Performance Evaluation of Network Slicing for Aerial Vehicle Communications

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***Abstract*—Using 5G networks for flying vehicles is an opportunity to provide reliable connectivity while reducing cost and requirements on size, weight and power consumption. Network slicing is one feature which is particularly of interest. It enables a reliable aerial vehicle control slice independent from payload communication, such as video streaming to the ground. For the Unmanned Aerial Vehicle (UAV) use case, we rely on a 5G testbed that serves cars on an operational highway and trains on a parallel rail section. To test the effectiveness of network slicing, we show that the UAV control slice is unaffected by an overloaded UAV payload slice.**

***Index Terms*—AV communication, UAV communication, network slicing**

I. Introduction

Commercial aviation is on the verge of utilizing the upcoming Fifth Generation (5G) network ecosystem for connectivity. UAVs and flying passenger vehicles, such as flying taxis and helicopters form a larger group called Aerial Vehicle (AV). This group has various Air-to-Ground (A2G) connectivity demands for vehicle control, AV payload, and passenger connectivity. While 5G offers many opportunities to transportation verticals such as cars and trains, a number of further subjects need to be scrutinized in aviation.

Besides cost, Size, Weight, and Power (SWaP) requirements of the flying vehicles are closely considered in aviation. As for the cost requirement, the use of available 5G ground networks is a great opportunity, especially for the Urban Air Mobility (UAM) case. The cost can be minimized by establishing connectivity to AVs over a flexible infrastructure which is already established for ground users. As for the size, weight and power demands, AVs can profit from the slicing features of 5G by enabling virtually isolated processes on-board systems. This way, the number of hardware components on AVs can be minimized as well, offering new on-board system realisations.

Last but not least, the safety requirements are paramount. Regulations are currently under discussion and might yield implications on the spectrum bands and transmission availability. Moreover, operations beyond pilots' visual Line of Sight (LoS) could become a reality, implying extremely robust and reliable communications.

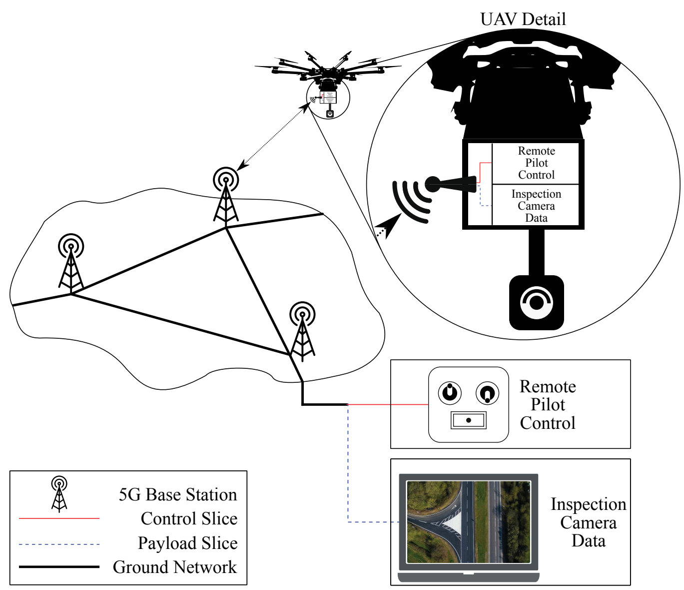

Figure 1. Example for remote piloted UAV into sliced network

For an efficient communication scheme, slicing can again become a key feature to meet the link availability and data rate needs. For AV we envision two slices, a control slice used for controlling the AV and payload slice for any type of payload communication depending on the vehicles' task as shown for the representative example in Figure 1. The control slice has strict requirements on Quality of Service (QoS) which should not be influenced even if other slices are overloaded.

In the course of these emerging aerial transportation trends, it is significant to demonstrate and evaluate critical 5G components for AV communication, which we aim to address in this paper by examining UAV flight trials at Ericsson's 5G testbed [1] located at the A9 highway in Germany. This testbed allows for testing 5G applications such as Vehicle-to-Vehicle, Vehicle-to-infrastructure, and Railway-to-infrastructure with the slicing feature. Even though we use an UAV for conducting the measurements, the results are applicable to any kind of AV needing multiple communication links with different QoS.

Firstly, we show the operations of a UAV in a network that is designed for automotive and rail connectivity, enabling the flexible use of available 5G ground infrastructure. We test end-to-end slicing to the utmost extent in a Commercial off-the-shelf (COTS) implementation by utilizing the enhanced Mobile Broadband (MBB) technology. With this implementation it is possible to direct terminals to slices in a way that fulfils the operator's need, allowing an End-to-end (E2E) partition of the network. Together with the fully-sliced ground and Radio Access Network (RAN), we use a flying system in the role of a User Equipment (UE) that virtually runs UAV control and payload processes on a common hardware (except for the modems). Finally, we demonstrate that slicing is effective in terms of inter-slice isolation, where the UAV payload communication does not affect the UAV control slice in an overload situation.

The remaining paper is organized as follows: In Section II, we introduce the related work in network slicing methods and the usage of cellular networks for AV communications. Section III is dedicated to the description of the system architecture. Subsequently, our measurement setup is described in Section IV. Afterwards, we present the measurement results from flight trials in Section V and the paper ends with the conclusion in Section VI.

II. Related Work

Recently, there has been rising interest in cellular networks for supporting UAV communication in the literature. In [2], an overview is presented regarding the usage of cellular technologies for UAV, explaining the benefits, communication and spectrum requirements and the techniques to support heterogeneous networking with ground and aerial users. Furthermore, [3] also proposes connectivity requirements for various UAV use cases and their simulation study shows that terrestrial Long Term Evolution (LTE)-advanced networks can support the communication demands of low-altitude UAVs.

In [4], a UAV-based study to measure A2G communication performance of LTE is provided. Their results show that LTE networks are capable of supporting low-altitude UAV communication with low packet loss rates. In [5], the effects of interference on uplink and downlink channels of LTE networks are evaluated for UAV communication. They conduct a simulation study to analyze the level of interference when a UAV is in the air. Their results suggest that interference minimization techniques should be developed to establish reliable UAV communications.

In [6], 3rd Generation Partnership Project (3GPP) evaluates the performance of LTE in aerial scenarios and presents potential interference issues in both uplink and downlink channels. They also propose several interference mitigation techniques such as Multiple-Input-Multiple-Output (MIMO), beamforming, coverage extension, intra-site coordinated multipoint as well as power control-based mechanisms to improve LTE performance for aerial coverage. Furthermore, [7] also discusses interference mitigation techniques in this topic. They propose open and closed power control mechanisms to mitigate uplink interference and coverage extension for downlink interference. They provide simulation studies for these methods and their results present $30\% - 50\%$ throughput gain on uplink channel and cell acquisition outage reduction from $33\% - 75\%$ to 0%.

The work of [8] presents an iterative algorithm to achieve fair performance and to maximize minimum throughput on served users in multi-UAV enabled wireless communication systems. They optimize multi-user communication scheduling as well as UAV trajectory and transmit power. Their simulation results show that UAV mobility can enhance air-to-ground channels, flexibility for interference mitigation and consequently, it improves the system throughput in downlink channel. Additionally, [9] studies a non-convex trajectory design optimization problem for UAVs served by cellular networks in order to maintain reliable connectivity during the entire trajectory with minimal mission completion time. Their analytical studies show that the proposed method has flexibility between complexity and performance, and its performance is close to the optimal solution.

Besides LTE technologies being considered for UAV communication, UAVs can also be utilized to extend the coverage and capacity of cellular networks. The authors of [10] propose a multi-tier UAV network architecture to complement the terrestrial cellular networks. The performance of this architecture is evaluated for a specific network load condition in which the deployments of UAVs can be beneficial for the ground users. Also, [11] presents a UAV-based Device-to-device (D2D) communication scheme to extend the ground network coverage. Their algorithms provide optimal positioning for UAVs to maximize the overall data rate.

Network slicing is a novel QoS scheme in the scope of cellular systems. Reference [12] provides a survey study on network slicing, presenting the existing slicing proposals in various layers and explaining what open research questions exist in this topic. In [13] and [14], theoretical studies are conducted related to increasing the system performance of network slicing in cellular networks. Their findings suggest that the overall efficiency of slicing can be further improved in next-generation networks.

Network slicing is also considered in the domain of UAV communication as it can increase the reliability and robustness of control links. [15] demonstrates a recent network slicing demo over 5G radio for UAV communication. A dedicated slice is used to send mission commands to a UAV and to receive the video surveillance data remotely. The demo presents a successful slicing implementation for UAV communications. In [16], an aerial control system is proposed for LTE/5G networks that separates the data and control plane of UAV communication and enables the control link between UAVs in the air. The performance evaluation of this scheme shows that the cluster formation and selecting adequate channels are the key elements in providing the required quality of service.

Although the literature contains variety of topics in the scope of UAV networks, there is certainly a demand to consider network slicing and to evaluate its performance for aerial use cases. Therefore, this paper is aimed to provide a novel evaluation study in this context.

III. System Architecture

Network slicing is a powerful virtualization capability and one of the key capabilities that will enable higher flexibility, as it allows multiple logical networks to be created on top of a shared physical infrastructure. The greater elasticity brought by network slicing will help to address the cost, efficiency, and flexibility requirements imposed by the future demands. The 3GPP considers network slicing as one of the key features of 5G. The 3GPP SA2 Working Group, responsible for overall system architecture, has specified the 5G Core architecture with Network Slicing being a main feature of 5G. Standard technical specification 23.501 defines Stage-2 System Architecture for the 5G System which includes Network Slicing.

A network slice is composed of a collection of logical network functions that support the service requirements and performance demands of a particular use case. It shall be possible to direct terminals to slices in a way that fulfils the operator's needs, e.g. based on subscription or terminal type. The network slicing targets an E2E partition of the network. Network slicing can be used to isolate different network services in an operator's network. The goal of the slice selection mechanism is therefore to direct a UE to the correct slice as early as possible and to avoid redirection from one slice to another, which breaks the isolation between the slices.

The 5G testbed network architecture is configured with three E2E Network slices ready for service. RAN slicing and Dedicated Core Network (DECOR) [17] are the functionalities that enable this configuration in a live network. RAN slicing based on radio resource partitioning enables configuring predefined shares for the usage of the radio resources. In Figure 2, we display the network configuration. The partitions are based on Subscriber Profile ID (SPID) values used for specific groups of UEs. The purpose is to ensure a fair distribution of radio resources between groups of users.

The separation of core networks for different services within a Public Land Mobile Network (PLMN) is provided by the DECOR feature. It enables service optimization by routing UEs to the best suited DECOR. Uses cases of the DECOR feature are isolation of specific UEs or subscribers and provide a particular DECOR with specific features such as security, QoS or resilience.

Today UAVs are controlled via a dedicated control link, mostly using Industrial, Scientific and Medical (ISM) spectrum. The control link is used to transmit information about status and movement of the UAV and in some cases also to transmit a video stream from a camera on the AV. This stream can either be used for controlling the UAV or to fulfill mission tasks, e.g. video recording or track inspection. We refer to the latter type of communication as payload communication, whereas control communication covers everything related to controlling the UAV.

Depending on the use case, payload communication needs to be separated from the control communication. For example, for UAM, control of the vehicle needs to be securely isolated from the payload, i.e. passenger communication. Also UAV communications can profit from slicing like in the case of track inspection, a remote operator could steer the UAV securely while the video is sent independently.

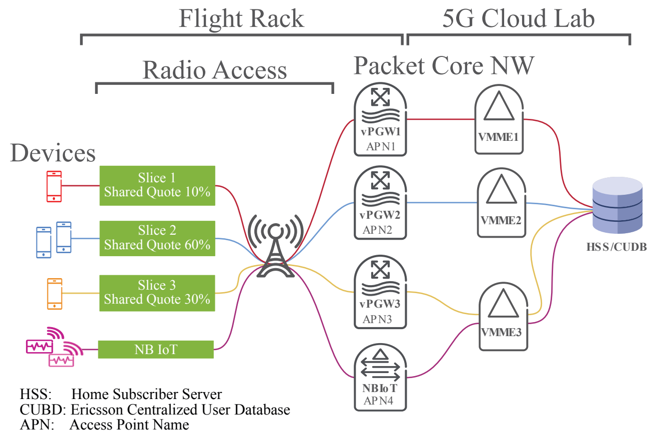

Figure 2. Testbed network slicing configuration

Network slicing can be an option to enable this separation as shown in Figure 1. The control slice can be operated with required QoS even if the payload slice is overloaded.

IV. Measurement Setup

Our measurement setup is described in the following sections. It consists of the 5G testbed for providing connectivity with network slicing and the UAV carrying the UEs needing high performance connectivity.

A. Network Setup

The 5G testbed consists of six base stations and covers 30 km along the A9 highway and train tracks close to Nuremberg, Bavaria, Germany. The flexible network setup allows amongst others testing of 5G features.

Figure 2 shows the end-to-end slicing concept at the 5G testbed network used for UAV measurements. For this particular case, RAN is configured into three partitions with flexible sharing quote values set to 10%, 60% and 30%, respectively. Each RAN partition (slice) is associated to one DECOR slice (virtual Evolved Packet Gateway (EPG) and virtual Mobility Management Entity (MME)). The core network is distributed into Central Cloud at Ericsson Eurolab in Aachen and Virtual Packet Gateway as part of the edge cloud (Flight Rack) located in Bavaria, Germany close to radio network.

B. UAV Setup

The flight trials are performed with a DJI S1000+ Octocopter [18] . The maximum vertical and horizontal speeds of the UAV are 18 km/h and 64.37 km/h, respectively. It can carry up to 4.9 kg of payload, which results in a maximum take-off weight of 11 kg. The components to connect the UAV to the network have been integrated into a wooden box mounted on the UAV as shown in Figure 3. The box also includes a Global Positioning System (GPS) device, used for

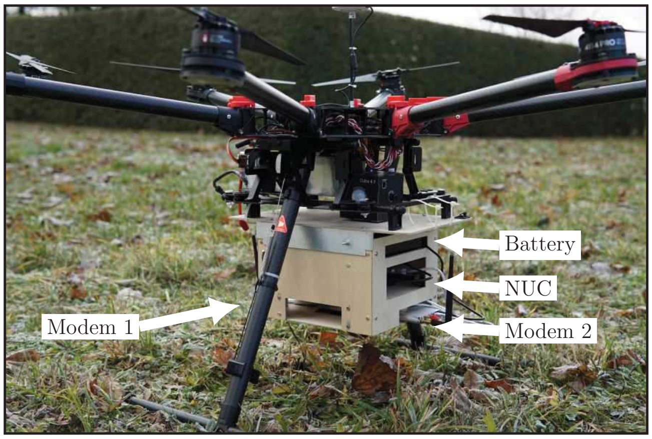

Figure 3. Setup of the UAV payload

time synchronization between measurements taken on both UE and UAV.

An Intel NUC computer is in charge of the logical processing in this setup. It runs two virtual operating systems, emulating the two applications on the same hardware. One virtual operating system corresponds to the control slice, the second virtual operating system corresponds to the payload link. Both operating systems run simultaneously and the hardware resources are evenly shared between them. Each of the two slices are connected to one Telit LM940 modem, establishing the connections to the network. This system architecture differs from the conventional architectures where two computers will be needed to perform our tests.

The majority of the trajectory is controlled by an autopilot under supervision of the pilot. The application Litchi [19] is used for the UAV to follow a predefined trajectory. This application allows the user to define a trajectory through its user interface or the trajectory can also be imported from a file in *csv* format.

C. Methodology

The measurements have been performed within the above described network close to Hilpoltstein (Germany). The UAV is flown at a distance of approximately 400 meters from the highway and train tracks. The flights are repeated at different altitudes to evaluate the influence of altitude on the network performance. The network performance in downlink and uplink was measured with Iperf [20] and Ping [21]. Iperf has been modified to add local time stamps to the file. GPS time stamps together with local time stamp on the virtual machine allow to relate the state of the UAV with the performance of the network.

The chosen trajectory can be seen in Figure 4. The autopilot is able to follow a certain trajectory defined by waypoints. All the waypoints are defined parallel to the highway and the position of the waypoints mimic one possible application of inspecting roads or train tracks. The speed of the UAV is set to 2 m/s when the height is 100 meters and to 4 m/s when the height is 50 meters.

Table I
TRIAL DESCRIPTION

	Control slice		Payload slice	
	Throughput	Direction	Throughput	Direction
Trial 1	2 Mbps	DL	Max	DL
Trial 2	2 Mbps	DL and UL	Max	DL and UL
Trial 3	Ping Measurement		Max	DL

Measurements were taken in December 2018. This particular month poses a challenge since temperatures drop below zero degrees. The batteries used to power the UAV are sensible to low temperatures and consequently, the flight time is reduced with temperature. At the moment of the trials, the UAV was able to fly a maximum of 8 minutes before battery exhaustion. The reduced UAVs flight time can be solved by using fuel-cell batteries, expanding the flight time to a couple of hours.

Different trials performed over the network with the UAV are described in Table I. From now on, Downlink (DL) refers to ground to air communication and Uplink (UL) refers to air to ground communication. The first trial consistsconsist of measuring Iperf values on control slice and payload slice. While the control slice is set to 2 Mbps DL, payload slice tries to use the maximum throughput the network is able to provide. This trial shows whether the control slice remains unaffected when payload slice demands the maximum available throughput. The second trial follows the same principle but in both communication directions (DL and UL). The control slice is set to 2 Mbps in both communication directions and payload slice uses the complete available throughput of the network. The final trial measures delay time on the control slice while payload slice uses the maximum available throughput and also with 10 Mbps. This trial shows whether the delay is affected by the payload use of the network.

Figure 5 shows an aerial view of the surroundings of the test field. The A9 highway, railway tracks, base station, UAV Flight Area and Sindersdorf (Germany) are marked to provide a better understanding of the dimensions of the test field. The antenna shown on the map is the only one that provides coverage to the flight area, preventing interferences from a neighbour base station or handover situations. The 3D view in Figure 4 shows an overlay of the performed trajectory of the drone and the satellite view of the area. Geographic coordinates are expressed in degrees and the height is represented in meters. The highway can be seen on the left of the map, showing that a safety distance is always maintained.

V. RESULTS

Our performed flight trials show that the network designed for ground coverage provides full coverage in the air up to 100 meters altitude. Hence aerial users can also be served. However, we have identified a decrease in throughput with increasing altitude. This can be seen in Figure 6. At a maximum height of 100 meters, the throughput decreases from 42.09 Mbps to a minimum of 8.755 Mbps on the payload slice.

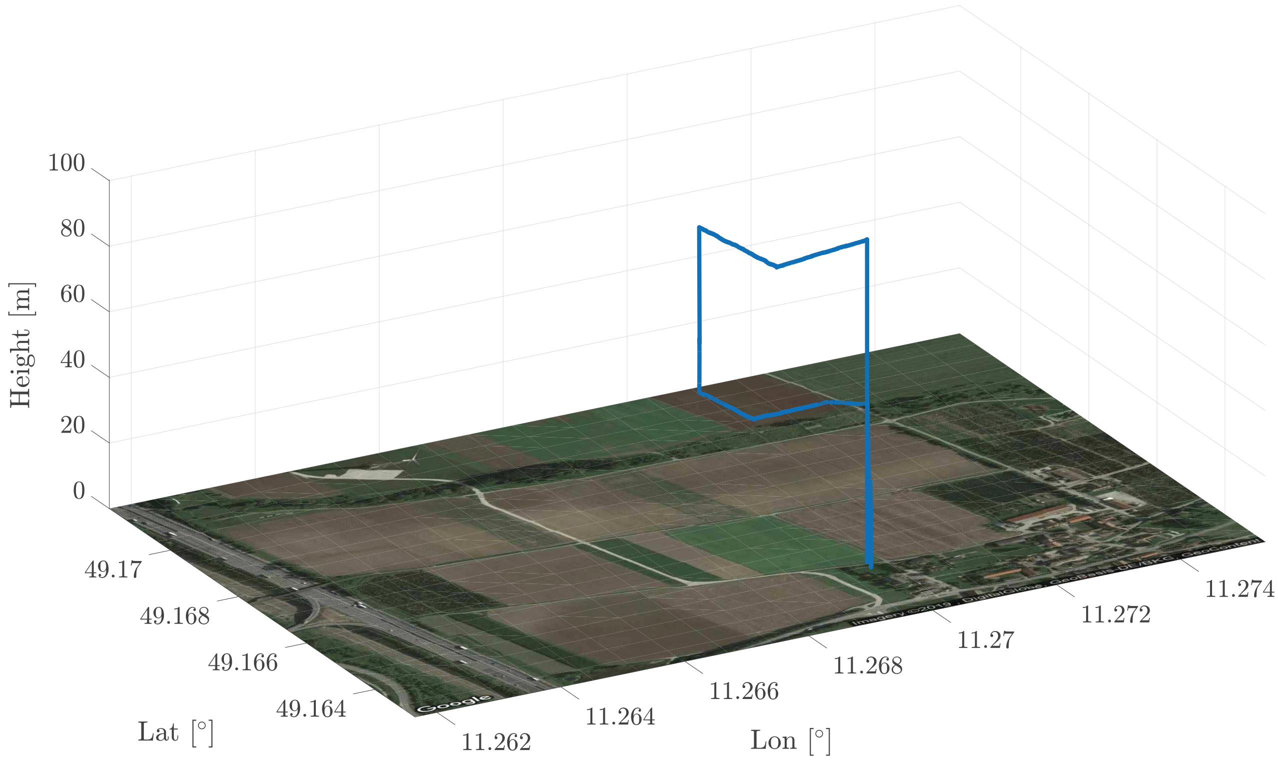

Figure 4. 3D Detail of the UAV flight area and trajectory followed by it

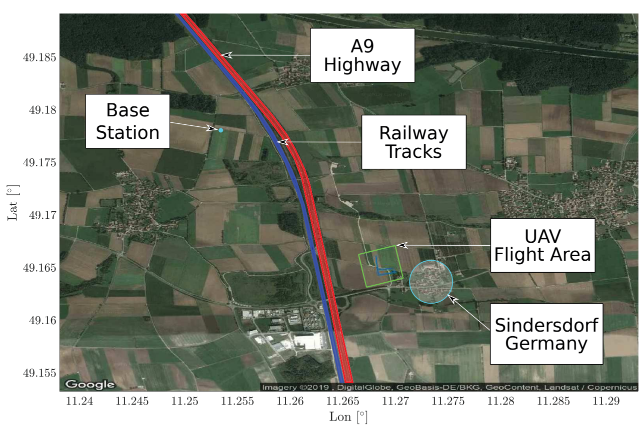

Figure 5. Trial setup

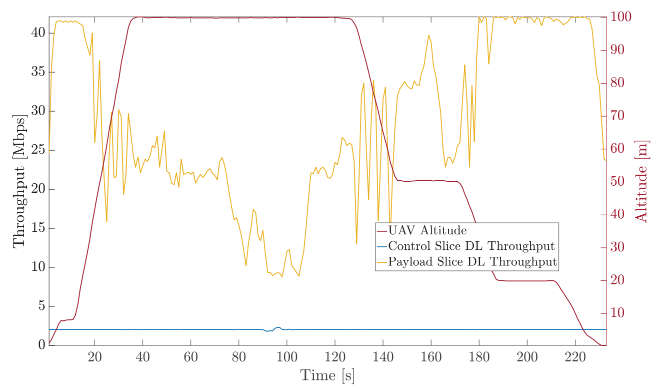

Figure 6. Trial 1: UAV altitude vs DL throughput.

Figure 6 also illustrates the results from the first trial. It is evident that the control slice can maintain the demanded 2 Mbps throughout the flight. The payload slice, however, is varying between 8.76 Mbps and 42.09 Mbps due to the remaining available capacity in the network.

The second trial increases the load on the network with DL and UL in parallel. Figure 7 shows that also in this case, control slice DL and UL achieve the required 2 Mbps during the flight. The remaining capacity is again used by the payload slices.

Results of the third trial are shown in Figure 8. The Round Trip Time (RTT) varies between 31.5 and 56.1 ms being in a normal range for LTE networks. The figure clearly shows that the RTT is not influenced by the payload throughput, which varies between overloading (first half) and 10 Mbps fixed throughput (second half).

VI. Conclusion

The emergence of 5G technologies advertises promising solutions towards enabling Aerial Vehicle communication. In this scope, we present the use of network slicing together with Mobile Broadband service for Air-to-Ground control and

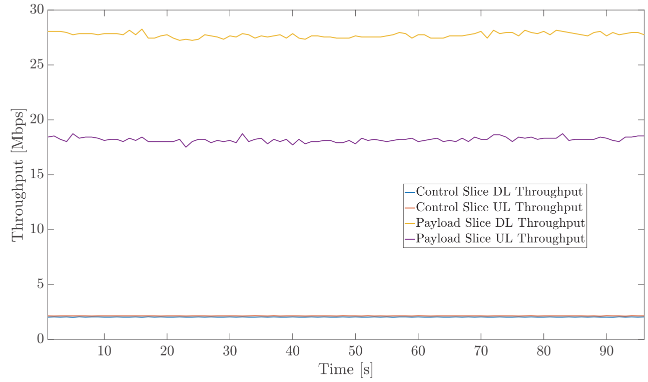

Figure 7. Trial 2: Control slice (UL+DL) unaffected by overloaded payload slice (UL+DL).

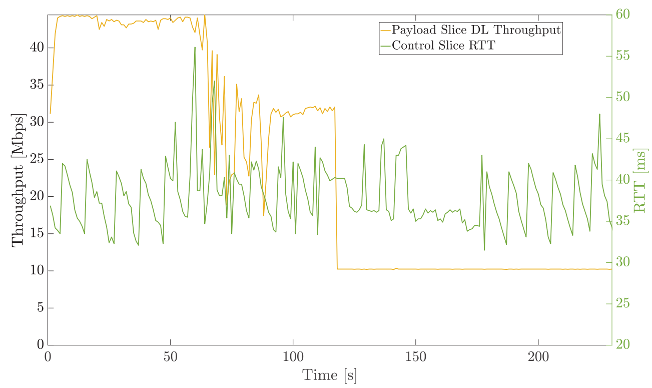

Figure 8. Trial 3: ping measurement unaffected by payload DL throughput.

payload communication. The results show that the slicing performs effectively in isolating the resources in the network and this way, the required resources for control communication are ensured. Furthermore, the 5G infrastructure, which is designed for rail and vehicle communication, is efficiently utilized for Unmanned Aerial Vehicles. Therefore, these results show that network slicing can be a key feature in meeting the robust and reliable communication demands of Aerial Vehicle use cases, including further Urban Air Mobility use cases.

There are number of open paths for further investigation in this topic such as a) studying the contribution of MIMO systems to UAV communications, b) testing the network performance over longer time intervals to increase the confidence level of measurements.

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