why UAV-enabled communication networks are becoming an emerging paradigm in beyond 5G (B5G) wireless networks that can handle high transmission rates, enable ubiquitous access to a wide set of end-users, and allow for wireless broadcasting [4]–[6]. In this scenario, a UAV might serve as a flying BSs, a relay in flying ad-hoc networks, or even as user equipment (UE) [7].

The UAV complements the ground BSs and serves some users in combination with the ground BSs. The fundamental idea behind this deployment is to send a wireless network supply where demand is in space and time, acting as a supplement to the terrestrial communication network [8]. The UAV will create interference to users served by the ground BSs and vice versa in any multi-cell network. However, with the additional degrees of freedom that a flying BSs provides, that are not available in regular TBSs, the problem can be solved. Designing the height and positioning of the UAV BSs, as well as the high likelihood of LoS linkages between the UAV and the served users, are among them [4].

UAV-enabled communication system provides a unique opportunity of boosting resilience against faults, natural disasters, and unexpected traffic demand in a timely fashion. The inherited ease of deployment and robustness to changing communication scenario due to its ability to manoeuvre in 3D space, makes UAV ideal to provide temporary hotspot for mass event [9] and to provide emergency coverage for disaster-stricken areas with malfunctioned BSs [10]. The incorporation of UAV hotspot to reap all the captivating benefits for 5G and B5G wireless communication networks needs thoughtful deliberation over the many challenges diminishing this synergy. The challenges encompass the aspects of real-world experimentation, multiple access, energy management and channel modelling. Existing results on UAV hotspots mainly focus on modelling, simulation and algorithm development, where real-world experimentation has not been considered [4]. The next generation of UAV networks is committed to increasing capacity and data rates so that the UAV can support numerous ground users at once. Nevertheless, served users must share a particular amount of bandwidth in order to be served by the same UAV simultaneously in each region, and traditional access techniques like time division multiple access (TDMA) and orthogonal frequency division multiple access (OFDMA) are insufficient for this. So, another access strategy, such as non-orthogonal multiple access (NOMA), which effectively increases the capacity of communication systems, can make the limited spectrum resources sufficient for additional users [11].

Existing studies have considered the use of orthogonal multiple access (OMA), which is spectrally inefficient because dedicated bandwidth resources have to be allocated to each user and the number of simultaneous connections is limited [9], [10]. Users inside a particular coverage area need to share a certain communication bandwidth in order to be serviced by the same UAV simultaneously in the coverage area, and OMA is insufficient for this purpose [12]. Liu *et al.* [13], randomly deployed mobile users in a NOMA UAV wireless network. The results show that the suggested approach performs better than a UAV that is deployed at random or an OMA that is used with varied ground user locations. As a result, NOMA can provide a significant improvement in both spectrum efficiency and user fairness when compared to traditional OMA [14]. The main concept of NOMA is to permit several users to simultaneously access a channel resource block, which is explicitly forbidden in traditional OMA [15]. All these issues motivate the authors to develop innovative NOMA-based UAV communication schemes for temporary hotspots and emergency coverage use cases.

Although previous studies have provided insight into numerous viewpoints for UAV communication networks, it is worthwhile to reflect on present successes to shed light on future 5G/B5G research trends. As a result, providing an overview of the emerging studies linked to the integration of 5G technologies with UAV communication networks is extremely important and necessary. We want to critically evaluate NOMA technique in UAV as well as a list of open research issues in this paper. Next, we give an in-depth look at the most recent research on UAV communications using NOMA integration with various 5G technologies: i) related works of the NOMA and UAV, ii) power allocation for NOMA-UAV, and iii) the application of UAV-enabled communications. Finally, based on recent advancements, we identified possible future trends for UAV communications.

The rest of this paper is organized as follows. In section 2, we overview the background of related topics, namely UAV communication, NOMA, NOMA-UAV, and power allocation schemes. In section 3, the applications of UAV-enabled communications are briefly described. Finally, in section 4, we outline several challenges and opportunities that will be addressed in future studies, followed by the conclusion in section 5.

2. RELATED WORKS
2.1. UAV communication

UAV capabilities in relaying information in critical situations are deemed vital for the general public. UAVs can help regular communication networks by functioning as flying (UAV-BSs) and managing traffic demand in unusual scenarios, such as sporting events, concerts, natural disasters, war crises, and traffic congestion [8], [16]–[20]. UAVs can potentially serve as temporary hotspots or relay nodes for establishing connectivity between safe zones and catastrophe zones [21]–[23]. LoS air-to-ground communication is expected for ground users served by the UAV-BSs. Consequently, UAV-enabled communication can effectively support wireless communications coverage and throughput [24], [25]. It is believed that UAV networks generally have the following properties:

2.1.1. Path loss

A simplified model has been adopted to assume that the LoS communications between the UAVs and the users are dominant, which are substantially less influenced by shadowing and fading, because there are usually few obstructions in the air. Both LoS and non-line-of-sight (NLoS) connectivity must be considered in more sophisticated actual scenarios, such as metropolitan regions where buildings and other barriers on the ground may hinder UAV flight and signal transmission [26]. The sum of free space loss (FSL) and excessive path loss is called path loss. The free space path loss model is only valid when the transmitter and receiver have an unobstructed LoS path and no obstructions in the first Fresnel zone as shown in Figure 1. The first fresnel zone establishes the minimum separation required between the UAV and the highest obstacle in the radio link's path [27].

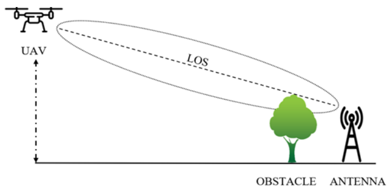

Figure 1. Air-to-ground link's first fresnel zone [27]

2.1.2. Flexibility

When a UAV flies around, it covers a wide range of places. As a result, the UAV can assist a variety of ground users. UAVs, for example, can roam above a group of users to improve channel conditions and hence deliver high throughput.

2.1.3. Agility

UAVs can be deployed fast, and their positions can be flexibly modified within a 3D environment based on the real-time requirements of users, allowing UAV networks to deliver flexible and on-demand services to ground users at a cheaper cost than terrestrial BS [26]. In recent years, there has been a huge interest in using UAV communication systems for a wide range of civil applications [28]. The coverage area, throughput, and energy efficiency of UAV-enabled communication can be improved by optimizing various parameters, such as UAV placement or UAV trajectory design [29]–[32], considering multiple-UAV settings [33], [34], beamwidth control [35], power allocation [36], joint power allocation and UAV placement optimization [16], [37]. This can potentially cater for the ever-increasing demands for high data rate applications and unexpected jump in the number of ground users.

Regardless of the deployment scenario, UAV-enabled communication systems' inherent flexibility in terms of better channel conditions ensuring LoS links, faster deployment, and maneuverability to find its parameters such as the best possible set of positions and altitudes to achieve better communication links with connected devices, can accommodate the ever-increasing diversification [38]. On the contrary, UAV-enabled wireless networks can be used as a backup when terrestrial cellular networks relying on ground base stations (GBSs) are rendered inoperable due to natural disasters [10]. They found that UAVs can be used to substitute terrestrial infrastructures in certain cases to create temporary communication networks for information transfer and disaster relief [39].

2.2. Non-orthogonal multiple access

As mentioned before, OMA is spectrally inefficient since there is a cap on the number of simultaneous connections and specialised bandwidth resources must be allocated to each user. This is where NOMA technique has received a lot of attention in recent years as a multiple-access technique that can provide massive connectivity, low latency, and high spectral performance [40], [41]. Different users' signals are broadcast in the same time slot and over the same frequency range in the NOMA technique, as opposed to the conventional OMA technique, which assigns orthogonal sub-channels to different users' signals [42]. The primary idea behind NOMA is to allow users to share non-orthogonal resources at the expense of additional receiver complexity, which is required to separate non-orthogonal signals.

Moltafet *et al.* [43], they use both the power domain and the code domain to broadcast several users' signals over a subcarrier concurrently in power domain sparse code multiple access (PSMA). With PSMA, a codebook can be reused multiple times in each base station's coverage region, increasing spectral efficiency. They show that, as compared to sparse code multiple access (SCMA) and power domain NOMA (PD-NOMA), a reasonable increase in complexity can enhance spectral efficiency by approximately 50%. Furthermore, Makki *et al.* [44] presents simulated comparisons between Welch-bound equality spread multiple access (WSMA)-based NOMA and multi-user multiple-input-multiple-output (MU-MIMO), where the prospective advantage of WSMA-based NOMA is smaller than that of MU-MIMO. They suggest several approaches for reducing the implementation complexity and latency of NOMA-based transmission on both the uplink (UL) and downlink (DL) as well as various ways to improve its efficiency. Various smart strategies can be used to increase the energy efficiency and end-to-end transmission delay of NOMA-based systems.

The performance of NOMA-2000 and PD-NOMA over Rayleigh fading channels is compared using a dynamic user grouping method for categorizing users. Under various signal-to-noise ratios, simulation results show that the PD-NOMA can always achieve a lower bit error rate (BER) than the NOMA-2000. It was proven that the performance of the PD-NOMA after user grouping is better than that of the NOMA-2000 in a Rayleigh fading scenario [45]. Hu *et al.* [46] proposed that the main principle of cognitive radio (CR) is dynamic spectrum access, which has been highlighted as a possible solution for spectrum scarcity. It can dynamically employ idle spectrum without impacting primary users' rights, allowing multiple services or users to share a portion of the spectrum, avoiding the costly cost of spectrum resetting and enhancing spectrum resource utilization. MIMO, massive MIMO, millimeter wave communications, cognitive and cooperative communications, visible light communications, physical layer security, energy harvesting, wireless caching, and other wireless technologies can all be easily coupled with NOMA. Combining NOMA with these technologies can improve future communication networks' scalability, spectrum efficiency, energy efficiency, and greenness. This study presents a thorough examination of the interactions between NOMA and the technologies [47]. NOMA has lately been researched as a design solution to overcome the above restriction of OMA. The main differentiating feature of NOMA is that it can accommodate more users than there are orthogonal resource slots, according to non-orthogonal resource allocation. This can be accomplished through sophisticated inter-user interference cancellation at the consequence of higher receiver complexity, such as polynomial or exponential order processing complexity.

The NOMA scheme family can be separated into two categories: power-domain NOMA and code-domain NOMA. Varying users are assigned different power levels based on their channel quality in power-domain NOMA, whereas the same time-frequency-code resources are shared by numerous users. At the receiver end, power-domain NOMA takes advantage of the users' power differences to distinguish between them through successive interference cancellation (SIC). Except for its predilection for low density sequences or non-orthogonal sequences with low cross-correlation, code-domain NOMA is identical to CDMA or multi-carrier CDMA (MC-CDMA) [48].

Recently, PD-NOMA has been examined in conjunction with code-domain NOMA (CD-NOMA) [49], however, this is beyond the scope of this work. To support the massive explosion of connected users predicted in the massive machine-type communications (mMTC) paradigm of 5G and beyond networks, academics, industry, and even standardization bodies such as the 3rd generation partnership project (3GPP) have expressed interest in adopting NOMA schemes [50].

2.3. NOMA-UAV

NOMA-based UAV-enabled networks have recently gotten a lot of attention in academia and industry. In UAV-enabled NOMA networks, the trajectory of the UAV and precoding vectors at the BSs were jointly tuned to maximize the cumulative rate of all users [51]–[53]. Tang *et al.* [54], a low-complexity mechanism for optimizing the number of users with satisfying quality-of-service (QoS) experience in a NOMA-based UAV system was proposed, in which the placement design, admission control, and power allocation were all optimized simultaneously. Nasir *et al.* [55], a max-min rate optimization in a UAV-enabled NOMA system was investigated, and the problem was handled using a path-following algorithm while keeping total power, bandwidth, flight altitude, and antenna beamwidth in mind.

Liu *et al.* [26] carried out three case studies; first, they use stochastic geometry to model the positions of UAVs and ground users to evaluate the performance of NOMA-enabled UAV networks; then, using a simplified 2D model of a UAV flying around at a fixed height, they look into joint trajectory design and power allocation for static NOMA users; they use machine learning (ML) techniques to demonstrate the UAV placement issue when ground users roam and the UAVs are capable of adjusting their positions in three dimensions accordingly. Sohail *et al.* [56] examines the energy efficiency of a NOMA UAV communication system, considering both transmission power and energy consumption during flight operations. The power-domain NOMA scheme is investigated in this paper for energy-efficient UAV-BSs placement. An alternating optimization technique based on a nested Dinkelbach structure is used to solve the formulated non-linear fractional problem (NLFP) as a function of transmission power and altitude.

Zhong *et al.* [39] proposes a novel framework for cellular offloading using multiple UAVs, with the NOMA technique being used at each UAV to improve the wireless network's spectrum efficiency. They propose a NOMA-enhanced UAV-enabled cellular offloading framework in which multiple UAVs are deployed in three-dimensional space to supplement terrestrial infrastructures. They formulate the sum-rate maximization problem based on the proposed system model by optimizing the dynamic trajectory and power allocation policy jointly. To solve the formulated problem, they propose a two-step approach. They use the upper bounded K-means algorithm to determine user clusters on a regular basis. A multi-agent mutual deep Q-network (MDQN) algorithm is proposed to jointly optimize UAVs' 3-D trajectory and power allocation policy to maximize total throughput based on the identified user association.

Tang *et al.* [54] consider a heavily loaded NOMA-based UAV system intending to increase the number of users who have a favorable QoS experience by combining placement design, admission control, and power allocation. However, the problem turns out to be an NP-hard mixed-binary non-convex programming. They use the penalty function method [57] to convert the original problem into a non-convex programming with only continuous variables. They then use the successive convex approximation (SCA) to obtain a karush–kuhn–tucker (KKT) point of the transformed problem in polynomial time.

Li *et al.* [58] propose a NOMA-based UAV wireless network, in which the UAV flies to serve users on the ground on a regular basis. To express the dynamic change of UAV trajectory, subperiods, or average divided parts of a complete period, are introduced. The goal of maximizing energy efficiency is formulated as a nonconvex problem. In comparison to the existing two-sided matching scheme for UAV in different subperiods, a matching and swapping (MS) algorithm is given to yield a user scheduling result with better performance. The energy efficiency optimization problem ensuring the users' QoS is then rewritten using the solved user scheduling and UAV trajectory. They compare different user scheduling algorithms, the relationship between energy efficiency and UAV trajectory and the number of users, and different channel models in this article. Existing algorithms are also compared, such as two-sided matching and various power optimization solutions.

Li *et al.* [59] look into NOMA-based UAV relaying by combining multiple ground users into a single NOMA user group. They look at a typical UAV relaying network that allows data to be relayed from a single BSs to multiple ground users. Furthermore, to maximize network throughput, they formulate a joint optimization problem involving user grouping, UAV position, and UAV power allocation. They also propose an iterative algorithm for efficiently solving the joint optimization problem. Several recent research have investigated using NOMA to improve the performance of UAV-enabled communication systems as shown in Table 1.

Table 1. NOMA applications in UAV-enabled communication

Articles	Years	Main Finding
Sharma and Kim [60]	2017	The authors evaluated the outage probability of a UAV-BSs communicating with two ground users using NOMA.
Rupasinghe *et al.* [61]	2017	Using NOMA and beam scanning, the authors examined a multi-antenna UAV-BSs to generate directional beams and serve numerous users to maximize their outage sum rates.
Wu *et al.* [62]	2018	The authors used two ground users to characterize the capacity zone of a UAV-enabled broadcast channel, and then worked together to optimize the UAV's trajectory and transmit power/rate allocations over time.
Sohail *et al.* [38]	2018	To maximize sum-rate for two users, the authors used a UAV system using NOMA to optimize power allocation and UAV altitude.
Liu *et al.* [26]	2019	Using stochastic geometry, NOMA-assisted UAV networks have been modelled and analyzed for single-UAV and multiple-UAV cases. To solve UAVs' dynamic placement and movement in 3D space, a ML framework has been proposed.
Sohail *et al.* [56]	2019	The proposed scheme shows a significant increase in the energy efficiency of the NOMA based UAV-BSs compared to OMA.
Zhong *et al.* [39]	2020	Their findings demonstrated the superiority of the NOMA framework, and the proposed MDQN paradigm outperforms the traditional DQN paradigm in terms of convergence.
Tang *et al.* [54]	2020	They proposed a low-complexity mechanism that can converge to a near-optimal solution in three iterations in polynomial time, maximizing the number of users with satisfied QoS experiences.
Li *et al.* [58]	2021	The simulation results were presented and analyzed to demonstrate the proposed scheme's superior performance over other schemes.
Li *et al.* [59]	2021	Compared to existing UAV relaying schemes, simulation results show that their design significantly improves network throughput and spectral efficiency.

2.4. Power allocation for NOMA-BSs

Due its complexity in the design of NOMA transmission as compared to OMA, the signal of each user is decoded using SIC. Signals with a higher power level will be decoded first, while signals with a lower power level will be considered interference [63]. NOMA's basic principle is to take advantage of differences in channel gains among users to provide multiplexing benefits. In a two-user NOMA scenario, for example, the user with the higher channel gain (the first user) receives the lower power level, while the user with the lower channel gain (the second user) receives the higher power level. The data of various users is then superimposed and transmitted. A novel framework for dynamic multiple access technology selection is proposed in this paper. They developed a two-step iterative algorithm to efficiently solve the proposed resource allocation problem. The subcarrier assignment and technology selection problem are transformed and solved using linear integer programming in the first step by introducing auxiliary variables. The power allocation is then solved in the second step by using DC programming [64].

In the downlink of NOMA, certain parameters like as user pairing and power allocation methods are introduced [65]. The availability of channel state information (CSI), QoS requirements, total power constraint, and system objective are all factors that influence power allocation in NOMA. Incorrect power allocation not only causes an unequal rate distribution among users but can also cause a system outage if the SIC fails. It has been proven that critical features of the NOMA system, such as power allocation, decoding order selection, and user grouping, may be solved in sensible methods [66]–[68]. NOMA assigns more power to consumers for poor channel conditions and vice versa. A power allocation principle like this is intended to find a better trade-off in two terms: user fairness and system throughput.

2.5. Power allocation for NOMA-UAV

Several methods have been proposed to perform power allocation for NOMA-UAV. Li *et al.* [58], they solve the power allocation problem by satisfying the KKT conditions. They considered a UAV-based NOMA downlink wireless network with a single UAV and multiple ground users, with the UAV's altitude assumed to be constant. They demonstrate that the proposed power allocation algorithm outperforms water filling and fixed power allocation schemes, particularly when power consumption is low.

Li *et al.* [59] consider a NOMA-based downlink UAV relay scenario in which the UAV is deployed to serve 12 randomly distributed users at a fixed altitude of 100 meters. They proposed a generalized NOMA user grouping scheme and formulated a joint user grouping, UAV position, and UAV power allocation optimization problem to maximize network throughput. A time division duplexing (TDD) mode is used at the UAV relay to avoid mutual interference and share limited spectrum resources between the uplink and downlink of the UAV. As a result, a one-time slot's worth of communication is split into two-time hops: BSs-to-UAV and UAV-to-users. During the second hop, all M users are divided into G NOMA groups, with each group sharing a resource block that is orthogonal to the frequency blocks of the other groups. Each user's throughput at the first hop is fixed in power allocation optimization, and the transmit power for users in the same group only affects the throughput at the second hop. As a result, the problem of UAV transmit power allocation can be reduced to the problem of UAV power allocation within each group. To obtain an approximate optimal solution, they use the iterative method, which is the first-order Taylor expansion.

Zhong *et al.* [39] propose a NOMA-enhanced UAV-enabled cellular offloading framework in which multiple UAVs are deployed in 3-D space to supplement terrestrial infrastructures. They formulate the sum rate maximization problem based on the proposed system model by jointly optimizing the dynamic trajectory of multiple UAVs and the power allocation policy based on users' CSI. They optimize the trajectory and power allocation policy of UAVs, subject to the maximum power constraint, spatial constraints, and the QoS constraint. The speed of UAVs is assumed to be constant. They also propose a multi-agent MDQN algorithm for optimizing the UAV's trajectory and power allocation at the same time. When NOMA is used, the proposed MDQN algorithm's dynamic decoding order and power allocation achieve gains of approximately 12% and 14%, respectively.

Jiang *et al.* [63], however, consider using a NOMA-UAV to connect a BSs and multiple isolated cell edge users. A double-loop iterative algorithm for optimizing the UAV's position and transmit power simultaneously is proposed in this letter. They introduce a series of binary variables $\alpha_{k,j}$ (k≠j) to express the signal-to-interference-plus-noise ratio (SINR) of the k^{th} user. When the k^{th} user's channel state is better than that of the j^{th} user, then $\alpha_{k,j}=0$. When the k^{th} user's channel state is worse than that of the j^{th} user, $\alpha_{k,j}=1$. The UAV can hover closer to ground users with higher BSs transmission power, resulting in better air-to-ground channels. As a result, the UAV requires less transmission power to meet the minimum information rate requirement. When the BSs transmission power is low, the UAV must fly closer to the BSs to achieve a better BSs-to-UAV channel, and the ground users require more UAV transmission power.

The UAV provides superposed signals to two users, as shown in Figure 2, with user 1 having higher channel gain than user 2. The strong user and the weak user are commonly referred to in NOMA as the user with the higher channel gain and the user with the lower channel gain, respectively. The strong user decodes its own signal after subtracting the weak user's signal via SIC; the weak user considers the strong user's signal to be noise and detects its own signal directly. To maintain fairness, the weak user is given more power in NOMA when the channel gain is lower and there is greater interference.

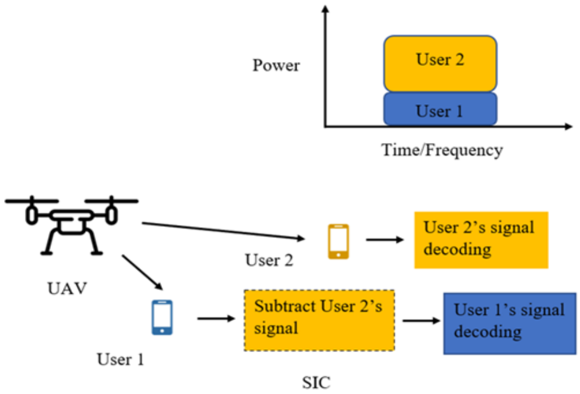

Figure 2. Power allocation technique for downlink NOMA system [69]

2.6. Advantages of NOMA-UAV

At close to optimum altitude, the proposed NOMA-based UAV communication system's energy efficiency, power allocation, and sum-rates are evaluated. Sohail *et al.* [56] shows a significant increase in NOMA gain due to improved channel uniqueness as a result of higher excessive loss in dense-urban environments compared to suburban and urban environments. In comparison to OMA, the proposed scheme saves up to 18% power on signal transmission and a maximum of 49% power during hovering operation of the NOMA aided UAV-BSs. In another aspect, using a single UAV for data transmission when internet of things (IoT) devices are deployed over a large area is inefficient due to the communication delay. As a result, Feng *et al.* [70] adopted a multi-UAV enabled NOMA system. All devices share the same subcarrier to extend IoT device wireless coverage and disseminate data to IoT devices.

Li *et al.* [58] compare their proposed joint optimization scheme with and without small-scale fading for various access methods. Because of its high spectrum efficiency, the total energy efficiency of their suggested joint optimization solution in NOMA beats that of OFDMA. They indicate that 0.1 watt may be the best maximum transmit power for the proposed UAV networks because the total energy efficiency of all four schemes begins to decline slowly once the maximum transmit power of the UAV exceeds 0.1 watt. Furthermore, in this simulation, they consider both small-scale fading and the LoS-determined channel model.

In conclusion, NOMA can outperform traditional OMA in UAV networks:

– Spectral efficiency has improved; multiple users of UAV networks using NOMA methods can share the same bandwidth, frequency, and resource block and minimizing interference through SIC. Meanwhile, in OMA schemes, the resource block may be assigned to a user with a low signal intensity, resulting in lower spectral efficiency.
– Massive connectivity: it increases the number of customers serviced at the same time, allowing for huge connectivity in UAV networks.
– Transmission latency is low; a user does not need to go through a predefined time slot to transmit their data while users in UAV networks using OMA methods must wait for an available orthogonal resource block to give transmission access.
– User fairness has improved; NOMA systems can handle numerous users of UAV networks in the same resource block while ensuring a guaranteed minimum rate. NOMA also can maintain a varied range of QoS by balancing power between strong and weak users.
– Increased throughput at the cell's edge; NOMA improves the cell-edge user experience by allocating more power to a weak user. It is because NOMA methods allow a UAV-BSs to flexibly modify the amount of power given to a cell-edge user to support a specific QoS.

3. APPLICATIONS OF UAV-ENABLED COMMUNICATIONS

UAVs in wireless communication systems promise to provide cost-effective wireless connectivity for devices without infrastructure coverage. Among the many uses made possible by UAVs, using UAVs to achieve high-speed wireless communications is predicted to play a key role in future communication systems. The following sections address three common use cases for UAV-enabled wireless communications [25]:

– UAV-enabled ubiquitous coverage, where UAVs are used to help the current communication infrastructure, if any, provide seamless wireless coverage throughout the service region. Rapid service recovery following partial or complete infrastructure damage caused by natural disasters, and base station offloading in extremely crowded regions (e.g., a stadium during a sporting event) are two examples of scenarios.
– UAV-enabled relaying, where UAVs are used to provide wireless connectivity between two or more people or user groups who do not have dependable direct communication links.
– Data collection and information distribution using UAVs, UAVs are used to distribute (or collect) delay-tolerant data to (from) many distributed wireless devices.

Emergency communication that is both reliable and flexible is a major difficulty for search and rescue in the event of a disaster, especially when BSs are down [10]. UAV-enabled networking such as quadcopters and gliders has gaining traction in public safe communications (PSCs) as a possible way to set up emergency networks [24]. Feng *et al.* [70], divided NOMA-based UAV-enabled networks' emergency communications architecture into three scenarios:

– Scenario 1: the UAV is launched to gather real-time data from IoT devices and transfer it to the control station for further processing and analysis in the scenario with IoT devices distributed in an area where unexpected and abrupt calamities occur.
– Scenario 2: multi-UAVs can be deployed to increase wireless coverage and offer wireless service for IoT devices in a scenario where IoT devices are distributed across a large geographical area as illustrated in Figure 3.
– Scenario 3: a UAV outfitted with an antenna array is dispatched as a flying BSs in the scenario with ultra-dense device deployment to distribute data to IoT devices.

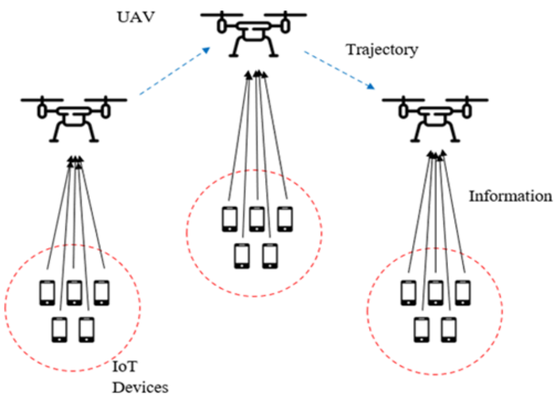

Figure 3. Illustration of uplink NOMA system in UAV [70]

When terrestrial cellular networks, which rely on GBSs, are disrupted by natural disasters, or saturated by users, UAV-enabled wireless networks can be used as a backup [10]. UAVs can be used to replace terrestrial infrastructures in these scenarios to create temporary communication networks for information transfer and disaster relief. UAVs, on the other hand, can be used in cellular network offloading scenarios to improve terrestrial network connectivity, throughput, and coverage [71]. The authors of [72] pointed out that UAVs can be connected to satellites to provide additional connectivity for users experiencing cellular network congestion.

As aforementioned in scenario 1, they created a real-time trajectory planning of UAV to avoid data overflow in IoT devices, in which the data transmission requirements priority of IoT devices and the wireless coverage of UAV are concurrently considered. Meanwhile in scenario 2, the UAV deployment and interference control are well-designed to increase the total rate of IoT devices that may be achieved. Furthermore, in scenario 3, the path planning, beam pattern, and transmit power of the UAV are all optimized to maximize the cumulative rate of all IoT devices [70].

Besides, Erdelj *et al.* [22] presented a vision for using the latest breakthroughs in wireless sensor network (WSN) technology and UAVs to improve network-assisted catastrophe prediction, assessment, and response capabilities. When the supporting WSN is fully operational after a type B disaster (climatological, hydrological, or human-induced), it can be used to aid the UAV operation by offloading some of the non-time-critical activities. When two significant earthquakes struck the emilia-romagna region of Northern Italy, for example, UAV operators were swamped with data retrieval chores [73]. Human errors in the operation of the

UAV, as well as its performance in the rescue mission, were produced by attentively monitoring the information that passes back and forth from the disaster region to the end controller [22].

For example, recently in Turkey 2023 earthquake, there were tens of thousands of fatalities and extensive damage. The importance of quickly establishing an effective emergency communication system becomes clear when the mobile communication facilities are destroyed, and the location loses contact with the outside world. The drone group may now be immediately lifted off in the area that is being used for local disaster response. The airborne base station can be constructed by transporting 5G communication modules.

4. OPEN ISSUES AND OPPORTUNITIES

With the density of UAV use in many situations especially when it comes to connecting the UAV network to ground users, there are also challenges that must be addressed. In this section, we will discuss some research challenges and open issues for characterizing UAV-enabled communications using NOMA for 5G and beyond. Specifically, we highlight several issues and opportunities for NOMA and NOMA intelligent reflecting surface (NOMA-IRS) in UAV system. In addition, the potential of NOMA-UAV for future 6G communications as well as energy-harvesting for UAV networks are also discussed.

4.1. NOMA in UAV

In the case of NOMA systems, some additional challenges should be addressed, such as the associated reference signal design and channel estimate, system scalability, channel-quality feedback design, BSs cooperation, and so on. Furthermore, the current multiple access design frequently assumes the use of a single scheme for all applications, regardless of their differing requirements. As a result, to accommodate the worst-case scenario, many system design variables must be considered, resulting in inefficient multiple access architecture in many applications. Consequently, software-defined multiple access technology is intended to offer the flexible setup of numerous access schemes, allowing for the provision of various services and applications in 5G. By tackling these issues, NOMA solutions are likely to deliver even greater performance gains. Nonetheless, there remain a few unoccupied research positions. Using relays, for example, can improve reception dependability while also expanding coverage area, but it requires an additional time slot for relaying. Developing full-duplex relays for NOMA networks is a promising research topic for removing the need for an additional slot [74]–[76].

4.2. NOMA-IRS in UAV

An IRS is a thin artificial surface that contains plenty of inexpensive and passive reflecting components. The propagation of incident signals can be changed by altering the amplitudes and phase shifts of each of these components. Reflected signals can be merged coherently with the non-reflected signal to increase the desired signal strength or destructively to decrease interference by optimizing the reflection coefficients of the IRS [77]. Furthermore, IRS can be readily and adaptably installed on building facades, or on the walls and ceiling of offices, with minimal power consumption [78]. Jiao *et al.* [79], author examines a straightforward design for a multiple-input single-output NOMA downlink network supported by UAVs. As a result, the performance of the two suggested methods which are semidefinite relaxation-based iteration algorithm and successive convex approximation technique, is demonstrated through simulation results to be much superior to that of the IRS-based UAV-assisted OFDMA scheme and the random phase shifting scenario. Reducing the significant interference brought on by the LoS-dominated A2G channel is a key issue in enabling UAV-enabled communications. So, a NOMA-IRS UAV communication can be proposed in order to achieve high energy and spectrum efficiency for wireless communication networks.

4.3. NOMA-UAV for 6G

6G is the sixth generation of wireless technology. 6G is growing every day as scientists and researchers realise the necessity for new wireless communication solutions for developing infrastructure [80]. After a few years, the 5G parameters will not be enough to meet the demands due to infrastructure progress and the rapid growth in wireless communication users. 6G wireless communication is therefore becoming a hot research topic since the major requirements today are for increased data rate, power optimization, ultra-low latency, low computation complexity, and ultra-high spectrum efficiency. Traditional multiple accessing techniques cannot accommodate a high number of users due to the limited bandwidth available. Numerous users require access for the IoT, UAV communication networks, and cell phone communication. For two users, power distribution is extremely simple, but as the number of users rises, it becomes more difficult to distribute power efficiently. So, in these cases, the combination of NOMA-UAV with 6G is required as the bandwidth and latency of 6G networks will be significantly higher than those of 5G networks due to their ability to operate at higher frequencies.

4.4. Energy harvesting for UAV networks

As for keeping the UAV to fly at a maximum, we can use energy harvesting among UAVs. Energy harvesting is a process where the external sources are converted to energy sources such as solar and windmill. simultaneous wireless information and power transfer (SWIPT) is a hybrid of wireless energy transmission and wireless information transmission (WIT), allowing for simultaneous energy harvesting and information transmission [81]. Nasir *et al.* [82] proposed two energy harvesting strategies for energy harvesting relay networks: time switching and power splitting and deriving the system's throughput expression. Zhou *et al.* [83] developed a universal receiver that separates received signals with adjustable power ratios for energy harvesting and information decoding, as well as calculating the rate-energy ratio of time switching, static power splitting, and on-off power splitting. Yang *et al.* [84], author examines a wireless communication system with energy harvesting that is compatible with UAVs, where the UAV transmits energy to users in half-duplex or full-duplex while the users collect energy for data transmission to the UAV. It is demonstrated that for energy transfer and information reception, the UAV should remain directly above the user at a low altitude.

5. CONCLUSION

In this paper, we investigated the challenges and opportunities of NOMA as a promising technology in UAV networks. To this end, we have overviewed the background of UAV-enabled communications using NOMA. Power allocation for NOMA-UAV systems performance optimization is also outlined. Furthermore, we group UAV-enabled communication applications according to whether they will be used in regular working environments or in emergency situations. Lastly, we discovered several open research questions that will be pursued in the future, including new opportunities. After that, we conclude that NOMA is a more appealing solution for UAV networks because it supports higher connectivity and can improve average user rate performance compared to the OMA techniques.

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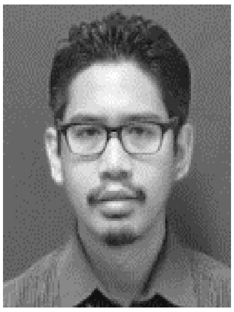

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