# Towards Efficient UAV-Assisted Network Slicing: Exploiting Slice-Dedicated, Customized UAV Fleets in RAN

Tarek Bouzid, Noureddine Chaib, Mohamed Lahcen Bensaad, and Pascal Lorenz

***Abstract*—With the rise of network slicing, Unmanned Aerial Vehicles (UAVs) can be a pivotal addition. Similar to UAV-assisted networks, drones can be integrated into slicing-capable networks to enable network slicing. With the increasing number of different network user types, UAVs can introduce the necessary flexibility and fast response and deployment in networks. As a result, this paper explores the potential in integrating UAVs to assist in network slicing by introducing dedicated and customized UAVs for each slice. This work addresses network slice improvement in 5G Radio Access Network (RAN), by exploiting specialized UAVs to serve slice users. We propose a multi-UAV solution with distinct types to address the special requirements of each slice. Extensive tests are performed to evaluate the proposed UAV types. The results proved that specific UAV types yield better performance and require fewer UAVs. Finally, some open issues and future trends are highlighted before concluding.**

***Index Terms*—Network Slicing, UAVs, drones, drone-assisted networks, QoS, QoE, eMBB, mMTC, URLLC, 5G, 6G, UAV fleets.**

## I. Introduction

Unmanned Aerial Vehicles (UAVs) have become increasingly popular in recent years due to advancements in technology and their potential for a wide range of applications. UAVs can be a great asset to networks. However, for the strict network slicing requirements, traditional UAVs may have limitations that makes them unfit to serve every slice. For instance, an enhanced throughput slice requires very high data rates which may need special, high power antennas. Whereas, Internet of Things (IoT) devices may require specialized protocols for their range and power limitations.

As networks are becoming heterogeneous, the Fifth Generation (5G) and beyond networks need to consider many device types and their requirements. This variety of devices, in turn, requires a multiple approaches, techniques, protocols, and hardware. Therefore, network slicing emerged as a way to serve different users with their respective priorities and network requirements.

Manuscript received January 15, 2026; revised February 26, 2026. Date of publication July 17, 2026. Date of current version July 17, 2026. The associate editor prof. Sofiane Hamrioui has been coordinating the review of this manuscript and approved it for publication.

T. Bouzid, N. Chaib, and M. L. Bensaad are with the University of Laghouat, Laghouat, Algeria (e-mails: {t.bouzid, n.chaib, l.bensaad}@lagh-univ.dz).

P. Lorenz is with the University of Haute Alsace, Colmar, France (e-mail: pascal.lorenz@uha.fr).

Digital Object Identifier (DOI): 10.24138/jcomss-2025-0303

Indeed, an important issue arises when exploiting typical all-slice UAVs to assist in network slicing. Due to the diverse and often conflicting requirements of different slices and user needs, one UAV type can not satisfy all users optimally. Therefore, this work addresses the issue of heterogeneous devices and multiple slices by introducing specialized UAVs for each of the three major network slices.

As UAVs are becoming more available and affordable, many works propose UAVs as a part of the network (*i.e.,* UAV-assisted networks) [1]–[3]. UAVs have great potential in extending the network converge, providing temporary connectivity in events, or collecting data. Moreover, UAVs can assist in disaster situations and search and rescue missions. The massive potential in UAVs should be exploited, as a result, UAV-assisted network slicing is explored in this work.

The new emerging network user types such as IoT devices, vehicles, drones, sensors, and smart appliances have different demands and priorities. A rigid physical infrastructure can not satisfy all user types and use cases. Therefore, 5G opted to have a dynamic core network and a flexible Radio Access Network (RAN). If UAVs are used to assist in networks, UAVs must posses the different necessary technologies [4].

As network slicing provides specific slice properties for each user, slices are very distinct. Therefore, the proposed solution is to provide distinct UAVs for each slice type. Each UAV type will have specific behavior, properties, and hardware suitable for the desired slice.

This paper exploits UAVs to enable UAV-assisted network slicing. This work aims to improve the performance in RAN by proposing special UAV types with distinct configurations for each slice. Moreover, introducing UAVs can assist in connecting non cellular users such as some IoT devices through their preferred wireless technology. In essence, this work conducts a comprehensive design and evaluation of dedicated UAV types for each slice, quantifying their performance gains over conventional all-purpose UAVs through extensive simulations. The contributions of this manuscript are summarized below:

- We explore the three predefined network slices, UAVs and their types.
- We propose UAV types and their properties specifically chosen for each major network slice's priorities.
- We perform extensive tests and simulations to evaluate the proposed methodology's performance.
- We outline major issues and showcase the future trends in the field of UAV-assisted network slicing.

The remainder of this paper is structured as follows. Section II provides a brief background on 5G and the Sixth Generation (6G), network slicing, and UAV classifications, and reviews related works. Section III details the proposed methodology and system description, outlining the customized parameters, specific UAVs types, and adopted channel models for each slice. Section IV presents simulation results and a comprehensive discussion, comparing the performance of the specialized UAVs against typical UAVs across various metrics. Section V highlights future opportunities and challenges within UAV-assisted network slicing before concluding in Section VI.

## II. Background and Related Work

*1) 5G and 6G:* Networks in general have experienced massive leaps in capacity over the recent years. The increase in user numbers required cellular networks to update their technologies, capabilities, capacities, and more. Each cellular network generation improves on multiple aspects over its predecessors. For instance, the 5G network enhanced many aspects as presented in the comparison between 5G and Long Term Evolution (LTE) [5]. The improved network aspects include capacity, spectrum efficiency, latency, throughput, connection density, and more. The improvements introduced in 5G are necessary for it to be a heterogeneous network, satisfying many user types such as IoT devices, vehicles, mobile devices, and more. Furthermore, many technologies have been adopted by 5G such as beamforming, network slicing, and massive Multiple Input Multiple Output (MIMO), all of which are candidates for the next generation.

*2) Network Slicing:* Network slicing is a concept that allows the logical separation of a physical network. Network slicing emerged as a way to enable multiple users with different network priorities to get their desired quality of service. Network slicing is achieved by having dynamic resources with a flexible and programmable network. This flexibility is offered by softwarization and virtualization of the network through the use of Software Defined Networks (SDN) and Network Functions Virtualization (NFV) [6]. Furthermore, a network needs to support slicing in each layer of the infrastructure, *i,e,.* RAN, core, and transport network.

Three major network slices are introduced in 5G by default:

- Massive Machine Type Communications (mMTC): mMTC or massive IoT (mIoT) is intended for massively connected devices which may exist with large densities in small areas. mMTC is most suited for sensors and IoT devices with low network needs and high energy efficiency requirements.
- Ultra Reliable Low Latency Communications (URLLC): The URLLC slice prioritizes high reliability and low latency. This slice is specifically targeted to various industrial applications, gaming, and other scenarios that require minimal delays and latency. Indeed, some IoT devices have high delay sensitivity and can be included in this slice.
- Enhanced Mobile Broadband (eMBB): The eMBB slice mainly covers typical internet usage and prioritizes high data rates. eMBB is a slice dedicated to 4k video consumption, fast download speeds, and high quality live streaming.
- Custom slices: The three major predefined network slices encompass most demands of cellular users including IoT devices, vehicles, and other User Equipments (UEs). However, service providers may create custom network slices based on their business goals or subscribers' demands, similar to cellular data plans. This work uses the three predefined slices as a proof of concept, other custom slices can also be served by UAVs if they are equipped accordingly.

*3) UAVs:* UAVs, or drones have risen as an important asset in many fields ranging from delivery and photography to military and rescue missions. One of the main promising applications for UAVs is UAV-assisted networks, where UAVs perform certain tasks for the network [2], [7]–[9].

UAVs are available in multiple types and properties. Choosing a specific UAV type is entirely dependant on the required task. For instance, a UAV with hovering capabilities is necessary for most delivery scenarios. Whereas, fixed-wing UAVs are favored in long flight missions. Furthermore, Table I outlines common UAVs and their respective abilities and properties. These notions are necessary to choose adequate UAVs for each slice type.

The most utilized UAV classification is according to wing types into Fixed-wing UAVs, Rotary-wing UAVs, and Hybrid UAVs. Other less common types are balloons that use helium to provide lift and propulsion. They are ideal for applications that require extended periods of airborne observation, such as meteorology and atmospheric research. Another UAV type is the flapping-wing that mimic bird flight techniques by using flapping wings. They are currently in the experimental stage but have potential applications in aerial surveillance and monitoring.

Furthermore, UAVs can be classified according to their maximum operating altitude into low, medium, and high altitude UAVs. Overall, choosing a specific drone type requires knowledge on the deployment scenario and application needs to select aspects like range, endurance, payload capacity, and maneuverability.

Many works exploit UAVs for UAV-assisted networks and address many issues such as coverage or data collection. Furthermore, the number of works on network slicing with UAVs is also increasing. However, most papers featuring UAVs combined with network slicing are either surveys [10] [11], or papers featuring a particular network slice. The most studied slice in UAV works is URLLC. Some works also feature mMTC, more specifically, UAV data collection and providing Mobile Edge Computing (MEC) capabilities [12].

The surveys [13] [14] study UAV assistance in the context of 5G. Whereas [15] and [16] discuss UAVs in the context of data collection for IoT devices and sensors. Moreover, [10] surveys 5G network slicing with UAVs. Overall, the surveys provide detailed discussions on state of the art, UAV optimization techniques [17], communication advancements, and novel approaches.

TABLE I
SUMMARY OF UAV TYPES AND THEIR RESPECTIVE PROPERTIES

| UAV type | Flight time | Maneuver-ability | Hovering and Vertical Take-Off and Landing (VTOL) | Height | Payload capacity | Typical use-cases |
|---|---|---|---|---|---|---|
| Multi-rotor UAVs | very short | HIGH | yes | Low Altitude Platform (LAP) | low | delivery photography |
| Single-rotor UAVs | short | MEDIUM | yes | High Altitude Platform (LAP) | high | delivery |
| Fixed-wing | very long | LOW | no | LAP HAP | high | missions reconnaissance |
| Hybrid | Long | MEDIUM | yes | LAP HAP | medium | variable |
| Balloon UAVs | very long | LOW | yes | HAP | high | atmospheric and weather measurements |

As for contribution articles, they can be classified according to the featured slice. Works studying the URLLC slice often prioritize low latency and exploit UAVs as relays. Furthermore, in URLLC, drones can be network users (taking advantage of the slice) or as assistants by providing URLLC slices to network users. For instance, the works in [18] and [19] exploit UAVs to assist in relaying data to and from a remote controlled mission robot under the URLLC slice. Whereas a drone piloting system with beyond visual line of sight (BVLOS) communication is introduced in [20]. BVLOS piloting is also considered in [21] under the millimeter wave (mm-wave) to satisfy URLLC slice requirements.

In the context of mMTC, UAVs are often exploited as data collectors or relays to assist Machine Type Communication Devices (MTCDs). Authors in [22] consider a network of mMTC devices assisted by drones, where they propose two algorithms to increase service duration while minimizing energy consumption. A maritime scenario is considered in [23], where UAVs are used to relay data from mMTC water buoys to the nearest ground Base Station (BS).

Moreover, the eMBB slice is considered in [24], where UAVs assist in an urban environment. The future locations of users is predicted in advance to proactively deploy UAVs to serve users. Authors in [25] optimize RAN resource allocation in a UAV-assisted network

Other works may feature a hybrid of multiple slices such as [26] and [27]. Whereas some works may explore non standard slices. For instance, Grasso *et al.,* [28] feature UAVs with MEC capabilities to extend a slice for video surveillance and monitoring.

The authors in [29] proposed the EASIER framework, which jointly optimizes UAV placement and radio resource slicing to support heterogeneous 5G services such as eMBB, URLLC, and mMTC. Similarly, Wei *et al.,* [30] introduced a two-timescale hierarchical slicing architecture for UAV-assisted networks that integrates inter-slice resource allocation with UAV deployment optimization using distributed learning techniques. Other works have explored UAV-enabled slicing in specific scenarios, such as vehicular networks where UAVs operate as aerial relays to enhance QoS metrics including throughput and latency [31]. In addition, prior studies have examined UAV deployment strategies and resource management mechanisms to support heterogeneous services and dynamic traffic demands in aerial wireless networks [32], [33]. These studies demonstrate the potential of UAV platforms to dynamically support multiple service types through intelligent resource management and deployment strategies.

However, existing approaches generally assume that individual UAVs or UAV swarms simultaneously support multiple slice types. In contrast, the approach proposed in this work investigates an alternative paradigm where physically distinct UAV types are dedicated to specific slices.

## III. METHODOLOGY AND SYSTEM DESCRIPTION

This section describes the proposed system model and UAV types, and their respective custom properties. Furthermore, the adopted channel model and physical link attributes are also discussed in this section.

### A. System Model Description

We assume an area where network slices are provided to users through UAVs. Fig. 1 represents the described system model with the proposed UAV types. The different UAVs serve their respective users and can relay data using the available ground BS or a satellite link (*see* Fig. 1).

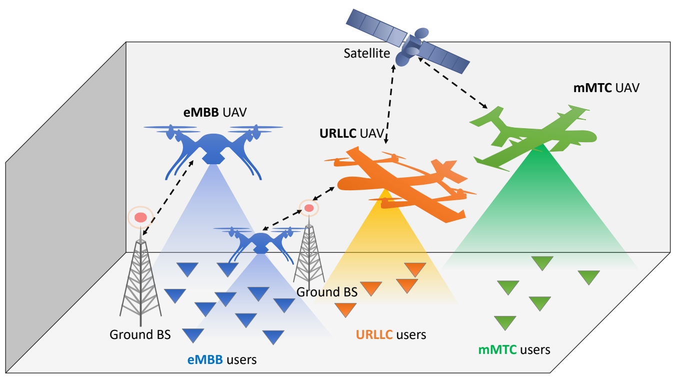


Fig. 1. The system model

### B. Customize-able Parameters

Network slices target heterogeneous device types with distinct and sometimes conflicting priorities, parameters, and requirements. Accordingly, employing different drone types and tailored network configurations enables slice-specific optimization. Beyond drone diversity, this work defines customized parameters for each drone and slice type, as outlined below.

*1) Frequency Ranges:* Frequency selection directly affects coverage, channel quality, and throughput, and must therefore be adapted to each slice. The eMBB slice benefits from higher frequencies due to their support for higher data rates. In contrast, mMTC devices prioritize energy efficiency and wide-area coverage rather than throughput; consequently, lower frequencies are preferred to ensure extended coverage and reduced power consumption.

*2) Transmit Power:* Transmit power significantly impacts network performance and depends on factors such as mission requirements, operating environment, flight duration, and regulatory constraints. Long-range communication scenarios may require higher transmit power to maintain connectivity, whereas dense urban deployments often favor lower power levels to mitigate interference. In practice, drone transmit power typically ranges from several hundred milliwatts to a few watts depending on the application. Nevertheless, minimizing transmit power is generally preferred to prolong drone battery life.

*3) Coverage Range:* Coverage range is influenced by UAV altitude, operating frequency, antenna characteristics, and transmit power. For mMTC scenarios, particularly in agricultural and forest deployments, coverage must be sufficiently large to serve numerous devices. Lower frequencies provide wider coverage but at the expense of achievable data rates, a trade-off that must be considered when selecting slice-specific channel configurations.

*4) Antenna Type:* Antenna selection plays a key role in signal quality while being constrained by UAV payload and aerodynamic limitations. Antennas must remain lightweight and aerodynamically efficient to preserve flight performance. High-throughput slices, such as eMBB, may require directional antennas to meet their data rate demands.

*5) Back-haul Connection Type:* Back-haul connectivity depends on deployment conditions and infrastructure availability. While direct connections to ground base stations are preferred when available, damaged or distant infrastructure may necessitate alternative solutions such as satellite links or multi-hop UAV relays. Multi-hop back-haul is suitable for mMTC scenarios in remote areas, whereas latency-sensitive URLLC services favor direct satellite connections to avoid excessive delays.

*6) Adopted Wireless Protocol:* Although network slicing is natively supported in 5G architectures, UAV communications may employ non-cellular physical-layer technologies. For instance, Wireless Fidelity (Wi-Fi) can be used for user access, while URLLC services may rely on latency-optimized protocols. mMTC devices, in particular, benefit from specialized low-power protocols designed for energy efficiency.

### *C. Design Methodology*

To ensure that the proposed UAV configurations are systematically derived and reproducible, this work adopts a structured design methodology that maps slice requirements to UAV parameters. The configuration process follows three main steps:

*1. Slice Requirement Analysis:* Each network slice (eMBB, URLLC, and mMTC) is first characterized based on its key performance indicators (KPIs), including throughput, reliability, device density, latency, and coverage requirements. These KPIs are derived from 3GPP specifications and representative use cases for each slice.

*2. Parameter Selection Principles:* Based on the identified requirements, a set of design principles is defined to guide the selection of UAV parameters. For example, high throughput demands in eMBB motivate the use of higher frequency bands (FR2), and higher transmit power. In contrast, mMTC prioritizes coverage and energy efficiency, leading to lower frequency selection, extended coverage range, and support for low-power communication protocols. For URLLC, reliability and low latency favor robust modulation schemes, reduced retransmissions, and minimal backhaul hops which encouraged the use of lower modulation combined with balanced frequency to carry sufficient data amounts.

*3. Configuration Synthesis:* Finally, UAV configurations are synthesized by assigning specific parameter values (e.g., frequency range, transmit power, antenna type, and communication protocol) based on the defined principles. Each selected parameter is linked to a slice requirement. Focusing on the requirements and configurations for each slice proved to be straightforward as each slice has distinct, clear objectives and target KPIs that would help derive the necessary configurations for UAVs and channel.

In addition to communication parameters, UAV platform characteristics such as type, endurance, and hovering capability are also selected based on slice requirements. For instance, URLLC services favor rotary hovering-capable UAVs due to maintain stable links, whereas eMBB deployments benefit from UAVs with extended flight endurance to compensate for the high communication and transmission energy consumption.

This methodology ensures that the proposed configurations are not arbitrary, but instead follow a clear and reproducible mapping from service requirements to UAV design choices.

The proposed parameter selection is not limited to the specific scenarios considered in this work. The same design methodology can be applied to different deployment environments by adapting the input requirements, such as user density, slice distribution, and coverage constraints. For example, dense urban scenarios may favor directional antennas and controlled transmit power to mitigate interference, while rural deployments prioritize wider coverage through lower frequencies.

### *D. Proposed UAV Types*

After establishing the state of the art, we can present the proposed UAV types, their specifications, and the methodology adopted for their selection.

As each slice and its users has its specific priorities, UAVs should be specifically designed to satisfy these priorities. Typical UAVs can not serve all slices optimally as different slices have different, often conflicting requirements.

Since the proposed architecture adopts a slice-dedicated UAV deployment strategy, this design differs from conventional network slicing paradigms that rely on shared infrastructure and inter-slice resource allocation. In this work, UAVs

TABLE II
PROPOSED PARAMETERS, UAV CONFIGURATIONS, AND DESIGN RATIONALE FOR EACH SLICE

| Slice | UAV task description | UAV type | Operating frequency | Wireless technology | Other parameters | Design rationale |
|---|---|---|---|---|---|---|
| eMBB | High-throughput service in dense events, cell-edge and rural areas | Any (preferably multi-rotor or hybrid) | FR1 + FR2 | Cellular, Wi-Fi | High transmit power, directional antennas, high spectral efficiency, high battery capacity | High data rate requirements drive the use of high frequencies (FR2) and directional antennas. Increased transmit power improves link quality, while high battery capacity compensates for energy consumption. |
| URLLC | Latency-sensitive and reliable communications (industrial, vehicular) | Rotary-wing or hybrid | Low (FR1) | Any (preferably low latency protocols) | Low SE modulation, single-hop backhaul, high maneuverability, stable hovering | Reliability and low latency are prioritized by reducing retransmissions and having reliable low modulation links and minimizing hops. Rotary hybrid UAVs ensure stable LoS links and fast positioning. |
| mMTC (mIoT) | Support massive device connectivity, data collection, MEC support, power transfer | Any (preferably long endurance UAV like fixed-wing) | Very low (sub-GHz / FR1) | dependant on devices (Wi-Fi, Zigbee) | Wide coverage, long flight time, low power communication, preferable MEC capability and wireless power transfer | Large-scale coverage and energy efficiency drive the use of low frequencies and long-endurance UAVs. Lightweight protocols enable massive connectivity. |

are considered as flexible, deployable access points at the RAN edge, which can be deployed to support specific service requirements without requiring modifications to the existing network infrastructure. Indeed, the slice-dedicated assignment should be interpreted as a deployment-level design choice that complements the network slicing framework, rather than replacing shared resource slicing mechanisms. This approach further enables a controlled evaluation of UAV specialization, allowing the impact of slice-specific configurations to be isolated.

Table II provides a summary on the different tasks expected of UAVs in each slice. The table also represents main adopted properties and the rationale behind the proposed parameters. Furthermore, the methodology adopted for each slice is described below:

*1) mMTC (mIoT):* UAVs are most suited to mMTC slice use cases. Most MTCDs are stationary and only require periodic data collection. This allows UAVs to fly and collect data gathered by mMTC users.

Since IoT devices are often delay-tolerant, multi-hops are allowed for UAVs serving MTCDs. Multi-hop relays may be necessary especially for environmental sensors that can be scattered to cover a large area.

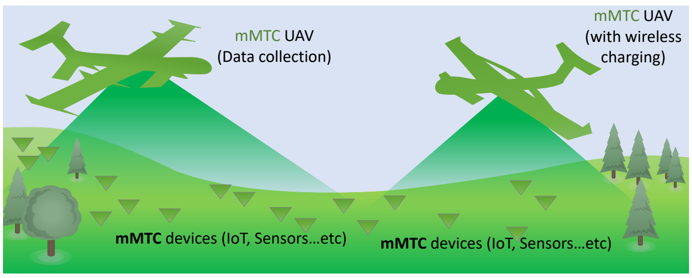


Fig. 2. mMTC (mIoT) scenario

The scenario depicted in Fig. 2 represents typical MTCDs for agricultural sensing where UAVs can assist and deliver mMTC services. UAVs are a great asset for the mMTC slice where they can perform data collection, provide compute and storage resources, or enable wireless power transfer to MTCDs.

*2) eMBB:* In eMBB, throughput is of the utmost importance. As a result, maximum spectral efficiency is highly desired. Using higher frequencies may also be needed and UAVs in this slice should support high frequencies such as the mm-wave. To achieve high throughputs, especially in high frequencies, high transmit powers must be adopted. Using high antenna transmission power depletes batteries faster. As a result, UAVs in this slice must have great battery life and efficiency and preferably, a variable transmit power. Overall, the UAV chosen for this slice must be able to hold a MIMO directional antenna as it is critical to achieving high data rates.

UAVs in this slice can benefit networks in several ways as depicted in Fig. 3. For instance UAVs can assure network connection in special events and flash-crowd areas, instead of deploying permanent BSs. Moreover, UAVs in this slice can assist the network by extending coverage to the cell-edge, ensuring high data rates in distant areas (*see* Fig. 3).


Fig. 3. eMBB scenario

*3) URLLC:* Latency may not be critical for devices such as sensors and typical mobile users. Indeed, other use cases such as Voice over Internet Protocol (VoIP) requires low latency, although, a delay below 150 ms can be unnoticeable. However, the URLLC slice has more strict latency requirements. URLLC is typically targeted for industrial, vehicular and other latency sensitive communications and scenarios.

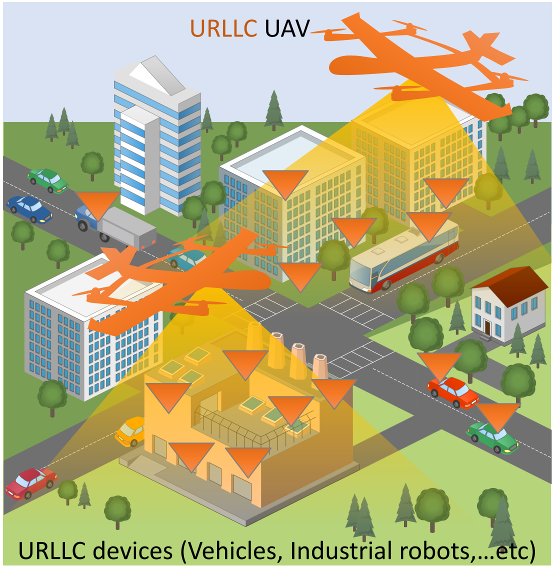


Fig. 4. URLLC scenario

Reliability is also a concern for URLLC slices. In RAN, reliability can be achieved by sacrificing spectral efficiency. This ensures that the transferred signal is noise-tolerant, ensuring reliability. Furthermore, bit error rate will be lower thanks to the low spectral efficiency, ensuring low latency as re-transmission probability is lower.

For minimum latency, only one hop should be allowed from the UAV to the backbone. Connecting to a satellite will have a longer delay, as a result, the UAV should relay directly to the BS.

UAVs serving URLLC slice to users mostly act as relays (*see* Fig. 4) and should be able to move and hover freely to ensure the best possible link, preferably with Line of Sight (LoS).

### *E. Considered Channel Model*

Works that explore wireless communications require real testings or simulations. Many academics resort to artificially reproduce test results using channel models to validate their work. Choosing an accurate and representative channel model is necessary to obtain realistic results.

The Third generation partnership project (3GPP) is an entity leading the cellular network architecture and standards development. The 3GPP proposes many channel models for their cellular networks in various standards and technical reports. For example, 3GPP offers channel models for 5G in multiple scenarios including Urban Micro (UMi), Indoor Hotspot (InH), Rural Macro (RMa), and Urban Macro (UMa) [34], the latter is considered for this paper.

Indeed, the heights $h_{UAV}$, $h_{UE}$ and the distances $2D_{dist}$ and $3D_{dist}$ are essential for estimating pathloss and performing other calculations related to the channel model between the transmitter and receiver.

*1) Pathloss:* The pathloss of the link between the user and the UAV can be calculated for both link types, Non-LoS (NLoS) and LoS. In the UMa model, pathloss using the following functions [34]:

*a) For LoS:* The break-point distance $BP_{dist}$ is calculated to later adopt the appropriate coefficient of pathloss [34].

$BP_{dist} = 4 \cdot h_{UAV} \cdot h_{UE} \cdot f/c$ where $h_{UAV}$ and $h_{UE}$ are the effective antenna heights, in meters, of the drone and the target user respectively. Whereas, the center frequency is given in Hz and is designated by $f$. The free space velocity of propagation is $c = 3 \cdot 10^8 m/s$.

Pathloss is given by the following formula (in dB) [34]:

$$Pathloss_{LoS} = \begin{cases} PL_1 & 10m \leq 2D_{dist} \leq BP_{dist} \\ PL_2 & BP_{dist} \leq 2D_{dist} \leq 5km \end{cases} \quad (1)$$

where

$$PL_1 = 28 + 22log_{10}(3D_{dist}) + 20log_{10}(Freq) \quad (2)$$

$$\begin{aligned} PL_2 = 28 + 40log_{10}(3D_{dist}) + 20log_{10}(Freq) \\ -9log_{10}((BP_{dist})^2 + (h_{UAV} + h_{UE})^2) \end{aligned} \quad (3)$$

The heights are designated as $h_{UE}$ and $h_{UAV}$, where the latter is the drone or the BS height. The user height is as follows : $1.5m \leq h_{UE} \leq 22.5m$. The frequency in this formula is designated by $Freq$ and is given in GHz, whereas, $2D_{dist}$, $3D_{dist}$, and $BP_{dist}$ are in meters.

*b) For NLoS:* Calculating the pathloss, for a NLoS link requires the following equation [34]:

$$\begin{aligned} Pathloss'_{NLoS} = 13.54 + 39.08log_{10}(3D_{dist}) \\ +20log_{10}(Freq) - 0.6log_{10}(h_{UE} - 1.5) \end{aligned} \quad (4)$$

The final LoS pathloss value, is determined by selecting the maximum value from the LoS and NLoS pathloss calculations.

$$Pathloss_{NLoS} = max(Pathloss_{LoS}, Pathloss'_{NLoS}) \quad (5)$$

*2) LoS Probability:* To determine whether a link is in LoS or NLoS, we calculate the LoS probability. The LoS probability $LoS_{prob}$ in 3GPP's UMa [34] allows us to choose between using $Pathloss_{LoS}$ or $Pathloss_{NLoS}$ and is calculated using the following formula [34]:

$$LoS_{prob} = \begin{cases} 1 \quad 2D_{dist} \leq 18m \\ \left[\left(\frac{18}{2D_{dist}}\right) + exp\left(-\frac{2D_{dist}}{63}\right)\left(1 - \frac{18}{2D_{dist}}\right)\right] \\ \cdot \left[1 + C'(h_{UE})\frac{5}{4}\left(\frac{2D_{dist}}{100}\right)^3 exp\left(-\frac{2D_{dist}}{150}\right)\right] \\ 2D_{dist} > 18m \end{cases} \quad (6)$$

wherein

$$C'(h_{UE}) = \begin{cases} 0 & h_{UE} \leq 13m \\ \left(\frac{h_{UE} - 13}{10}\right)^{1.5} & h_{UE} > 13m \end{cases} \quad (7)$$

$LoS_{prob}$ is the probability of LoS which decreases with distance, and is dependent on $h_{UE}$ height and the ground distance $2D_{dist}$ from the BS to the UE. $LoS_{prob}$ is inversely related to distance, and is determined by the ground distance $2D_{dist}$ between the BS to the UE and the UE height $h_{UE}$.

*3) Penetration Loss:* Two penetration loss models are proposed by 3GPP, characterized as high-loss and low-loss penetration models. In this study, the low-loss model is employed, where $L_{glass}$ and $L_{concrete}$ are the glass and concrete penetration losses respectively (in dB) [34] :

$$Loss_{penetration} = 5 - 10log_{10}(0.3 \cdot 10^{\frac{-L_{glass}}{10}} + 0.7 \cdot 10^{\frac{-L_{concrete}}{10}}) \tag{8}$$

$$L_{glass} = 2 + 0.2 \cdot Freq \text{ and } L_{concrete} = 5 + 4 \cdot Freq \tag{9}$$

*4) Overall Link Model:* The overall received signal level at each user is determined using the following simplified expression, which includes the computed channel losses (outlined in III-E).

$$\begin{aligned} R_{signal} = Rx_{gain} + Tx_{gain} + Tx_{power} - Tx_{cable\_loss} \\ - Rx_{cable\_loss} - Loss_{path} - Loss_{penetration} \end{aligned} \tag{10}$$

where, the calculated signal received by the device is $R_{signal}$ and is given in dBm, and the device transmit power is given in dBm as $Tx_{power}$. Furthermore, the antenna gains for the receiver and transmitter are $Rx_{gain}$ and $Tx_{gain}$, respectively, whereas the loss in the transmitter and receiver antennas are respectively denoted as $Tx_{cable\_loss}$ and $Rx_{cable\_loss}$.

Finally, two losses are subtracted from the equation, where the loss due to propagation is denoted as $Loss_{path}$ and its calculation is described in III-E. The penetration loss ($Loss_{penetration}$) however, is calculated in Equation 8.

*5) Spectrum Efficiency:* The key metric in numerous wireless communication systems is the Modulation Coding Scheme (MCS). MCS index mapping tables assign specific modulation schemes and target code rates according to the perceived channel conditions. The 3GPP standard [35] defines three distinct tables for particular devices and use cases. For scenarios where a device lacks support for 256 QAM modulation or experiences poor radio conditions, Table 1 (designated 'QAM64') is applicable. Table 2 offers the highest data rates through its high spectral efficiency and modulation scheme, this table is also known as 'QAM256'. In contrast, Table 3 is a Low Spectral Efficiency (Low SE) 64 QAM table named 'QAM64LowSE'. Ultimately, the selected MCS index mapping, and consequently the resulting modulation rate and data rate, are governed by the chosen table, the state of the radio channel, the device's antenna sensitivity, and the Signal-to-Noise Ratio (SNR) [36].

*6) The Frequency Spectrum:* The 3GPP standard organizes the complete 5G band into two primary ranges, outlined as follows : The range between 410 MHz and 7.125 GHz are referred to as Frequency Range 1 (FR1). Whereas, frequencies between 24.25 GHz and 52.6 GHz are designated as Frequency Range 2 (FR2) [37] [38].

*7) Throughput Calculations:* The 5G New Radio (NR) data rate is determined by the subsequent calculation, derived from 3GPP standards [39]:

$$\begin{aligned} \text{datarate}_{Mbps} = \frac{m_{order} C_{rate}}{10^6} \\ \cdot \frac{RB_{BW,\mu} \cdot 12}{S_{time}} (1 - overhead) \end{aligned} \tag{11}$$

where, the data rate is given in Mbps, and the used modulation scheme is designated as $m_{order}$ (which is derived from the used MCS index tables and channel state). Finally, $C_{rate}$ denotes the target coding rate obtained from the MCS index table. Moreover, the used numerology is defined in [40] and is designated as $\mu$. Whereas, $RB_{BW,\mu}$ is given as the maximum number of resource blocks [37] in the current numerology, bandwidth, and frequency configuration [41], [42]. The $overhead$ is dependent on the employed frequency range where FR1's and FR2's overheads are 0.14 and 0.18, respectively. The chosen numerology dictates the resulting symbol duration $S_{time}$, which is given as: $S_{time} = \frac{(14 \cdot 2^{\mu})^{-1}}{10^3}$

*8) Interference Coordination:* While the baseline channel model parameters (pathloss, LoS probability, and penetration loss) are fixed by the 3GPP UMa standard and cannot be altered, interference mitigation is assumed to be addressed at the deployment level. UAVs can be coordinated by the base station on a cell basis, with resource allocation depending on the number of users and UAVs available. Practical adjustments include UAV antenna orientation, center frequency selection, and location. Height can also influence interference, but in our proposed system it is a fixed design parameter, and changing it would directly affect performance.

Since the simulations specify user spacing and bandwidth per user type, these values remain unchanged. However, a wide carrier frequency range is considered, allowing interference reduction through frequency planning. Different center frequencies can be assigned to UAVs, with higher frequencies used in dense scenarios where shorter propagation ranges naturally limit overlap and lower frequencies applied to broader coverage in less dense cases. Thus, while standardized propagation equations remain unchanged, interference coordination is achieved through BS-controlled deployment strategies and frequency planning tailored to UAV availability and user load.

## IV. Results and Discussions

This section provides multiple thorough evaluations and discussions on the proposed dedicated UAV types against typical UAVs. The comparisons showcase the performance benefits of exploiting specialized slice UAVs instead of typical all-purpose UAVs.

### A. Assumptions

The system model includes randomly moving end users and serving UAVs. The UAVs keep flying over an area of 1 by 2 Kms. When a user and its serving UAV move too far from each other, the system will elect the UAV with the best link quality and required throughput. If an alternative UAV is found then the user is handed over, otherwise the user is disconnected until another UAV is available.

The overall network capacity is considered sufficient and not limited. This assumption was made to test each scenario at its maximum efficiency and ensure a fair comparison across all slices. By removing capacity bottlenecks, the evaluation isolates the impact of UAV deployment strategies and slice requirements. However, this simplification reduces realism, since in practice limited capacity would introduce competition between slices, potential bottlenecks, and fairness challenges. Future work will extend the framework to incorporate capacity constraints for a more realistic assessment.

In practical network slicing deployments, multiple slices dynamically share limited radio and backhaul resources, resulting in inter-slice competition, bandwidth contention, and scheduling constraints. In this work, inter-slice competition and resource contention are not considered in order to enable a controlled, proof-of-concept evaluation that isolates the impact of UAV configurations. As a result, performance metrics may be optimistically estimated, and the reported results should be interpreted as an upper-bound performance under idealized conditions.

However, the capacity for each UAV is limited and is given in Table III. The UAV capacity is assumed as large but limited where it can have a maximum of 60 Gbps link to the backhaul due to antenna and battery limitations. As a result, the typical UAV will share the capacity between all its slice users. However, the custom slice UAVs will not require the full capacity to achieve a better performance as will be presented in the test results.

An energy consumption model is considered for all UAVs. The battery loss is affected by multiple factors such as the type of UAV and its rotors, weight, speed, antenna power, operating frequency, and number of connected users. The battery capacities for each UAV type are given in Table III.

The number of UAVs is critical in achieving the best possible performance. In each test, the number of typical and custom UAVs is similar for an accurate and fair representation. Furthermore, the tests are done with varying UAV numbers to highlight its effect on overall performance. However, keeping UAV numbers similar across slices can limit the generality of the results. In scenarios such as mass events, deploying many low-capacity UAVs may be necessary, but this can increase collision and interference coordination complexity and reduce throughput. Since UAVs are valuable resources, efficiency in their number remains a key performance metric, as further discussed in subsubsection IV-C4.

The simulation tests are executed across a distributed environment, comprising a server equipped with dual Intel Xeon Silver processors and a workstation featuring an Intel i7 processor. Furthermore, the resulting data and performance metrics are collected using a suite of software tools, specifically Simu5G [43] [44], MATLAB, OMNET++, and NYUSIM [45] [46].

### *B. Adopted Parameters*

We chose a somewhat powerful UAV to represent traditional UAVs for a more coherent test. The typical UAV is similar to the eMBB slice's UAV as it is the most demanding.

TABLE III
ADOPTED PARAMETERS FOR UAVS

| Properties | Typical UAV | eMBB UAV | URLLC UAV | mMTC UAV | Unit |
|---|---|---|---|---|---|
| UAV type | Hexacopter | Hexacopter | Hybrid | Fixed-Wing | / |
| Speed | 5 | 6 | 5 | 4 | m/s |
| Transmit Power | 30 | 30 | 25 | 20 | dBm |
| Carrier frequency range | 3.5 - 5 | 3.5 - 5, 28 (FR2) | 1.8 - 3 | 0.5 - 1 | GHz |
| Height range | 50-120 | 80-120 | 80 | 30-60 | meters |
| battery capacity | 16000 | 16000 | 11000 | 10000 | mAh |
| Throughput capacity | 20 (for each slice) | 40 | 20 | 10 | Gbps |

The adopted UAV types and their respective properties are summarized in Table III. For URLLC, the selected frequency range (1.8–3 GHz) is relatively high compared to traditional reliability-centric bands. This range reflects a deliberate trade-off between reliability and capacity in line with 3GPP URLLC requirements, which call for user-experienced data rates around 100 Mbps [47]. In our simulations, average throughput under typical conditions (moderate distance between UAV and user) is measured at 92 to 104 Mbps, which matches the 3GPP URLLC target. While throughput can theoretically reach 300 Mbps in optimal very close-range conditions, the UAV heights alone can prevent reaching such high throughputs. Moreover, reliability is prioritized by employing low-modulation tables (QAM64LowSE) to reduce bit error probability and avoid retransmissions. Selecting higher modulation at these frequencies would compromise reliability, while combining low modulation with low frequencies would severely limit URLLC traffic capacity.

The configurations used in this study were selected after analyzing the requirements of each slice type and their default user profiles and demands, followed by preliminary tests to identify balanced capacities that maximize performance at the wireless physical layer. For instance, eMBB slices were configured with FR2 (mm-wave) to exploit wider bandwidths (200 MHz) and finer sub-carrier spacing (120 kHz), thereby maximizing throughput. In contrast, URLLC and mMTC slices were assigned FR1 due to its superior range and signal quality, which better supports reliability and user limitations. Furthermore, other UAV attributes such as height, speed, etc were chosen to give the best performance, efficiency, and battery life. The configurations used are intended to be representative rather than globally optimal, serving as baselines and proof of concept.

UAV velocities are set to relatively low levels to reflect realistic urban operation, where stability and controlled positioning are prioritized. At such speeds, rotor-based UAVs can achieve around 30 minutes of flight time, which represents a practical endurance limit. Higher velocities would deplete batteries more rapidly and reduce deployment feasibility. For mMTC scenarios, where fixed-wing UAVs are deployed, energy constraints are less critical, but higher speeds could negatively affect low-capacity, short-range sensors and users. In urban environments, obstacles and quick changes in the landscape combined with the UAV passing by too quickly would not maintain reliable connections and can require re-transmissions. In addition, higher velocities increase handovers and variability in link quality, adding computational overhead and degrading user experience.

TABLE IV
ADOPTED PARAMETERS FOR EACH SLICE

| Setting | eMBB (FR1) | eMBB (FR2) | URLLC | mMTC |
|---|---|---|---|---|
| MCS table | QAM256 | QAM256 | QAM64-LowSE | QAM64-LowSE |
| Numerology $\mu$ | 1 | 3 | 2 | 0 |
| Subcarrier spacing $= 2^{\mu} \cdot 15kHz$ | 30kHz | 120kHz | 60kHz | 15kHz |
| Bandwidth | 100 MHz | 200 MHz | 100 MHz | 5 MHz |
| message size | 4 Kbits | 4 Kbits | 3 Kbits | 1 Kbits |
| maximum user data rate | 1 Gbps | 1 Gbps | 200 Mbps | 10 Mbps |

The selected radio channel and physical layer properties are summarized in Table IV. The attributes are chosen in accordance with each slice's priorities and its typical device's capabilities.

### C. Tests and Results

This work studies a multi-drone system serving users with heterogeneous network slice and data-rate requirements. Performance is evaluated using user-centric metrics (achievable data rates, connected users, received/failed messages, traffic volume, and service time) to derive user satisfaction, alongside drone-centric metrics such as battery lifetime and overall performance.

Although URLLC is included in the scope of this study, no latency simulations were performed because accurately modeling end-to-end delay in multi-UAV systems requires incorporating several timing components, including scheduling delays, queuing dynamics, retransmissions, and additional control signaling between UAVs and BSs. Without these elements, latency results risk being incomplete or misleading. Consequently, computing reliable end-to-end latency values within the current simulation framework would require introducing significant assumptions that could lead to inaccurate conclusions. Therefore, the analysis focuses on transmission reliability indicators that are closely related to latency behavior. In particular, failed traffic is used as an indirect indicator of latency effects, since retransmissions triggered by failed transmissions directly contribute to additional delay in URLLC communications.

Two user-distribution models are analyzed: (i) a fully random distribution, used mainly for evaluating the hybrid system where users with different slice requirements coexist in the same area, and (ii) a slice-aware distribution, where each slice is tested separately with realistic spatial deployments (e.g., mMTC in agricultural areas and eMBB in urban zones). Additionally, a hybrid scenario—combining slice-dedicated drones with conventional drones—is investigated as the main focus of the paper.

Each slice and scenario is evaluated independently. The number of drones varies from 5 to 150, and up to 500 in some experiments, while the number of users ranges from 100 to 50,000. Reported values represent averages across all repetitions in each scenario configuration, and variability was monitored by calculating the spread of outcomes across runs. Each scenario was repeated until the results stabilized and variability was reduced. Fluctuations mostly disappeared after approximately 10–14 runs for low-density user scenarios and after 4–7 runs for high-density cases. As a result, low-density scenarios were repeated about 25 times, while high-density cases were repeated 10–15 times, despite the exponential increase in computational time with user load.

The reported values represent averages across repetitions, with variability monitored to confirm stability of outcomes. This procedure improves the robustness of the evaluation by reducing the impact of random fluctuations.

*1) Number of Served Users:* The number of connected users is considered as the main attribute to compare performance in each slice scenario individually. This metric allows us to evaluate how many users are served on average for each slice and UAV type compared to typical UAVs. The evaluations presented in Fig. 5 showcase the connected user rates for averaged UAV numbers for each slice. The results are presented as the average number of connected users across all tested UAV counts (from 5 to 150 in this instance). This averaging collapses the results and removes UAV-specific fluctuations and allows clearer comparison of user connectivity trends between typical UAVs custom UAVs as the number of users increases. This test emphasizes on the performance in the context of user numbers, whereas, subsubsection IV-C4 analyzes the performance of varying UAV numbers specifically

*a) eMBB Users:* We observe in Fig. 5 that the proposed eMBB UAVs deliver the best performance compared to typical UAVs. The proposed eMBB UAVs allow for more capacity and better overall link quality. As a result, the proposed UAVs can deliver higher data rates. High throughputs are required by eMBB UEs which explains the higher connection rate with eMBB UAVs. However, due to the stringent requirements of eMBB, we notice about 48% connection rate when using eMBB UAVs and a lower 32% with typical UAVs when considering 50000 users.

*b) mMTC:* In Fig. 5, we notice a slight improvement when comparing typical and mMTC slice UAVs. However, it should be mentioned that mMTC UAVs are considered to have half the capacity of typical UAVs. Moreover, when calculating the percentages of connected users we find that typical UAVs have an 84% connection rate whereas mMTC UAVs average at 92%. Thanks to the low requirements of MTCDs, high connection rates can be achieved if supported by the back-haul. Whereas, eMBB and URLLC connection rates often remain lower than 80%.

*c) URLLC Users:* Even with lower frequency and transmit powers, we see URLLC UAVs perform similar to typical UAVs. Furthermore, the URLLC UAVs should have longer flight times thanks to the low transmit power and frequency. When calculating average percentages of connected users, the

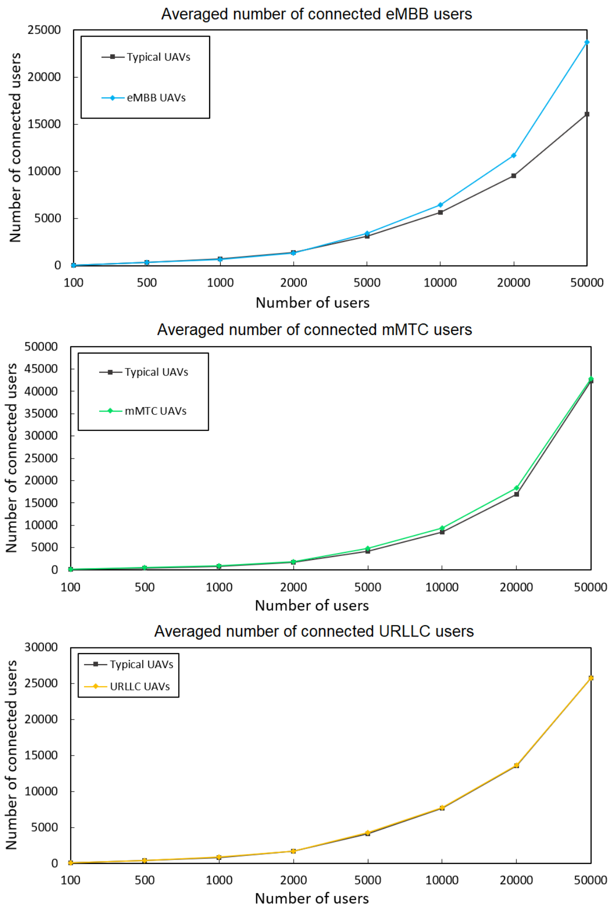


Fig. 5. Averaged numbers of connected users

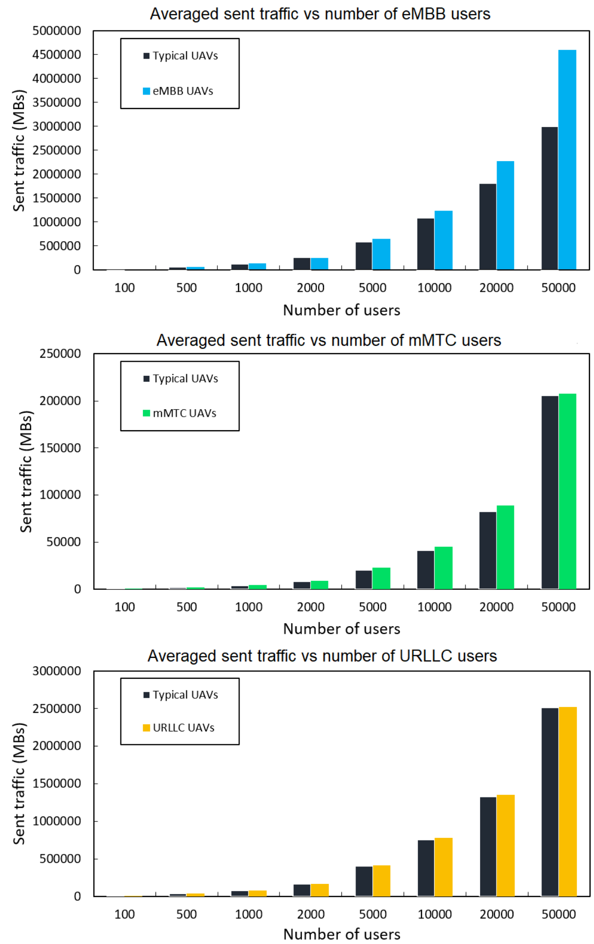


Fig. 6. Averaged sent traffic for the three slices

typical and specialized URLLC UAVs have similar performance with 76% and 77% respectively.

*2) Maximum Traffic / Throughput:* The averaged traffic is depicted in Fig. 6 for each slice. This test showcases the amount of bytes sent in each scenario. A higher traffic is preferred as it means better link quality and more user satisfaction.

*a) eMBB:* For eMBB, higher traffic is critical as it demonstrates that users experience more throughput. We can observe in Fig. 6 that both typical and slice UAVs types perform similarly when user numbers are lower than 3000. However, at higher user numbers, the eMBB UAVs can support more traffic.

*b) mMTC:* As shown in Fig. 6, the mMTC UAVs allow for more traffic when compared to typical UAVs. The average traffic supported by mMTC UAVs is 9% higher than typical UAVs.

*c) URLLC:* In URLLC, we observe similar performance when considering the amount of sent traffic (Fig. 6). The URLLC UAVs have lower frequency and transmit power since URLLC users do not prioritize data rate.

For URLLC, the amount of sent traffic is less important than latency. However, failed messages are a major issue for the URLLC slice. Failed transmissions typically trigger retransmissions, which introduce additional delay and may violate strict latency requirements. Consequently, reducing failed traffic contributes to minimizing retransmission-induced latency. Therefore, Fig. 7 depicts the percentage of failed messages and provides insight into latency-related performance trends by highlighting improvements in communication reliability.

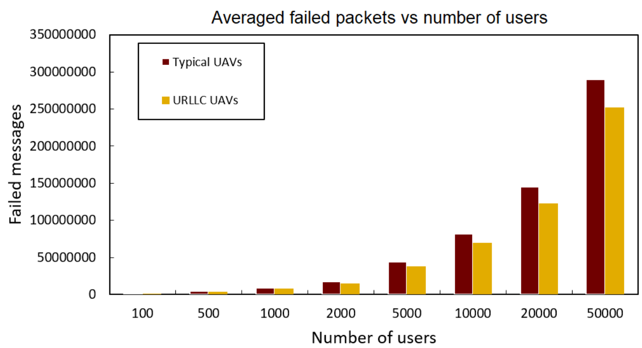


Fig. 7. Averaged failed traffic for the URLLC slice

We see that with somewhat similar sent traffic, the number of failed messages are noticeably lower when using URLLC UAVs. Although some failed messages can be corrected at the receiver end, others may be too erroneous to be recovered and will require re-transmission. The low frequencies used in URLLC UAVs proved to be essential in lowering the rate of failed messages. When comparing the percentages of failed messages, typical UAVs average at 4%, whereas URLLC UAVs average at 3.1% out of the total sent messages.

*3) User Connection Time:* Since both users and UAVs are mobile, users can be disconnected anytime due to channel conditions. To test the stability of the UAV-assisted network, the total connection times of users have been collected and are discussed below for each slice.

Multiple simulation times are tested, as a result, we use the percentage of connection time from the overall simulation times. The connection time percentage represents the proportion of the users' requested service duration that is successfully maintained by the UAVs. Users specify connection periods that vary in length, which makes it impractical to compare results by listing individual times directly. Instead, the metric is expressed as a percentage: if the UAVs sustain the connection for the entire requested duration, the value is 100%, while partial service results in a lower percentage proportional to the time actually served. The reported values are averaged across all users, providing a normalized and comprehensive measure of UAV performance in sustaining user connections.

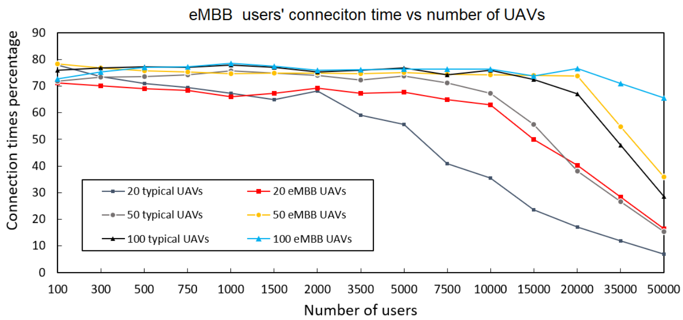


Fig. 8. eMBB users' connection time percentages vs number of deployed UAVs (20, 50, and 100)

*a) eMBB:* The eMBB slice is very demanding, requiring more UAVs to be deployed for a good satisfaction rate, as illustrated in Fig. 8. For eMBB, the connection time percentages start falling drastically with high user numbers as eMBB devices have high throughput demands and cannot connect if their required data rate is not met.

By comparing connection times, there is a noticeable improvement when using eMBB UAVs. We observe that typical UAVs provide lower connection times whereas deploying the same and even fewer eMBB UAVs can yield better results with higher user numbers. For example, when considering 20000 users, 100 typical UAVs are needed for a 67 % connection time rate, whereas, 50 eMBB UAVs are sufficient for a better performance (74% connection time).

*b) mMTC:* In Fig. 9, we see the proposed UAV types can satisfy users better than typical UAVs by allowing more connection times. For instance, when deploying 10 UAVs, typical UAVs allow for an average 64% connection time compared to the custom UAVs' 83%. The increased performance is due to the frequency, range, and height of the custom UAVs, allowing better link quality for their respective users.

We also observe that Typical and mMTC UAVs reach 96% and 99% respectively, meaning almost all mMTC devices are connected throughout the simulation run. This is achievable

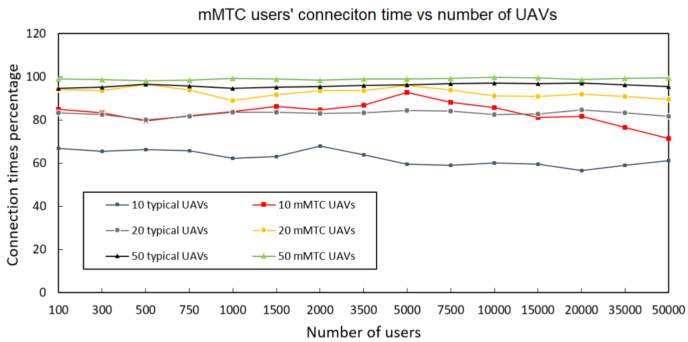


Fig. 9. mMTC users' connection time percentages vs number of deployed UAVs (10, 20, and 50)

thanks to the low demands of MTCDs, combined with using the QAM64-LowSE table, providing adequate wireless connections even with average quality links.

Moreover, deploying more than 100 UAVs for the selected area and number of users will yield a 100% connection time.

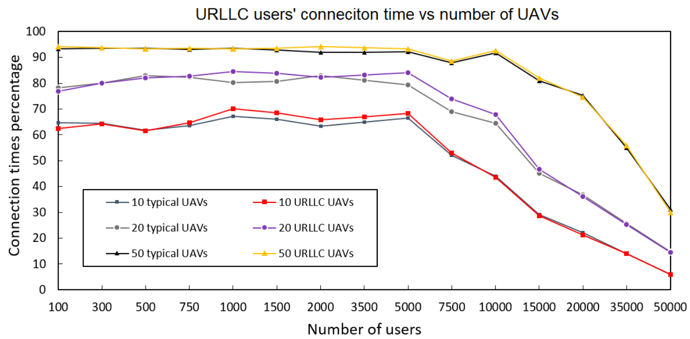


Fig. 10. URLLC users' connection time percentages vs number of deployed UAVs (10, 20, and 50)

*c) URLLC:* The URLLC scenario is illustrated in Fig. 10. We observe that both systems offer similar performances with URLLC UAVs having a slight 0.9% advantage overall. However, URLLC requires further latency and delay testings as it is the priority of this slice.

*4) Optimal UAV Numbers:* Given that the proposed UAV types are more specialized, fewer UAVs should be needed to achieve the desired performance. To observe the effect of UAV numbers on performance, multiple simulations are performed by varying user numbers from 100 to 50000 and the number of UAVs from 5 to 500.

The results depicted in Fig. 11 represent the percentages of connected users to estimate an optimal ratio of users to UAVs.

The results given below will prove that specialized UAVs can support more users. As a result, deploying fewer slice UAVs achieves similar or better performance compared to typical UAVs.

*a) mMTC:* For the mMTC slice, we can clearly observe in Fig. 11 that a user connection rate of 100% is achievable. This high satisfaction rate is obtainable thanks to the very low requirements of mMTC devices.

The proposed UAVs can reach 98.5 % users connected with a rate of 100 users per UAV. Whereas, a rate of 50

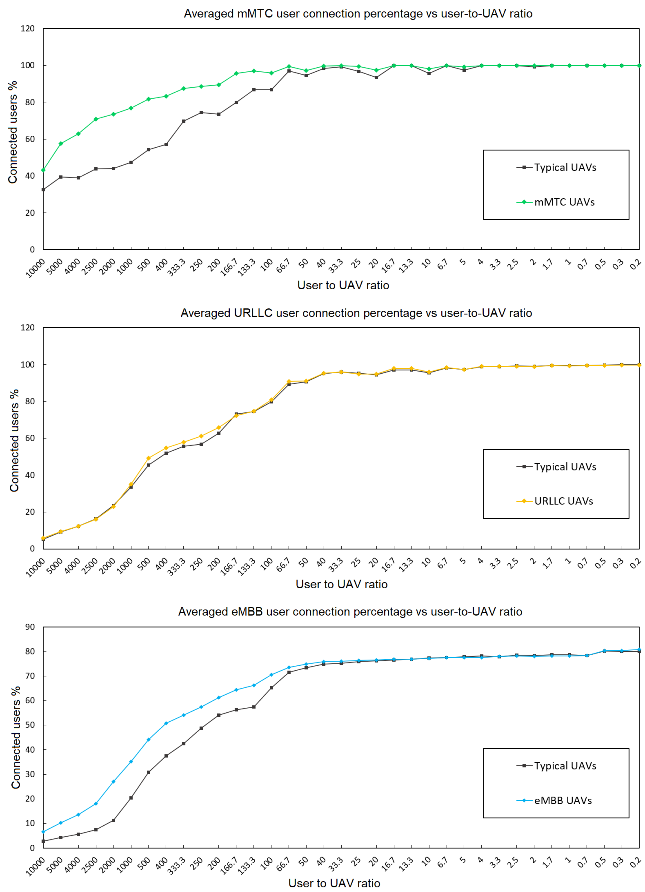


Fig. 11. Effect of UAV numbers on user connection rate

users per UAV is needed to achieve similar performance with typical UAVs. Therefore, typical UAVs should be double that of mMTC UAVs even with having half the capacity of typical UAVs (10 Gbps). However, at a rate of 50 users per UAV, the performance is similar, satisfying over 99% of users for both UAV types.

We also observe an increased connection percentages at high user-to-UAV ratios for the proposed mMTC UAVs. This further indicates fewer custom slice UAVs are needed to outperform typical all-slice UAVs. The percentage of connected users surpasses 90% at a ratio of 400 for typical UAVs, whereas a ratio of 500 is sufficient with mMTC UAVs. Therefore, each specialized UAV will be able to serve 100 more users.

We conclude that an mMTC UAV for each 100 users is sufficient for the maximum achievable performance. Adding more UAVs will not benefit performance.

*b) URLLC:* For URLLC, we notice similar performance from both UAV types. URLLC UAVs allow for a slightly improved performance between 500 to 200 user-to-UAV ratio. As apparent in Fig. 11, URLLC devices can reach 100% connectivity. However, this is achieved with very low user-to-UAV ratios.

*c) eMBB:* As for the eMBB slice, we notice an improved connection rate when deploying eMBB UAVs over typical UAVs. The eMBB UAVs hold a better connection percentage up to a 33 user-to-UAV ratio. After this rate, the typical and eMBB UAVs yield the same performance with 76% to 80% users connected.

Moreover, to observe the effect of UAV numbers further, another eMBB slice scenario is tested. The plots in Fig. 12 represent connected user percentages for 10000, 20000, and 50000 users for a more distinct comparison. We can observe that as the number of users rise, the performance of typical UAVs is decreasing when compared to custom eMBB UAVs. Furthermore, we observe that when the number of UAVs exceeds a certain threshold, the performance does not increase accordingly. From the data in Fig. 12 we derive that beyond a rate of 200 users per UAV, the performance gains are negligible when serving eMBB users.

In essence, based on the connectivity trends observed in Fig. 11 and Fig. 12, practical deployment guidelines can be derived for user-to-UAV ratios for each slice. For mMTC traffic, one specialized UAV per approximately 100 users is sufficient to maintain connectivity above 98%, whereas twice the number of typical UAVs may be required to achieve similar performance. For eMBB services, connectivity improvements stabilize beyond approximately 200 users per UAV, indicating that additional UAVs beyond this point provide limited benefits. In contrast, URLLC traffic requires relatively low user-to-UAV ratios (about 40 URLLC users per UAV) to ensure connectivity, reflecting its stringent reliability requirements. Overall, these observations indicate that specialized UAV deployments can efficiently support higher user densities (especially mMTC users) and that the system scales with increasing user demand when UAV density is increased accordingly.

*5) Changing the Carrier Frequency:* The eMBB slice requires providing its users with the highest achievable data rates. Therefore, the use of higher frequencies such as the mm-wave can be necessary in the eMBB slice.

We compare the UAVs against special eMBB UAVs with FR2 to see its effect on performance (*see* Table IV for the adopted R2 parameters). The Typical UAV frequency is kept in FR1 as it is not suitable for other slices such as mMTC and URLLC. eMBB UAVs with FR1 are also included for a coherent comparison.

The results in Fig. 13 prove that having specific slice UAVs is necessary since each slice has different needs. Overall, the sent traffic is larger when exploiting eMBB UAVs, especially with FR2. We notice a 30% improvement over using specialized eMBB UAVs with FR1 and over 70% over using typical UAVs.

As for user data rates, we see in Fig. 13 that users can experience more than 100 Mbps, which is the target data rate in 5G [5]. However, the data rate decreases when increasing the number of users. moreover, eMBB UAVs maintain throughputs above 100 Mbps for more users when compared to typical UAVs. However, FR2 provides more throughput overall, and maintains user experienced data rates above 100 Mbps with 50000 system users.

*6) Hybrid / All Slices Full Comparison:* Hybrid performance evaluation is included to observe the effect of deploying typical and proposed UAV types. In this hybrid mode we include all slices. The hybrid system is compared to a system

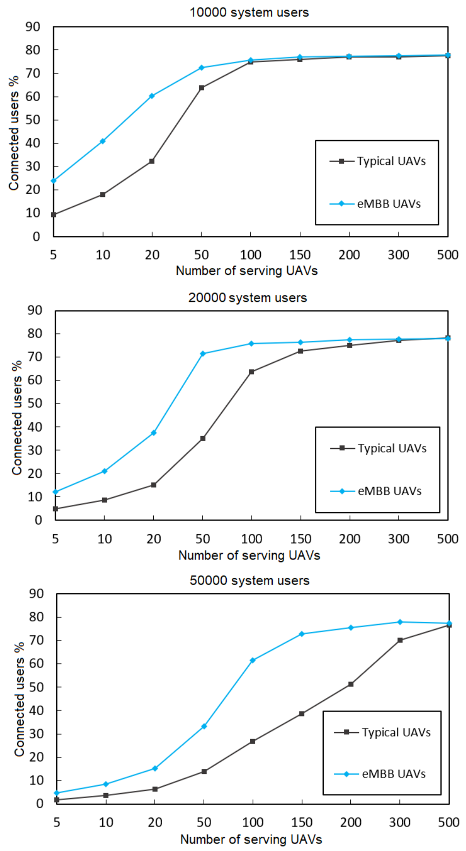


Fig. 12. UAV numbers effect on user connection rate for 10000, 20000, and 50000 users

with typical UAVs. Deploying all four UAV types should increase availability, stability, and satisfaction rates.

As apparent in Fig. 14, increasing the number of UAVs will result in better performance for all systems. The user numbers range from 100 to 50000 for each set of UAV numbers to observe the effect of UAV numbers on results.

Figure 14 represents connection rates for typical and proposed UAV types. Results in Fig. 14 prove that having all slice types in addition to typical UAVs yields better performance compared to a typical UAVs-only system.

we can see that when using 500 UAVs, the number of connected users reaches 46000 and 48000 for typical and hybrid systems respectively, delivering rates of 92% and and increased 96% connection rate for the hybrid system.

Furthermore, in Fig. 15 the hybrid system is compared to typical and slice UAVs. The connection times logically increase by increasing the number of deployed UAVs. We observe that slice UAVs offer better performance with numbers lower than 20. Both slice UAVs and the hybrid mode offer more connection times compared to typical UAVs with numbers lower than 150. The slice UAVs and hybrid system deliver more connection times for users, reaching 34% more when compared to typical UAVs. Between 150 and 200 UAVs, the typical UAVs offer slightly higher connection times (about 0.9% to 1.4% more than hybrid mode) due to the large availability and coverage of all-purpose UAVs. However, when UAVs are more than 200, the hybrid system starts

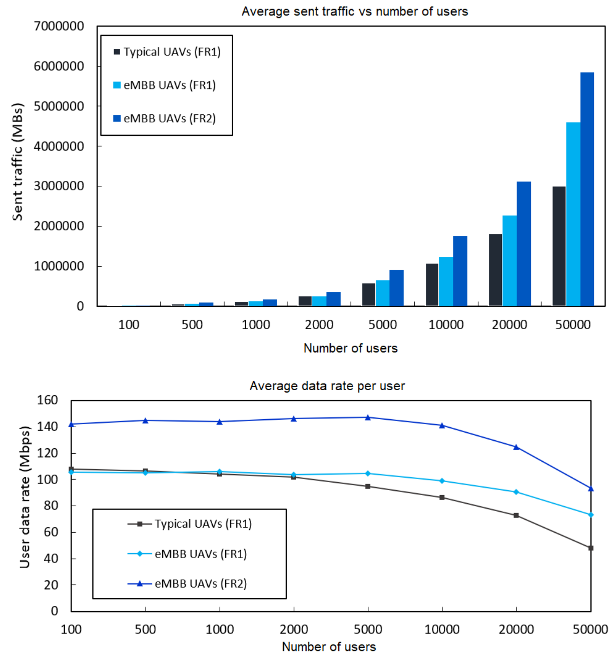


Fig. 13. Average sent traffic and user experienced data rates in FR1 and FR2 for typical and eMBB UAVs

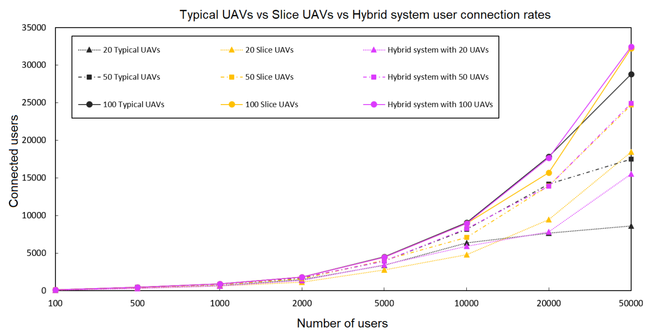


Fig. 14. Typical system vs proposed hybrid system with all slices

outperforming the typical UAV system.

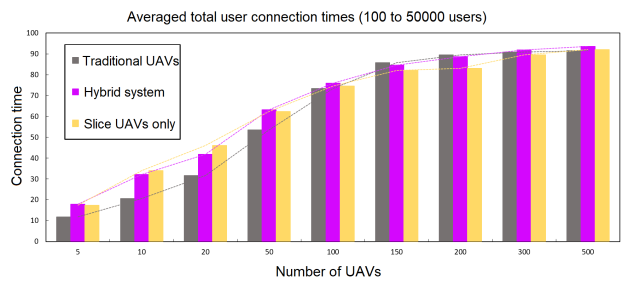


Fig. 15. Averaged connection times for typical UAVs vs slice UAVs vs a hybrid system

Indeed, the higher performance results of typical UAVs is limited to the range of 150 to 200 UAVs. This small performance edge is caused by having a sufficient number of typical UAVs that cover the user area, where the proposed systems' coverage is lower. This is caused by custom UAVs' limit of only serving one user type. In addition, for the hybrid system, the number of UAVs is divided into typical and custom UAVs, which explains the performance gap. Below the 150 range, the number of UAVs is not sufficient to satisfy demanding slice users, especially with their all-purpose capabilities that are inferior to custom equipped drones. As a result, we see the proposed systems surpass the typical UAVs' performance. This proves that having custom equipped drones will have better efficiency at lower numbers. Alternatively, when the number of UAVs is higher than 200 we see the rise in the performance of the proposed systems, as the custom UAVs' capabilities and improved availability allow for serving more users than typical drones.

*7) UAV Energy Endurance:* The endurance curves in Fig. 16 show battery lives for all UAVs, calculated from various factors such as propulsion variables (number of rotors, UAV wing type, speed) and communication (transmit power, number of connected users, traffic) along with the battery capacity of each UAV type.

Fig. 16 shows that the typical UAV outperforms all other UAV types below 400 users thanks to its superior configuration, however, as numbers increase, so does its depletion rate. The typical and the eMBB UAV exhibit similar behavior as they share similar hardware configurations. At low traffic levels, both types maintain comparable flight times. However, as user numbers increase, the eMBB UAV slightly outperforms the typical UAV as it only serves eMBB users, unburdened by the overhead of other slices. In contrast, the typical UAV must handle all slice traffic simultaneously, accelerating its battery depletion. At the very end of the stress test, the typical UAV's capacity is fully saturated, which explains why its loss rate slows down, while the eMBB UAV continues to lose endurance steadily as its capacity still allows for additional users.

The URLLC UAV, with a smaller battery and reduced transmit power, shows moderate endurance consistent with its design trade off of prioritizing reliability and latency over flight duration. Finally, the mMTC UAV is constrained by its lowest battery capacity combined with the large number of users it serves, which explains its shorter endurance overall. However, the fixed wing design helps it hold a steady battery loss, outliving all other UAV types at higher user numbers which is essential for mMTC requirements.

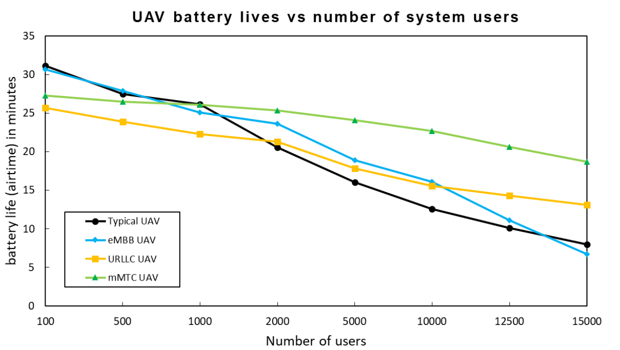


Fig. 16. Average battery lifetimes for all UAV types vs number of system users

### D. Learned Lessons

The distinction between UAVs in our study and conventional drones lies in their technological features and intended functionality. In contrast to typical drones, the proposed UAVs are equipped with slice-specific resources and capabilities and are aligned with 5G NR standards. These capabilities are different depending on the targeted slice, as different slices require different metrics. Tests indicate that customized slice UAVs outperform typical UAVs due to attributes such as carrier frequency and deployment height tailored to user requirements in each specific slice. These enhancements enable them to connect more users, sustain higher connection times, and achieve greater throughput, as demonstrated across the results.

*2) mMTC and URLLC:* Evaluating these slices focuses on massive user capacity and reliability rather than throughput. URLLC UAVs reduce failed messages and queuing delay, minimizing hops to the backbone. Dedicated mMTC UAVs utilize specific protocols and lower frequencies to support massive connections, particularly in open agricultural fields.

*3) Link quality:* Link quality depends on frequency, bandwidth, SNR, LoS, and modulation, directly impacting BER and PER. Optimizing UAV transmission power, frequency, and height is critical to minimize re-transmission delays.

*4) Hybrid deployment:* While custom UAVs perform better per slice, a hybrid system combining specialized and typical UAVs offers the best overall results, providing high performance with necessary fallback capabilities.

*5) Energy efficiency:* Dedicating UAVs to specific slices improves energy efficiency, whereas using single-type UAVs for all services—particularly eMBB—depletes batteries significantly faster.

### E. Issues

*a) Back-haul link:* Where wired links are impossible, UAVs must rely on wireless back-haul (mm-wave, satellite, or nearest BS) or high-frequency V/E-bands [48].

*b) URLLC and guaranteeing low latency:* To ensure low latency, RAN must minimize hops and the Core Network must prioritize URLLC traffic. UAVs should dynamically select relay paths (satellite vs. ground BS) based on estimated delay.

*c) User distribution:* Dedicated UAVs become inefficient in mixed-user scenarios. A hybrid system assisted by optimization of UAV paths and deployment addresses these distribution challenges while considering energy efficiency.

*d) Limited capacity and inter-slice competition:* This study assumes sufficient network capacity to remove the bottleneck and ensure fair comparison across slices. While this simplification highlights efficiency and trade-offs, it reduces realism since capacity constraints are central to network slicing. Future work will incorporate smart capacity management strategies to address resource competition and bottlenecks, enabling a more realistic and adaptive evaluation framework.

Furthermore, it is important to note that these results are obtained without inter-slice competition. In practical deployments, shared resource constraints would introduce contention between slices, potentially reducing the observed performance gains. Therefore, the results highlight the benefits of slice-dedicated UAV configurations in a controlled setting, showing promise for more realistic deployments.

## V. Conclusions and Future Opportunities

This work investigated the integration of UAVs into network slicing by proposing slice-dedicated and customized UAV fleets for eMBB, URLLC, and mMTC services. The results demonstrate that specialized UAVs outperform typical all-purpose UAVs, achieving higher user connectivity, improved throughput, and longer connection times, while requiring fewer deployed UAVs. These findings highlight the effectiveness of tailoring UAV configurations like frequency, transmit power, and deployment strategies to the specific requirements of each network slice. Hybrid deployments combining specialized and conventional UAVs provide the best overall performance by balancing efficiency, flexibility, and coverage. The results also confirm that UAV-assisted slicing can significantly enhance QoS while maintaining compatibility with existing 5G RAN architectures. Beyond economic benefits to service providers, introducing UAVs as relays in each cell benefits non-cellular users such as mMTC devices by enabling alternative connection protocols and wireless charging capabilities [49]. Despite these promising results, several challenges remain. Energy consumption is a critical limitation, as flight endurance is directly impacted by communication load, hardware configuration, and deployment density. The analysis in IV-C7 quantifies this trade-off and shows the distinct UAV energy profiles, motivating future research into energy-efficient deployment, adaptive power control, and joint optimization of communication and mobility to extend UAV operational lifetime. Furthermore, capacity constraints and resource allocation were simplified in this study to isolate and analyze the impact of UAV specialization and validate their effectiveness. Incorporating realistic capacity limitations and inter-slice resource competition represents an important direction for future work. Similarly, as this work provides a proof-of-concept evaluation of slice-dedicated UAV configurations, future work will extend this model by incorporating inter-slice competition, capacity constraints, and scheduling mechanisms to assess performance under realistic network slicing conditions. Security and resilience also present critical challenges arising from the wireless and distributed nature of UAV communications. Potential risks include jamming attacks that could disrupt UAV-to-user or UAV-to-BS links, as well as physical threats such as drone capture, tampering, and spoofing of navigation signals. Future research should investigate proactive strategies such as intelligent path planning to avoid jamming, spread spectrum techniques, and dynamic multi-band operation, as well as reactive countermeasures like fast handover, adaptive power control, and cooperative multi-UAV relaying. Future work will also explore hybrid architectures where UAVs are shared across multiple slices, enabling inter-slice interaction and resource allocation aligned with practical network slicing principles. Finally, optimizing UAV placement, trajectory, and slice assignment through machine learning and real-time analytics remains a key research direction for enhancing deployment efficiency and adaptability. Overall, UAV-assisted network slicing remains a promising paradigm for beyond 5G networks, provided these challenges are effectively addressed.

## References

[1] M. Ahmed, A. A. Soofi, S. Raza, Y. Li, F. Khan, W. U. Khan, M. Asif, and Z. Han, "A comprehensive survey on ris-enhanced physical layer security in uav-assisted networks," *IEEE Internet of Things Journal*, 2025.

[2] S. A. Owaid, A. H. Miry, and T. M. Salman, "A survey on uav-assisted wireless communications: Challenges, technologies, and application," in *2024 11th International Conference on Electrical and Electronics Engineering (ICEEE)*. IEEE, 2024, pp. 333–340.

[3] X. Gu and G. Zhang, "A survey on uav-assisted wireless communications: Recent advances and future trends," *Computer Communications*, vol. 208, pp. 44–78, 2023.

[4] X. Fan and Y. Huo, "An overview of low latency for wireless communications: an evolutionary perspective," *arXiv preprint arXiv:2107.03484*, 2021.

[5] M. Series, "Imt vision–framework and overall objectives of the future development of imt for 2020 and beyond," *Recommendation ITU*, vol. 2083, p. 0, 2015.

[6] P. Subedi, A. Alsadoon, P. Prasad, S. Rehman, N. Giweli, M. Imran, and S. Arif, "Network slicing: A next generation 5g perspective," *EURASIP Journal on Wireless Communications and Networking*, vol. 2021, no. 1, p. 102, 2021.

[7] T. Bouzid, N. Chaib, and M. L. Bensaad, "Crowd-sourced and incentive driven uav system to assist with network slices," *Transactions on Emerging Telecommunications Technologies*, vol. 35, no. 1, p. e4920, 2024.

[8] S. Alqefari and M. E. B. Menai, "Multi-uav task assignment in dynamic environments: Current trends and future directions," *Drones*, vol. 9, no. 1, p. 75, 2025.

[9] Y. Li, Y. Bi, J. Wang, Z. Li, H. Zhang, and P. Zhang, "Unmanned aerial vehicle assisted communication: applications, challenges, and future outlook," *Cluster Computing*, vol. 27, no. 9, pp. 13 187–13 202, 2024.

[10] T. Bouzid, N. Chaib, M. L. Bensaad, and O. S. Oubbati, "5g network slicing with unmanned aerial vehicles: Taxonomy, survey, and future directions," *Transactions on Emerging Telecommunications Technologies*, vol. 34, no. 3, p. e4721, 2023.

[11] H. Sun, Y. Liu, A. Al-Tahmeesschi, A. Nag, M. Soleimanpour-Moghadam, B. Canberk, H. Arslan, and H. Ahmadi, "Advancing 6g: Survey for explainable ai on communications and network slicing," *IEEE Open Journal of the Communications Society*, 2025.

[12] Y. Yazid, I. Ez-Zazi, A. Guerrero-González, A. El Oualkadi, and M. Arioua, "Uav-enabled mobile edge-computing for iot based on ai: A comprehensive review," *Drones*, vol. 5, no. 4, 2021.

[13] R. Shahzadi, M. Ali, H. Z. Khan, and M. Naeem, "Uav assisted 5g and beyond wireless networks: A survey," *Journal of Network and Computer Applications*, vol. 189, p. 103114, 2021.

[14] L. Zhang, H. Zhao, S. Hou, Z. Zhao, H. Xu, X. Wu, Q. Wu, and R. Zhang, "A survey on 5g millimeter wave communications for uav-assisted wireless networks," *IEEE Access*, vol. 7, pp. 117 460–117 504, 2019.

[15] Z. Wei, M. Zhu, N. Zhang, L. Wang, Y. Zou, Z. Meng, H. Wu, and Z. Feng, "Uav-assisted data collection for internet of things: A survey," *IEEE Internet of Things Journal*, vol. 9, no. 17, pp. 15 460–15 483, 2022.

[16] M. T. Nguyen, C. V. Nguyen, H. T. Do, H. T. Hua, T. A. Tran, A. D. Nguyen, G. Ala, and F. Viola, "Uav-assisted data collection in wireless sensor networks: A comprehensive survey," *Electronics*, vol. 10, no. 21, p. 2603, 2021.

[17] M. Basharat, M. Naeem, Z. Qadir, and A. Anpalagan, "Resource optimization in uav-assisted wireless networks—a comprehensive survey," *Transactions on Emerging Telecommunications Technologies*, vol. 33, no. 7, p. e4464, 2022.

[18] H. Ren, C. Pan, K. Wang, W. Xu, M. Elkashlan, and A. Nallanathan, "Joint transmit power and placement optimization for urllc-enabled uav relay systems," *IEEE Transactions on vehicular technology*, vol. 69, no. 7, pp. 8003–8007, 2020.

[19] C. Pan, H. Ren, Y. Deng, M. Elkashlan, and A. Nallanathan, "Joint blocklength and location optimization for urllc-enabled uav relay systems," *IEEE Communications Letters*, vol. 23, no. 3, pp. 498–501, 2019.

[20] M. Ozger, M. Vondra, and C. Cavdar, "Towards beyond visual line of sight piloting of uavs with ultra reliable low latency communication," in *2018 IEEE global communications conference (GLOBECOM)*. IEEE, 2018, pp. 1–6.

[21] P. Wang, M. Ozger, C. Cavdar, and M. Petrova, "Beyond visual line of sight piloting of uavs using millimeter-wave cellular networks," in *2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*. IEEE, 2019, pp. 1–7.

[22] K. Zhu, X. Xu, and Z. Huang, "Energy-efficient routing algorithms for uav-assisted mmtc networks," in *2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*. IEEE, 2019, pp. 1–6.

[23] P. Rahimi, C. Chrysostomou, I. Kyriakides, and V. Vassiliou, "An energy-efficient machine-type communication for maritime internet of things," in *2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*. IEEE, 2020, pp. 0668–0676.

[24] P. Yang, X. Xi, K. Guo, T. Q. Quek, J. Chen, and X. Cao, "Proactive uav network slicing for urllc and mobile broadband service multiplexing," *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 10, pp. 3225–3244, 2021.

[25] P. Yang, X. Xi, J. Chen, T. Q. Quek, X. Cao, and D. O. Wu, "Ran slicing in a uav network for embb service provision," *arXiv preprint arXiv:1912.03600*, 2019.

[26] I. Donevski, J. J. Nielsen, and P. Popovski, "Standalone deployment of a dynamic drone cell for wireless connectivity of two services," in *2021 IEEE Wireless Communications and Networking Conference (WCNC)*. IEEE, 2021, pp. 1–7.

[27] B. Yu, X. Guan, and Y. Cai, "Joint blocklength and power optimization for half duplex unmanned aerial vehicle relay system with short packet communications," in *2020 International Conference on Wireless Communications and Signal Processing (WCSP)*. IEEE, 2020, pp. 981–986.

[28] C. Grasso and G. Schembra, "A fleet of mec uavs to extend a 5g network slice for video monitoring with low-latency constraints," *Journal of Sensor and Actuator Networks*, vol. 8, no. 1, p. 3, 2019.

[29] D. Mishra, E. Traversi, A. Trotta, P. Raut, B. Galkin, M. Di Felice, and E. Natalizio, "Network slicing in aerial base station (uav-bs) towards coexistence of heterogeneous 5g services," *Computer Networks*, vol. 261, p. 111146, 2025.

[30] F. Wei, G. Feng, S. Qin, Y. Peng, and Y. Liu, "Hierarchical network slicing for uav-assisted wireless networks with deployment optimization," *IEEE Journal on Selected Areas in Communications*, vol. 42, no. 12, pp. 3705–3718, 2024.

[31] E. Skondras, E. T. Michailidis, A. Michalas, D. J. Vergados, N. I. Miridakis, and D. D. Vergados, "A network slicing framework for uav-aided vehicular networks," *Drones*, vol. 5, no. 3, p. 70, 2021.

[32] S. Zhang, H. Zhang, Q. He, K. Bian, and L. Song, "Joint trajectory and power optimization for uav relay networks," *IEEE Communications Letters*, vol. 22, no. 1, pp. 161–164, 2017.

[33] Y. Zeng, J. Xu, and R. Zhang, "Energy minimization for wireless communication with rotary-wing uav," *IEEE transactions on wireless communications*, vol. 18, no. 4, pp. 2329–2345, 2019.

[34] 3GPP˙RAN˙group *et al.*, "Study on channel model for frequencies from 0.5 to 100 ghz (release 15)," 3GPP TR 38.901, Tech. Rep., 2018.

[35] 3GPP, "Technical specification group radio access network; nr; physical layer procedures for data (version 16.2.0 release 16)," *3rd Generation Partnership Project (3GPP), Technical Specification (TS) 38.214*, 2020.

[36] R. Kovalchukov, D. Moltchanov, Y. Gaidamaka, and E. Bobrikova, "An accurate approximation of resource request distributions in millimeter wave 3gpp new radio systems," in *Internet of Things, Smart Spaces, and Next Generation Networks and Systems*. Springer, 2019, pp. 572–585.

[37] ETSI, "Base station (bs) radio transmission and reception (3gpp ts 38.104 version 17.5. 0 release 17)," *European Telecommunications Standards Institute (ETSI), 3rd Generation Partnership Project (3GPP): Sophia-Antipolis, France*, 2022.

[38] 3GPP, "Technical specification group radio access network; 5g; nr; user equipment (ue) radio transmission and reception; part 1: Range 1 standalone (release 17), 3gpp ts 38.101-1 v17. 5.0," 2022.

[39] 3GPP-Release-15(TS-38.306), "5g;nr;user equipment (ue) radio access capabilities v15.3.0," 3GPP, Tech. Rep., 2018.

[40] 3GPP, "Nr; physical channels and modulation," *3rd Generation Partnership Project (3GPP), Technical Specification (TS) 38.211*, vol. 9, 2018.

[41] ——, "Technical specification group radio access network; nr; user equipment (ue) radio transmission and reception; part 1: Range 1 standalone (release 15), 3gpp ts 38.101-1 v15. 5.0," 2019.

[42] ——, "Technical specification group radio access network; nr; user equipment (ue) radio transmission and reception; part 2: Range 2 standalone (release 15), 3gpp ts 38.101-2 v15. 5.0," 2019.

[43] "Simu5g." [Online]. Available: http://simu5g.org/

[44] G. Nardini, D. Sabella, G. Stea, P. Thakkar, and A. Virdis, "Simu5g–an omnet++ library for end-to-end performance evaluation of 5g networks," *IEEE Access*, vol. 8, pp. 181 176–181 191, 2020.

[45] "Nyusim." [Online]. Available: https://wireless.engineering.nyu.edu/nyusim/

[46] T. S. Rappaport, S. Sun, and M. Shafi, "Investigation and comparison of 3gpp and nyusim channel models for 5g wireless communications," in *2017 IEEE 86th vehicular technology conference (VTC-Fall)*. IEEE, 2017, pp. 1–5.

[47] 3GPP, "Technical report digital cellular telecommunications system (phase 2+) (gsm); universal mobile telecommunications system (umts); lte; 5g; (release 15), 3gpp tr 121 915 v15. 0.0," 2019.

[48] M. G. L. Frecassetti, B. Backemo, D. Gentina, G. Ferrari, J. Edstam, L. Yigal, N. Zein, P. Nava, P. Volpato, R. Macchi *et al.*, "E-band and v-band-survey on status of worldwide regulation," *European Telecommunications Standards Institute (ETSI)*, 2015.

[49] Z. Xiong, Y. Zhang, W. Y. B. Lim, J. Kang, D. Niyato, C. Leung, and C. Miao, "Uav-assisted wireless energy and data transfer with deep reinforcement learning," *IEEE Transactions on Cognitive Communications and Networking*, vol. 7, no. 1, pp. 85–99, 2020.


## References

**Bouzid Tarek** received his masters degree and Ph.D. from the university of Laghouat, Algeria, and is now continuing his research and contributions. He has published books and patents in the field of Unmanned Aerial Vehicles and networks and cellular technology. He is a member of the Science and Mathematics Lab (LIM). His research interests include cellular networks, radio access, network slicing, network security, UAVs, and computer architecture.

**Chaib Noureddine** (Senior Member, IEEE) received his Ph.D. degree in computer science from the University of Laghouat and served as a Secretary of the IEEE Algeria Section. He is an associate professor in the Computer Science Department, the Chief Information Officer of the University of Laghouat, and an IEEE Senior member. He is a member of the Science and Mathematics Lab (LIM) and a member of IEEE Vehicular Technology and the Transportation Systems Societies. He received a degree of engineering in computer science from the University of Laghouat, in 2007, and the degree of Master of engineering in computer science from the University of Batna in 2011. His research interests include Security, Privacy, Mobile and Vehicular networks, and other networking topics.

**Bensaad Mohamed Lahcen** received his engineering degree in 2003 with a first class reward and a scholarship to study Master in China. He received his Master's degree from Hunan University (China) in 2006. Upon his return from China to Algeria, he was appointed as an assistant professor at Laghouat University. He continued his studies in this university where he received his doctorate in information security in 2014. Dr. Bensaad served as a member of the Scientific Council of the Science Faculty and is a member of the Laboratory of Mathematics and Computer Science. His research interests include Information Security, Internet of Things and Machine Learning.

**Pascal Lorenz** received the M.Sc. and Ph.D.degrees from the University of Nancy, France, in 1990 and 1994, respectively. From 1990 to 1995, he was a Research Engineer with WorldFIP Europe and with Alcatel-Alsthom. He has been a Professor with the University of Haute-Alsace, France, since 1995. He has authored/coauthored three books, three patents, and 200 international publications in refereed journals and conferences. His research interests include QoS, wireless networks, and high-speed networks. He is an IARIA Fellow and a member of many international program committees. He was the IEEE ComSoc Distinguished Lecturer Tour, from 2013 to 2014. He was the Chair the Communications Systems Integration and Modeling Technical Committee (2003–2009), the Vertical Issues in Communication Systems Technical Committee Cluster (2008–2009), the Communications Software Technical Committee (2008–2010), the Technical Committee on Information Infrastructure and Networking (2016–2017), and the IEEE ComSoc France (2014–2018), and the Financial Chair of the IEEE France (2017–2019). He has served as the Co-Guest Editor for special issues of the IEEE Communications Magazine, Networks Magazine, Wireless Communications Magazine, Telecommunications Systems, and LNCS. He is an Associate Editor of the International Journal of Communication Systems (IJCS-Wiley), the Journal on Security and Communication Networks (SCN-Wiley), the International Journal of Business Data Communications and Networking, and the Journal of Network and Computer Applications (JNCA-Elsevier). He has been a Technical Editor of the IEEE Communications Magazine Editorial Board (2000–2006), the IEEE Networks Magazine, since 2015, and the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, since 2017.