5G Experimentation: The Experience of the Athens 5GENESIS Facility

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***Abstract*—5G is the latest wireless standard designed to comply with stringent performance requirements for supporting diverse use cases spanning over different verticals, considered not feasible with previous cellular network technology. In this context, the European Commission has funded multiple research projects aiming at validating 5G Key Performance Indicators (KPIs) over large scale field trials on different use cases. The 5GENESIS project provides a flexible and open experimentation suite with network slicing, in order to support and facilitate validation of KPIs over 5G infrastructure. This paper discusses the experimentation framework of the Athens 5GENESIS Facility, presents results on throughput, Round-Trip-Time (RTT) and latency and summarizes the lessons learned from the activities that took place.**

***Index Terms*—5G, experimentation, network slicing, KPIs, testing**

I. INTRODUCTION

The promise of the emerged fifth-generation (5G) cellular communications reaches every aspect of future digital communities and industry verticals [1]. Network virtualization is integrated into the greater 5G ecosystem via concepts, such as network slicing [2]. This evolution enables new and innovative services, such as intelligent transportation systems, industrial automation, massive connected utilities and immersive multimedia experience. These services impose stringent requirements, such as ten- to hundred- fold peak data rates for enhanced mobile broadband (eMBB), large device density for massive-machine type communications (mMTC) and latency below 1ms for ultra-reliable low latency communications (URLLC), presenting serious challenges to 5G commercial deployments [3].

Beyond the aforementioned challenges, there is a need to create 5G testing and validation facilities, allowing verticals to develop, test and validate innovative services. 5GENESIS [4] is dedicated at deploying 5G facilities in distributed sites across Europe, capable of enabling well-articulated, open and flexible experimentation frameworks [5]. This paper briefly discusses the experimentation framework of the Athens 5GENESIS facility and presents results on throughput, round-trip-time (RTT) and latency (one-way delay), showcasing the capabilities of selected 5G Non Standalone (NSA) setups. Finally, we conclude summarizing the lessons learned from the activities that took place.

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II. 5G EXPERIMENTATION ARCHITECTURE

The 5GENESIS architecture has been designed to provide a unified and open experimentation framework in order to facilitate the interactions between the experimenters and the testing facilities, as well as to provide a considerable variety of technologies and vendor-specific 5G solutions. As illustrated in Fig. 1, the architecture comprises three reference layers, namely the Coordination, the Management and Orchestration (MANO) and the Infrastructure Layer. The functional components of each Layer are described in detail in [6].

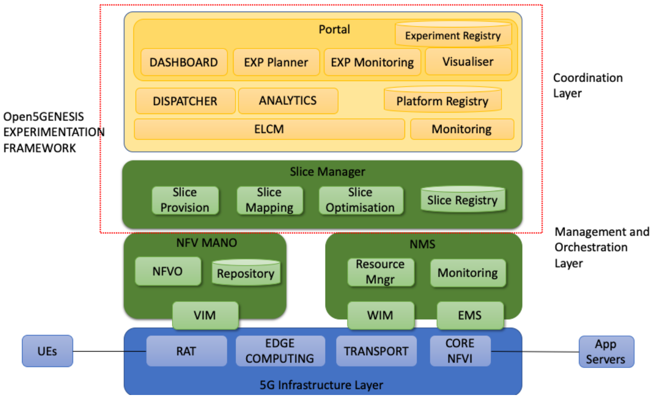

Fig. 1. 5GENESIS Architecture

The Coordination Layer is the interface between the platform and the experimenter and is responsible for the experiment's instantiation and lifecycle management. The MANO Layer includes all the management and orchestration capabilities necessary for deploying the experiments on the underlying networks, including slice management.

The 5GENESIS Slice Manager (released under the open source project Katana) [7] is responsible for controlling all devices comprising the network and provides an interface for creating, modifying, monitoring and deleting slices. The Coordination Layer along with the Slice Manager form the Open5GENESIS Suite Experimentation Framework [8] (red designated area in Fig. 1). Finally, the Infrastructure Layer contains the physical and virtual components, including radio, core, compute and networking nodes.

III. Test Cases and Infrastructure Setup

A. *Test Cases for 5G KPIs Validation*

The objective of 5GENESIS is the validation of 5G KPIs for various use cases, in controlled setups and large-scale events. The 5G KPIs under consideration include among others capacity, throughput, latency, RTT, reliability, service creation time, as well as application-specific KPIs, such as video stream jitter and 360° live video streaming Quality of Experience (QoE) [9].

This paper concentrates on throughput, RTT and latency experiments, conducted according to the 5GENESIS experimentation methodology [10]. This methodology includes the definition of Test Cases per KPI, which define the sequence of actions in the experiment, as well as the scenario template, which provides the information related to network configurations.

B. *Infrastructure Setup*

Despite the on-going deployment of commercial 5G networks around the globe, a proper KPI validation process requires dedicated and fully controllable testing environments [10], which is not possible in commercial networks.

A small scale but fully operational 5G infrastructure was used for the experimental part of this paper, depicted in Fig. 2. This infrastructure is part of the Athens 5GENESIS Facility and consists of both radio access (RAN) and core networks (CN) provided by Amarisoft [11] and Athonet [12]. The RAN comprises one gNodeB (gNB) and one eNodeB (eNB) acting as the LTE anchor point. The CN includes two distinct Rel.15 Evolved Packet Cores (EPCs). The Commercial-Off-The-Shelf User Equipment (COTS UE) that was used in the experiments is a Samsung A90 5G.

The experiments were executed on two 5G NSA setups of the Athens 5G Facility:

- Setup 1: Amarisoft RAN - Amarisoft CN
- Setup 2: Amarisoft RAN - Athonet CN

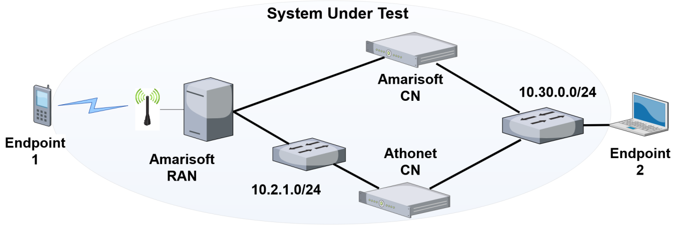

Fig. 2. Test Systems Setup

IV. 5G Experiments and KPIs Validation

The Athens Facility trials focused on conducting experiments on throughput, RTT and latency, in order to assess the capabilities of the deployed networks. The RAN configuration is the same in both Setups, as seen in Table I.

We also provide the radio network conditions throughout the experiments, by stating the average Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ) and Received Signal Strength Indicator (RSSI). RSRP is defined from -156dBm to -44dBm, RSRQ from -34dB to 2.5dB and RSSI from -100dBm to -25dBm [13]. The radio network conditions in our experiments correspond to acceptable levels, providing reliable service delivery.

TABLE I
Radio Configuration in Setups 1 & 2

Parameters	***4G***	***5G***
Frequency	2.1 GHz	3.5 GHz
Bandwidth	10 MHz	50 MHz
Antennas	MIMO 2x2	MIMO 2x2
Maximum Modulation	64 QAM DL	256 QAM DL
Duplex Mode	FDD	TDD

A. *Throughput*

In this experiment, we measured the downlink UDP throughput in Setup 1 & 2 using *iperf3*, in order to assess the maximum throughput value of the systems. Table II shows the average radio conditions during the experiments.

TABLE II
Radio Conditions in Setups 1 & 2 during throughput

Mobile Setup	**Average Radio Measurements**		
	RSRP (dBm)	***RSRQ (dB)***	***RSSI (dBm)***
Setup 1	-70.48 ± 0.20	-6.51 ± 0.21	-51.00 ± 0.00
Setup 2	-71.00 ± 0.00	-7.00 ± 0.00	-51.00 ± 0.00

The theoretical maximum throughput of this radio configuration corresponds to approximately 477 Mbps. However, the maximum achievable throughput in Setup 1 was measured at 369.27 ± 0.61 Mbps and in Setup 2 at 363.28 ± 1.00 Mbps. The difference between the theoretical and experimental values is due to the Time Division Duplex (TDD) mode in 5G, that uses 7 slots for downlink, 2 slots for the uplink and a special subframe.

In addition, the average throughput of Setup 2 is slightly less than the average throughput of Setup 1. This can be attributed to the transport network between Amarisoft's RAN and Athonet's CN. Setup 1 does not have such transport network in-between, therefore the RAN and CN communicate directly.

B. *Round Trip Time (RTT)*

a) RTT per packet size: This experiment evaluates the impact of packet size on the RTT by transmitting 32, 64, 128, 512 and 1500 bytes using the *ping* utility. These packet sizes showcase the network's response on various use cases, ranging from file sharing to audio and video traffic streaming. Table III provides the typical radio conditions throughout the experiments.

Fig. 3 and Fig. 4 depict the first order statistics per packet size, where the mean RTT for 64 bytes is comparable to the mean RTT of a pure LTE network running on top of standard Linux [14]. Whether an RTT value is acceptable or not, depends on the target value of the use case. In [15],

TABLE III
TYPICAL RADIO CONDITIONS IN SETUPS 1 & 2 DURING RTT EXPERIMENTS

Mobile Setup	**Average Radio Measurements**		
	RSRP (dBm)	***RSRQ (dB)***	***RSSI (dBm)***
Setup 1	-71.80 ± 0.00	-6.67 ± 0.16	-51.00 ± 0.00
Setup 2	-74.95 ± 0.11	-6.98 ± 0.05	-51.00 ± 0.00

there are end-to-end latency target values (one way delay) for applications like remote monitoring, tactile interaction and intelligent transportation systems. Both setups could accommodate services related to remote monitoring and process automation.

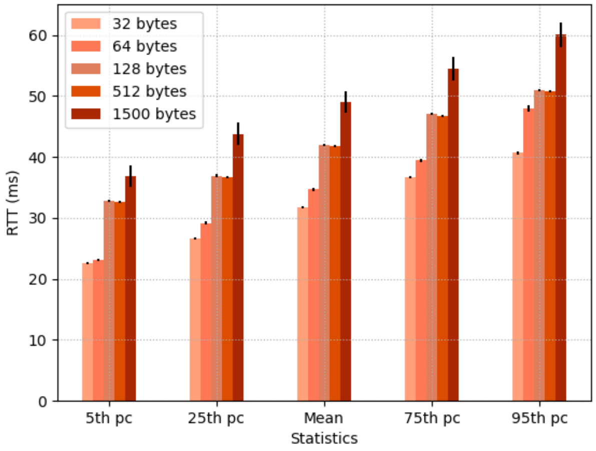

Fig. 3. End-to-end RTT for packet sizes 32, 64, 128, 512 and 1500 bytes in Setup 1

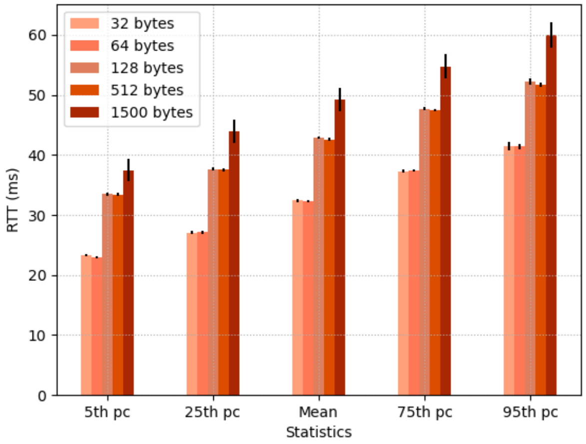

Fig. 4. End-to-end RTT for packet sizes 32, 64, 128, 512 and 1500 bytes in Setup 2

Fig. 5 and Fig. 6 depict the Empirical Cumulative Distribution Functions (ECDFs), highlighting the performance degradation (i.e. higher RTT values) as packet size increases. We also notice an overlap between 128 and 512 bytes in both Setups and an overlap between 32 and 64 bytes in Setup 2. This might be attributed to optimized buffers for traffic with these packet sizes in the mobile networks.

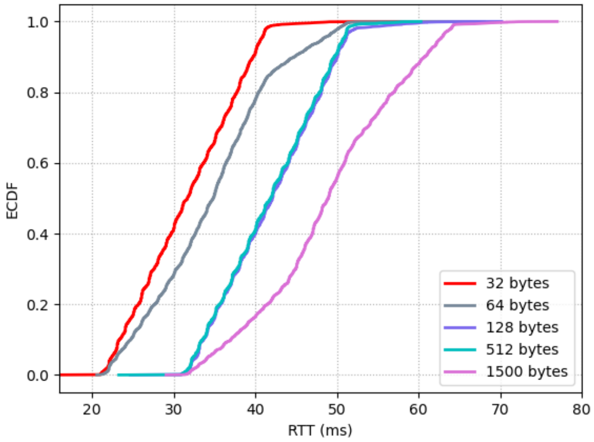

Fig. 5. ECDF of end-to-end RTT per packet size in Setup 1

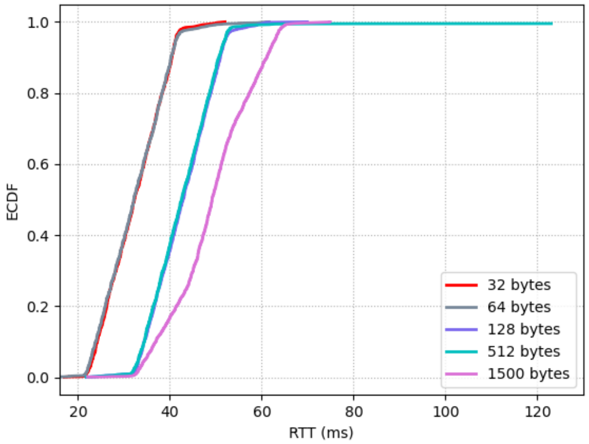

Fig. 6. ECDF of end-to-end RTT per packet size in Setup 2

b) RTT versus Radio Link Quality: This experiment evaluates the impact of Radio Link Quality to the end-to-end RTT in Setup 1 with one connected UE to the network. We measured the RTT of 64 and 1500 bytes packet sizes in three different cell locations with diverse radio conditions (peak, mid-cell and edge-cell conditions), using the *ping* utility.

Table IV provides the typical radio conditions in each location. In our case, the cell edge was at 30m away from the base station, which was the most distant location in the cell allowing the proper execution of the experiment without disconnections.

TABLE IV
RADIO LINK CONDITIONS IN VARIOUS CELL LOCATIONS

gNB - UE distance	***RSRP (dBm)***	***RSRQ (dB)***	***RSSI (dBm)***
3m	-86.00 ± 0.00	-7.79 ± 0.41	-61.48 ± 0.00
10m	-90.97 ± 0.02	8.85 ± 0.04	-64.64 ± 1.34
30m	-105.41 ± 0.49	-20.06 ± 1.04	-61.84 ± 1.30

According to Fig. 7, radio link quality does not affect the RTT of small packet sizes (64 bytes), in agreement with similar experiments in [16]. However, the impact is moderate at the cell edge when transmitting 1500 bytes, yielding an increase of 21.76% compared to normal cell conditions.

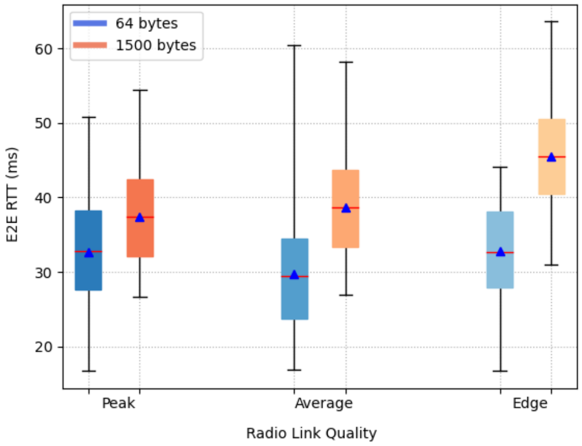

Fig. 7. Mean end-to-end (E2E) Round-Trip-time in different cell conditions for packet sizes of 64 and 1500 bytes

C. Latency (One-way delay)

This experiment employs application-based traffic profile to measure the latency between the UE and the CN. We transmitted Real-Time Protocol (RTP) 10 Mbps data rate traffic over the network and conducted separate experiments for the Downlink (DL) and the Uplink (UL) to highlight potential differences in the latencies of our network. It is important to note that our network is symmetric, so packets follow the same route on both directions. while there is no severe traffic load that would result in queuing delays in any of these routes. Table V provides the average RSRP, RSRQ and RSSI which were stable and in excellent levels throughout the experiment.

TABLE V
RADIO CONDITIONS IN DL AND UL LATENCY EXPERIMENTS

Experiment	**Average Radio Measurements**		
	RSRP (dBm)	***RSRQ (dB)***	***RSSI (dBm)***
Downlink Latency	-75.00 ± 0.00	-6.75 ± 0.02	-51.00 ± 0.00
Uplink Latency	-75.00 ± 0.00	-6.17 ± 0.02	-51.00 ± 0.00

We used IXIA's IxChariot Traffic Generator [17] to generate the appropriate traffic. During the experiment, all nodes of the network were synchronized to the same NTP server. The endpoints used IXIA's proprietary synchronization algorithm to estimate the clock difference between them while measuring one-way delays.

Fig. 8 depicts the moderate difference between the DL and UL Latency values, which can be attributed to the estimated clock errors (DL: 5.68 +/- 0.24 ms,UL: 5.78 +/- 0.18 ms). Latency is reported for the specific type of traffic (RTP at 10Mbps) and should not be generalized to different traffic profiles.

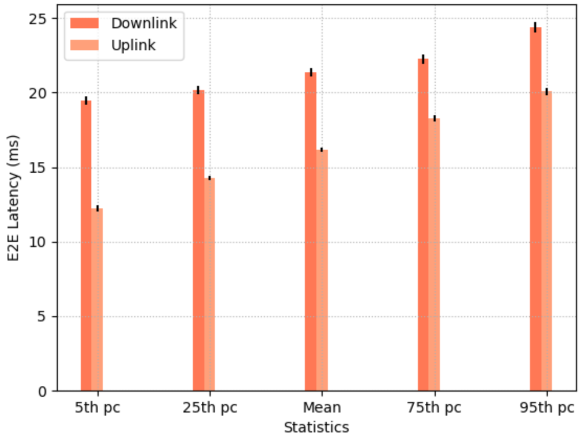

Fig. 8. Downlink and uplink end-to-end latencies in Setup 1

V. LESSONS LEARNED

This paper described the experimentation framework of the Athens 5GENESIS facility and presented results on throughput, RTT and latency KPIs over two selected 5G NSA setups. The lessons learned revolve around two distinct parameters: i) the design and deployment part and ii) the capabilities of the deployed networks expressed in the experimental results.

The design and deployment part includes the integration of heterogeneous technologies, the practical end-to-end deployment and the automated management of provided services. Each action comes with its own issues and shortcomings in terms of functionality, making the on-going troubleshooting procedure especially complex. This adds complexity to verticals that wish to test and validate their services in a 5G ecosystem and makes the creation of controlled 5G experimentation facilities imperative. Such facilities should follow continuous integration and testing procedures all along the course of the deployment, reassuring the experimenter on the soundness of the testbed before the experimentation cycle.

Regarding the experimental results on throughput, RTT and latency, they mostly highlight the capabilities of the deployed networks, in order to be used by interested verticals and application developers. This paper concentrated on 5G NSA setups, which can be considered as validation testbeds by verticals in several use cases, including remote monitoring and process automation. However, there are scenarios requiring extremely low latency values, like tactile interaction, that can only be accommodated by 5G SA deployments.

VI. ACKNOWLEDGEMENTS

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