Dynamic Connectivity Solutions: UAV Integration with 5G Networks

Jesús Pérez[†], Luis Diez[†], Johnny Choque[†], Luis Muñoz[†], Pedro Velasco[¶], José Ramón Soldado[¶]
[†]*Universidad de Cantabria*, Santander, Spain. {jesus, ldiez, jchoque, luis}@tlmat.unican.es
[¶]*Amper*, Madrid, Spain. {pedro.velasco, ramon.soldado}@grupoamper.com

***Abstract*—The research community is increasingly driven to develop new approaches to meet the demands of ubiquitous connectivity. This includes addressing spontaneous communication requirements arising from crowd events or responding to the communication challenges posed by natural disasters or other emergency situations. Agile network management techniques, empowered by artificial intelligence, and leveraging the third spatial dimension, offer promising solutions to address these challenges. This paper explores the integration of unmanned aerial vehicles (UAVs) with 5G network technologies to enhance mobile network performance and coverage. By deploying gNodeB on UAV platforms, dynamic resource allocation and network function scalability could be improved, facilitating rapid deployment of temporary mobile network nodes. The work describes a practical integration and communication performance emulation to evaluate the capabilities and performance of UAV-mounted gNodeBs. Special attention is payed to the impact backhaul link, which connects the base stations with the terrestrial core network, over service performance.**

***Index Terms*—UAV, 5G, NVF, gNodeB, CN, Backhaul**

I. Introduction

The advancement of software-defined networking (SDN) and network function virtualization (NFV) represents the cornerstone of software/programmable networking, reconfiguring the landscape of both public and non-public networks (NPN).

This programmable approach permits carrying out dynamic allocation of resources based on real-time demand, optimizing the delivery of services and applications to users. Similarly, NFV virtualizes network functions, allowing them to be instantiated and scaled on-demand, further enhancing the efficiency of mobile networks.

Additionally, the integration of SDN and NFV also sets the basis for the incorporation of the third dimension into mobile network deployments. This evolution introduces the concept of aerial infrastructure, facilitated by the use of unmanned aerial vehicles (UAVs), such as drones. By leveraging drones, operators can establish temporary ad-hoc network nodes in areas where terrestrial infrastructure is limited or inaccessible. This approach enhances the scalability and adaptability of mobile networks, especially in remote or disaster-stricken regions, where rapid deployment is critical for supporting emergency response efforts and ensuring uninterrupted communication services. Despite the agreement regarding the role of drones as network infrastructure, it remains essential to conduct practical experiments to assess their capabilities and requirements for leveraging new network and service paradigms.

In this context, this paper describes the work carried out to exploit drones for advanced communications and services. First, we describe the integration of a 5G gNodeB in a drone. Secondly, the impact of the backhaul impairments over service performance is analyzed.

The rest of the paper is structured as follows. In Section II, we review the current research status of UAV integration in 5G Networks. Following this, Section III presents the deployment of the drone-based 5G gNodeB. Then, Section IV presents the tests and results of the backhaul link analysis. The paper concludes in Section V, where we provide an outlook of our future work.

II. Related Work

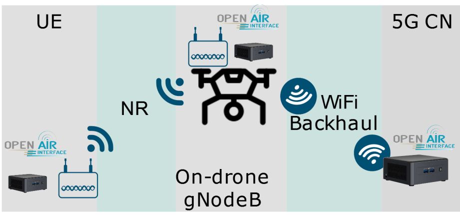
The integration of UAVs into 5G networks is an emerging field of research that focuses on enhancing network performance and coverage. Various studies have measured key performance indicators (KPIs) using UAVs in 5G networks. Some of them vary in their approach, encompassing both experiments using UAVs [4, 3] and simulations [6] to address the challenges and potentials of 5G-enriched UAV applications. These works explore scenarios where drones act as aerial User Equipment (UE) within the network. Additionally, other studies have focused on assessing, through simulations, the improvement yielded by deploying 5G gNodeB in UAVs [8, 1]. In particular in [8] system level simulations are performed to study the average throughput obtained deploying flying base stations. Similarly, in [1] Shah and Kelley study through simulation the benefits of embarking gNodeBs in High Altitude Platform Stations (HAPS) over vehicular scenarios. Other work presented the measurements carried out by flying a base station and including some backhaul results collected [5, 7].

We consider it essential that these studies continue by analyzing the performance of practical deployments. In this regard, this work presents a real integration of a aerial 5G gNodeB in a drone and analyzes the impact of imperfect and limited backhaul link over end-to-end communications.

III. Drone-based 5G network

As stated before, this work aims at evaluating, from a practical perspective, the potential of UAVs for ensuring connectivity, even in situations where terrestrial infrastructure is

ISBN 978-3-903176-63-8 ©2024 IFIP



(a) Communication schematic

(b) Drone with gNodeB on-board

Fig. 1: Description of the drone-based gNodeB setup

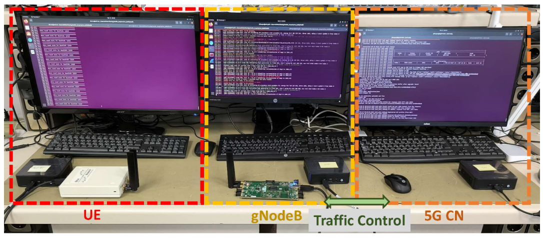


Fig. 2: 5G network and computing equipment for tests

Scenario	A	B	C	D	E	F
RTT (ms)	0	⟸		25	⟹	
Data Rate (Mbps)	0	⟸		20	⟹	
PER (%)	0	0	0.2	0.5	1	2

TABLE I: Backhaul link configurations

unavailable. To achieve this goal, the scenario will include the virtualization of network functions and services. The scenario considered in this work is depicted in Figure 1a. It embraces a gNodeB integrated in a UAV that is able to provide cellular connectivity over the New Radio (NR) interface to UEs. Besides, the backhaul link between the gNodeB and the 5G Core Network (CN) is implemented over WiFi.

As can be observed in Figure 1b, the gNodeB is integrated on a DJI Matrice 300 drone able to load up to 2.7 kg. Specifically, the base station is built over a USRP B210, a Software Defined Radio (SDR) by Ettus Research, which provides the radio functionalities. Then, we adopt the Open Air Interface (OAI) [1] gNodeB implementation, which runs on an Intel NUC-PC with an i5 processor and 32 GB RAM Memory. The gNodeB is configured as Stand-Alone (SA) running at the N78 band (3.5 GHz) in TDD, using 9 symbols for downlink and 5 for uplink. Finally, the number of Physical Resource Blocks is 106 with 30 KHz of sub-carrier-spacing.

Then, the gNodeB is connected to the 5G CN through a WiFi link. As for the CN, it is also based on the solution provided by OAI and instantiated in another NUC device. Finally, a UE is implemented using the same approach as the gNodeB; that is using an USRP B210 device connected to a NUC-PC.

IV. Performance Evaluation

This section presents the analysis conducted to study the impact of the backhaul link over end-to-end communications. To that end, we use the setup depicted in Figure 2. The different network entities (gNodeB, UE and CN) present the same configuration as the ones in the UAV, but we emulate the backhaul link using the Linux Traffic Control utility.

Over such setup, we transmit traffic from the UE to the CN via the gNodeB, both uplink and downlink under different conditions of the backhaul link. Besides, in order to better understand the effect of an imperfect backhaul, results using the NR link are compared with those yielded with a perfect communication between the UE and gNodeB. The latter case is obtained using the OAI radio emulation capabilities where I/Q symbols are transported through Ethernet, so that the communication performance is only limited by the NUC-PC computation capabilities.

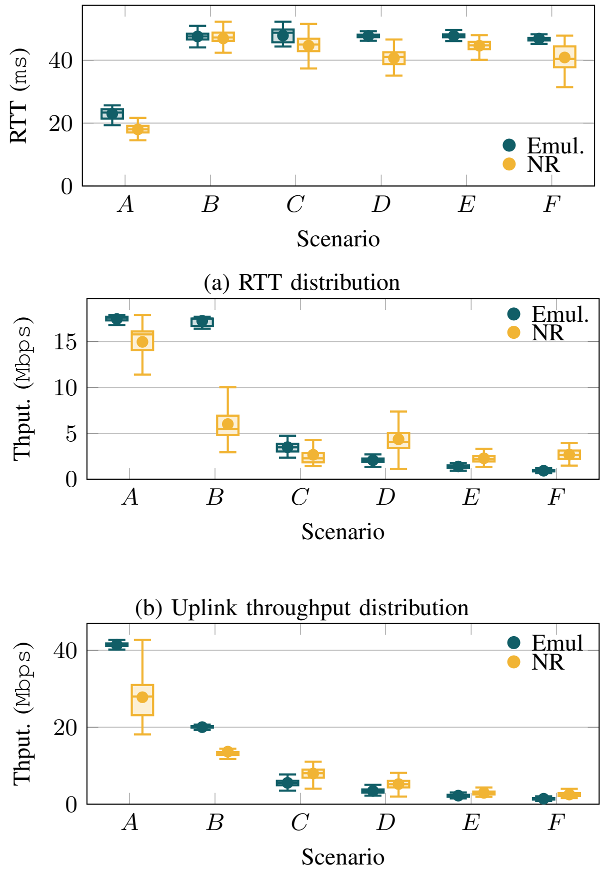
Table I presents the different backhaul communication configurations evaluated, defined by its Round Trip Time (RTT), data rate and Packet Error Rate (PER). The values are defined based on those use in other works for WiFi links[2]. It is worth noting that scenario A does not present any communication impairment and thus it is used as an upper bound performance.

Figure 3 depicts the performance results in terms of end-to-end delay, and uplink and downlink throughput. The results are obtained from 200 *iperf* runs. In each run 10 seconds of TCP traffic is sent, and the corresponding average value is obtained. Then in Figure 3, for each performance metric, we represent the distribution of the 200 runs by a boxplot for each scenario when using the actual NR interface and the emulation between the UE and the gNodeB.

As can be observed in Figure 3a, the minimum RTT (scenario A) is around 20 ms and it doubles when emulating the WiFi link, which is the expected behavior since the backhaul link adds 20 ms delay. Besides, we observe that the variance of the RTT using the NR link is higher, as compared with the configuration with the UE-gNodeB emulation.

In terms of throughput, the differences when using the real NR and the emulation are more notable. In terms of uplink throughput (Figure 3b) the performance when using the real NR interface is strongly affected when a WiFi emulated backhaul is used. Indeed, for the scenario B, which does not add errors, we observe a remarkable throughput degradation, going down from 16 to 5 Mbps. In the case of downlink throughput (Figure 3c) the most remarkable impact comes from the NR interface itself. On the other hand, the impact of the backhaul impairments in scenario B is not as relevant as in the uplink case. Finally, in both cases, uplink and downlink,

[1] https://openairinterface.org/



(a) RTT distribution

(b) Uplink throughput distribution

(c) Downlink throughput distribution

Fig. 3: En-to-end performance comparison under different backhaul configurations. Results are shown with both a real NR interface (green) and a radio emulation (yellow)

the addition of errors in the backhaul would make end-to-end communication hardly usable.

V. Conclusion

In this paper, we describe the integration of a 5G base station, based on Open Air Interface, in a drone. This on-board infrastructure communicates with the CN deployed at ground through WiFi, thus providing agility and adaptability in locations where connectivity is needed.

Before deploying the drone in the wild, in this work we analyze the impact of backhaul impairments over end-to-end communication. In general the results evince that the WiFi backhaul has a strong impact on the end-to-end performance. In this sense, the results show that backhaul impairments could yield working performance except when errors are present. It provides insightful information for the configuration of the WiFi communication, especially regarding the number of MAC retransmissions.

In our future we will broaden the analysis emulating other backhaul technologies. In addition, in the field measurements will be conducted to validate the analysis. Finally, we will also compare the performance yielded by a commercial gNodeB instead of SDR-based one.

Acknowledgment

This research has been supported by the Eureka CELTIC-NEXT project "Intelligent Management Of Next Generation Mobile Networks And Service" (IMMINENCE, C2020/2-2), funded in Spain by the Centro para el Desarrollo Tecnológico Industrial E.P.E. (CDTI), and by the Government of Cantabria through the project "Enabling Technologies for Digital Twins and their application in the chemical and communications sectors" (GDQuiC) of the program "Grants for research projects with high industrial potential of of technological agents of excellence for industrial competitiveness TCNIC".

References

[1] Mohammad Shah Alamgir and Brian Kelley. "Fixed Wing UAV-based Non-Terrestrial Networks for 5G millimeter wave Connected Vehicles". In: *2023 IEEE 13th Annual Computing and Communication Workshop and Conference (CCWC)*. 2023, pp. 1167–1173. DOI: 10.1109/CCWC57344.2023.10099281.

[2] Pablo Garrido et al. "rQUIC: Integrating FEC with QUIC for Robust Wireless Communications". In: *2019 IEEE Global Communications Conference (GLOBECOM)*. 2019, pp. 1–7. DOI: 10.1109/GLOBECOM38437.2019.9013401.

[3] Mohammed Gharib et al. *5G Wings: Investigating 5G-Connected Drones Performance in Non-Urban Areas*. 2023. DOI: 10.1109/PIMRC56721.2023.10294063.

[4] Samira Homayouni et al. "On the Feasibility of Cellular-Connected Drones in Existing 4G/5G Networks: Field Trials". In: *2021 IEEE 4th 5G World Forum (5GWF)*. 2021, pp. 287–292. DOI: 10.1109/5GWF52925.2021.00057.

[5] Mehrdad Moradi et al. "SkyCore: Moving Core to the Edge for Untethered and Reliable UAV-based LTE Networks". In: Oct. 2018. DOI: 10.1145/3241539.3241549.

[6] Silvia Sekander, Hina Tabassum, and Ekram Hossain. *Multi-Tier Drone Architecture for 5G/B5G Cellular Networks: Challenges, Trends, and Prospects*. Nov. 2017. DOI: 10.1109/MCOM.2018.1700666.

[7] Hiroyuki Shinbo et al. "Flying Base station for Temporary Mobile Communications in an Area Affected by a Disaster". In: *2018 5th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)*. 2018, pp. 1–7. DOI: 10.1109/ICT-DM.2018.8636379.

[8] Nikita Tafintsev et al. "Utilization of UAVs as Flying Base Stations in Urban Environments". In: *2023 15th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*. 2023, pp. 7–11. DOI: 10.1109/ICUMT61075.2023.10333093.