5TH GENERATION END-TO-END NETWORK, EXPERIMENTATION, SYSTEM INTEGRATION, AND SHOWCASING

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Portable 5G Demonstrator (Release C)

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Version History

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List of Acronyms

Acronym	Meaning
3GPP	3rd Generation Partnership Project
5G PPP	5G Infrastructure Public Private Partnership
5G-IA	The 5G Infrastructure Public Private Partnership
APN	Access Point Name
COTS	Commercial Off-The-Self
DL	Downlink
eMBMS	Evolved Multimedia Broadcast Multicast Services
eNB	eNodeB, evolved NodeB, LTE eq. of base station
EU	European Union
EPC	Evolved Packet Core
gNB	gNodeB, 5G NR, next generation NR eq. of base station
GPP	General Purpose Processor
HetNet	Heterogeneous Network
HSS	Home Subscriber Server
H-RAN	Heterogeneous RAN
ICIC	Inter-Cell Interference Coordination
ICMP	Internet Control Message protocol
IDS	Intrusion Detection System
IOT	Internet of Things
KPI	Key Performance Indicator
LNA	Low Noise Amplifier
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution - Advanced
MANO	MANagement and Orchestration
MCS	Modulation Coding Scheme
MIMO	Multiple-input-Multiple-output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications
NBI	North Bound Interface
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NSA	Non standalone
NSMF	Network Slice Management Function
NR	New Radio
OAI	Open Air Interface
OSA	OpenAirInterface Software Alliance
OAM	Operations, Administration & Management
OEM	Original Equipment Manufacturers
OF	OpenFlow
ONAP	Open networking Automation Platform

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Acronym	Meaning
OSM	Open Source MANO
PA	Power Amplifiers
PRB	Physical Resource Block
QoS	Quality of Service
RAN	Radio Access Network
RRH	Remote Radio Head
RRM	Radio Resource management
RTT	Round-Trip-Time
RU	Radio Unit
SDN	Software Defined Network
SDR	Software Defined Radio
SFP	Small form-factor pluggable
SPGW	Serving & PDN GateWay
SISO	Single-Input Single-Output
TDD	Time Division Duplex
UAS	Unmanned Aerial Systems
UE	User Equipment
UL	Uplink
VM	Virtual Machine

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Executive Summary

This document presents the 5GENESIS portable demonstrator, i.e., a portable platform that is used in the 5GENESIS project for participating in exhibitions/demo events and, also, to provide vertical sectors with a full 5G reference testbed for on-site testing. The main content of the document refers to the description of the integration activities conducted during the period up to M37 of the project.

As it is explained in the document, the development of the 5GENESIS portable demonstrator targets a compact physical layout to guarantee portability. However, the developments are not limited to a monolithic approach. Multiple building blocks have been integrated in a modular way to enhance the variety of test cases and experiments that the 5GENESIS portable demonstrator can support. In that sense, both open-source software solutions (such as the Open Air Interface (OAI), provided by EURECOM, over Ettus USRPs) and commercial off-the-shelf products (i.e., Amarisoft) have been adopted.

All the activities reported in this document abide by the need to meet a major objective of the project, i.e., the realisation of the 5GENESIS reference architecture (released from WP2 of the project). In this context, the reader can find infrastructure level integrations as well as installations and configurations of the 5GENESIS facility layer, i.e., the set of tools (released from WP5 of the project) that are being developed to enable automated experimentation, slice management, and performance monitoring. From the infrastructure perspective, research-oriented set ups for 4G and 5G technologies have been integrated, while a 5G SA/NSA solution is available for performance testing from verticals, such as the ones conducted for UAV vertical industry.

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1. INTRODUCTION

1.1. Purpose of the Document

This document is the second document dedicated to the work performed in WP4 for the realization of the 5GENESIS portable demonstrator. The document serves as a reference point for the current status of the conducted integration activities, as well as a comprehensive descriptor of the functional and infrastructure components of the demonstrator. We note that the work reported in this document is linked to the activities of WP7 of the project (especially the dissemination and demonstration tasks) and as such, it can complement any participation in related events.

In the table below, the documents that have been released in the context of the 5GENESIS project are provided, including the relevance level with this document.

Table 1 Relevant deliverables

ID	Document title	Relevance
D2.1 [1]	Requirements of the Facility	The document sets the ground for the first set of requirements, related to the features that the platform should support and the Use Cases that should be tested.
D2.2 [2]	5GENESIS Overall Facility Design and Specifications	The 5GENESIS facility architecture is defined in this document. The list of functional components to be deployed in each testbed is defined.
D2.3 [3]	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D4.16/D4.17 [4]	The Portable 5G Demonstrator	D4.16 is the initial deliverable of the 5GENESIS Portable demonstrator. In D4.16, the focus was mainly on the description of the technologies and the different components that was available for the integration of the 5GENESIS portable demonstrator. In D4.17, the focus was on well-integrated setups and on the evolution of the developments for the portable demonstrator. Also, since D4.17 was a public deliverable, effort allocated to avoid strong correlation with the content in its predecessor (treated as confidential). Finally, in D4.18 we provide a reference document for the portable 5GENESIS demonstrator, together with the use-case specific development performed during 5G showcasing events, where the current infrastructure provided 5G connectivity.

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D5.1/D5.2 [5]	System level tests and verifications	These documents provide guidelines, tests and software for the realization of the 5GENESIS facility coordination layer components, considering the two releases of the Open 5GENESIS Suite.

1.2. Structure of the Document

The document is composed of four sections where the second one includes the core technical aspects of the document. It includes a comprehensive overview of the 5GENESIS demonstrator, and separate subsections have been assigned to i) mobile network technologies i.e., the Radio Access Network (RAN) and core set ups, ii) the transport network and how it is emulated in the context of the demonstrator, and iii) the network management and control tools used to support experimentation and testing. The third section refers to the activities conducted for the evolution of the demonstrator across the three phases of the WP4, while it also discusses use-case specific developments, needed for the support of specific showcasing events. Finally, the fourth section includes the conclusions.

1.3. Target Audience

This document targets primarily the 5GENESIS consortium in order to be used as a reference document for the planning of WP5 and WP6 activities, but also aims at external non-5GENESIS-related people, either from other 5G-PPP projects or from the research community and the ICT industry. The document may help appreciate design decisions for the deployment of 5G components and evaluate the adoption and deployment progress of the 5G infrastructure. The deliverable will help that interested audience to:

- Be informed on the latest 5G developments of the portable demonstrator
- Be informed on the use-case specific developments needed to support vertical industry-driven showcasing events.
- Understand the requirements and risks for each deployed component within the portable demonstrator
- Facilitate technology selection and design decisions for their components
- Understand the limitations and restrictions in technology deployment and usage.

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2. PORTABLE DEMONSTRATOR OVERVIEW

2.1. Target Deployment Overview

The Portable Demonstrator of the 5GENESIS project provides a mobile end-to-end platform for demonstration purposes in exhibitions and various events, as well as a fully functional tool that enables on-site testing and experimentation for vertical industries. The main principle of the development process for the 5GENESIS Portable Demonstrator refers to a compact and mobile platform that integrates all the necessary components needed to support 5G Experimentation as a Service.

To facilitate its portability and the feature of "on-site testing", the 5GENESIS Portable Demonstrator is realized with small form factor PC cases and laptops, while all the software and tools are onboarded in order to be self-contained and autonomous. However, the potential of connecting the infrastructure part of the 5GENESIS Portable Demonstrator with other 5G components, such as using different 5G core network or EPC provided by other vendors, is also feasible. This potential enables the support of new demonstration and benchmarking scenarios, which give to the portable demonstrator the value of a performance testing tool for 5G networks, a feature that is not widely available at the time of writing this deliverable.

Figure 1 depicts the physical components of the Portable 5G Demonstrator. It is noted that the diagram in Figure 1 includes the full set of physical components that are currently active for the development process, meaning that it shows commercial nodes, auxiliary PCs/monitors, as well as the nodes where open-source or project specific software is installed (e.g., OAI, WAN emulator etc.).

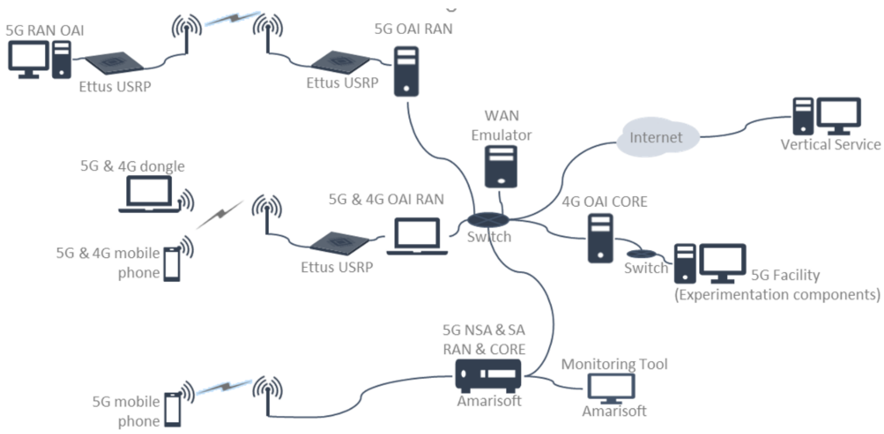

Figure 1 Physical diagram of the Portable Demonstrator

In terms of the functional components as of Open 5GENESIS Suite Release B (please refer to WP5 D5.2), the features of the Portable Demonstrator are:

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- 5G NR radio front-end (eNB/gNB) and user equipment (UE), based on open source SDR and software components by ECM, as well as Commercial Off-The-Self (COTS) solutions (especially for commercial 5G mobile phones);
- 4G and 5G core functions, including both open source implementation by ECM (OAI) and commercial 5G core solutions (Amarisoft). Some third party open source implementations, such as Open5GS, Free5GC are also under testing, but currently not stable enough to support field trials;
- Coordinator layer components (w.r.t. the 5GENESIS reference Architecture) on top of NFV/SDN MANO stack.

2.2. Platform Infrastructure Layer

Table 2 includes the technical characteristics of the physical components that comprise the 5GENESIS Portable Demonstrator.

Table 2 Infrastructure layer components of the Portable Demonstrator

Component	Product/Technology	Mode of Implementation
LTE and 5G-NR UEs/CPEs	• 5G NR UE: Dell G5 5587, i9-8950HK & USRP N310 (National Instruments) • COTS 5G NSA/SA UEs (e.g. Samsung A90 5G, Samsung Galaxy Note 20, Google Pixel 5etc.) • Waveshare SA/NSA 5G CPE • Waveshare SA/NSA open 5G UE • 4G UE: Commercial LTE mobile phones and dongles	4G and 5G SA/NSA UEs
eNB/gNB	• OAI gNB: Dell G5 5587, i9-8950HK & USRP N310 (National Instruments) • Amarisoft Callbox eNB & gNB (Amari Callbox Classic) • OAI eNB: Dell Inspiron 5570 (i7-8550U CPU) & USRP B210	LTE and 5G-NR Base Stations
10GbE Adapter Module between OAI based host PCs and SDRs	• 2xThunderbolt-3 10GbE Adapter Module (Sonnet)	Provides 10GbE Ethernet connectivity between the gNB/5G UE SDRs and the respective OAI PC hosts
EPC	• OAI vEPC: Dell Vostro 3470 (i7-8700 CPU) • Amarisoft EPC & 5GC (Athens Platform)	4G Evolved Packet Core
5GC		5G New Core
Transport Network Emulator	Intel NUC 6i7KYK	
Switch	Generic Top-of-the-Rack Switch	

Traffic Generators for performance / benchmarking / monitoring	• iPerf • Ping • Speedtest	Testing and Measurement
Router	• Cisco RV180	Router for external connectivity

2.2.1. Mobile Network Technology

The 4G and 5G RAN and Core open-source solutions provided by ECM (OAI software) have been integrated in the Portable 5G Demonstrator and will continue to be updated as more functionalities become gradually available in the course of 5GENESIS. The inclusion of an open-source solution in the Portable Demonstrator serves mainly for showcasing its significant efficiency in RAN and Core design from both innovation and cost perspectives to appropriate target audiences, given that there is a trend towards open interfaces. It is also an approach that allows for the full integration of the management and coordination layer of the 5GENESIS reference architecture, i.e., the layers that enable the run of automated and controlled tests. As an alternative solution for demonstration purposes with commercial 5G COTS UEs, the Portable 5G Demonstrator adopts the Amarisoft Callbox Classic[1]. All the approaches are described in the following subsections, while the roadmap for the three integration cycles of the project (phases) is summarized in Table 3.

Table 3 Portable 5G Demonstrator Technology roadmap

	Mobile Core Product	Radio Access Products	UE
Phase 1	OAI vEPC	OAI eNodeB	Commercial 4G
	Athonet EPC	OAI eNodeB	Commercial 4G/4G Dongle
Phase 2	N/A	OAI gNodeB	OAI nr-UE/SDR ETTUS
	Commercial EPC/5GC (Amarisoft Athens Platform Solution)	Commercial eNodeB/gNodeB (Amarisoft Athens Platform Solution)	Commercial 5G UE (Amarisoft Athens Platform)
Phase 3	OAI vEPC/ Commercial EPC/Amaristoft 5GC	OAI gNodeB	Commercial SA/NSA 5G/OAI NR-UE
	Commercial Solution adopted by Athens Platform		

[1] https://www.amarisoft.com/app/uploads/2019/09/Amari_Callbox_classic.pdf

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2.2.1.1. OAI-based 5G NSA end-to-end setup

5G NR setup

The 5GENESIS Portable Demonstrator has integrated the 5G RAN open-source solution provided by ECM. The setup has been implemented bearing high processing power and portability in mind, satisfying the Portable Demonstrator's requirements. ECM's OAI application implements the NR features at the gNB and UE side (the so-called nrUE component in OAI) in compliance to the Rel.15 Standards. It also provides utilities for debugging, monitoring and demonstration purposes.

The OAI gNB and OAI nrUE software runs on top of two laptops with overclocked i9-proceesors, in order to support the high processing requirements of the OAI software. The software implements the whole chain of signal processing functions of the 5G-NR protocol stack, ranging from the physical to the higher layers of the RAN protocol stack.

The ETTUS USRPs N300 convert the RF signal to and from baseband using analog filtering, digital up and down conversion circuits. They feed the signal through 10GbE SFPs, which are required to support the sampling rates of 5G-NR (61.44Ms/s and 122.88Ms/s, depending on the 5G configuration). The laptops are connected to the USRPs with 10GbE-Thunderbolt3 adapters, capable of supporting the required rates.

Figure 2 5G NR Setup of the Portable Demonstrator

The connection between the two USRPs takes place either over-the-air or wire with proper attenuators to protect the radio frequency units. The supported bandwidths are 40, 80 and 100

MHz (106, 217 and 273 Physical Resource Blocks (PRBs) respectively) and the frequency band of operation is 3.5GHz. When transmitting over-the-air in areas with assigned license, the USRPs shall utilize a set of omnidirectional antennas, while the proper transmission and reception gains of the SDRs will be configured through the OAI application.

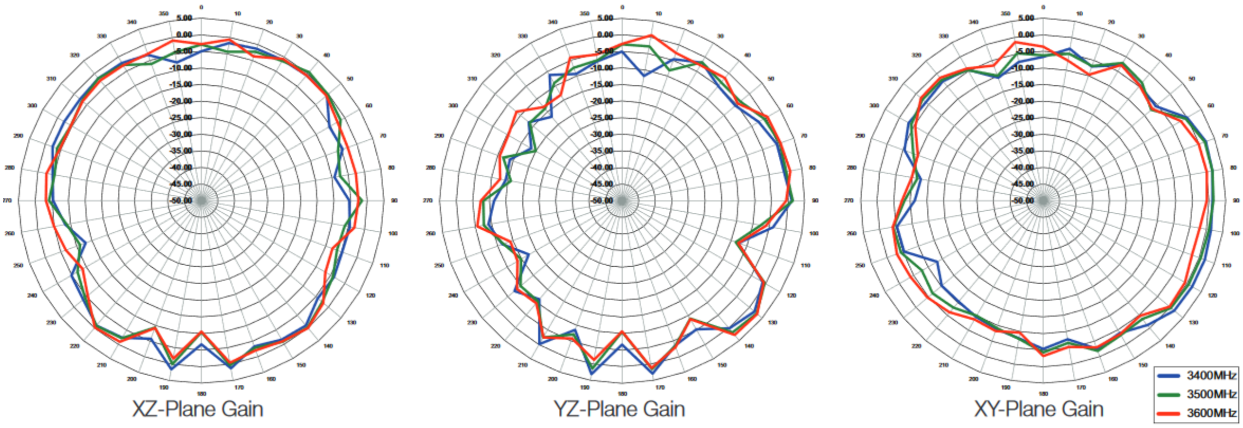

Figure 3 Antennas gain plots on 3.5GHz[2]

The ETTUS USRPs are synchronized with the Octoclock-G Clock Distribution Module[3], providing 8 pulse per second and 10MHz reference signals for time and frequency synchronization. The reference signals of the Octoclock-G are generated either by an internal GPS-disciplined, oven-controlled crystal oscillator or an external source.

Figure 4 Octoclock-G Clock Distribution Module

The OAI gNB and OAI nrUE laptop hosts have been configured with Ubuntu 18.04 LTS and 5.0.0.25-low-latency kernel version.

5G RAN monitoring takes place using the *T-Tracer* and *XForms* utilities. The figure below depicts the XForms application running in the nrUE laptop, providing information on the received signal (both control and data channels at the physical layer).

[2] https://gr.mouser.com/datasheet/2/238/ant-lte-mon-1659497.pdf
[3] https://www.ettus.com/all-products/octoclock-g/

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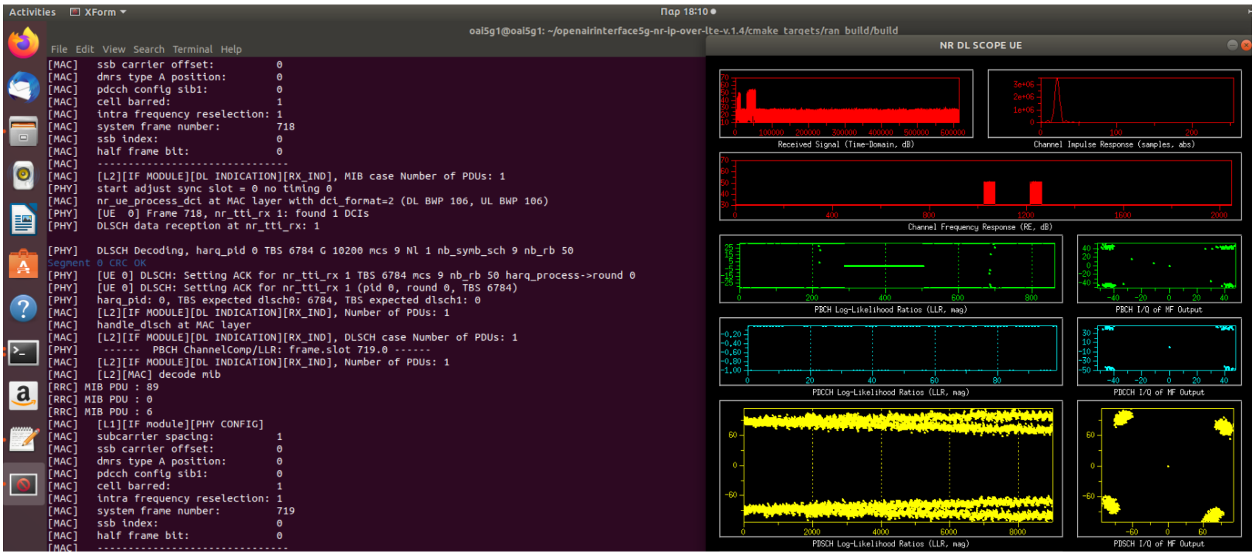

Figure 5 5G-NR OAI Scope monitors detection of 5G NR physical channels

On the other hand, the T-tracer utility (Figure 6) includes the *textlog tracer* that provides timestamped logs for metrics defined by the user.

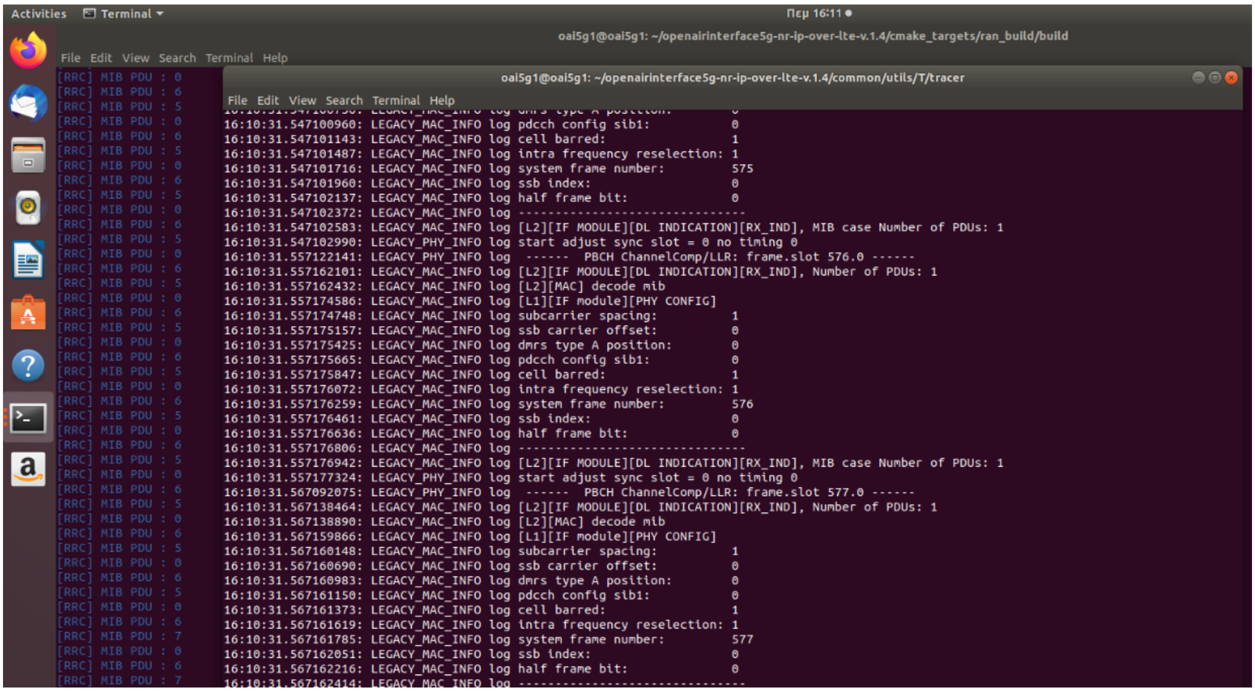

Figure 6 OAI Textlog T-tracer timestamped logs on the OAI gNB and nrUE

In Release B of the Portable Demonstrator, there have been IP-based connectivity tests between the OAI gNB and the OAI nr-UE, using iPerf and ping utilities (Figure 7). For the realization of these tests, a special mode (noS1) has been integrated in OAI, as an intermediate step until the complete NSA developments in OAI become available in Release C, as reported in this deliverable. The noS1 mode allowed in phase 2 to preconfigure the required parameters for data-plane communications (Data radio bearer, PDCP and RLC entities, IP interfaces) and establish an IP communication link between the gNB and the nrUE, without having an actual RRC Connection establishment and UE attachment to the core network. In phase 3, the noS1 mode was replace with proper S1 connectivity with OAI EPC, and the NSA 5G OAI-based system was properly assessed in terms of performance, as the following subsection reports.

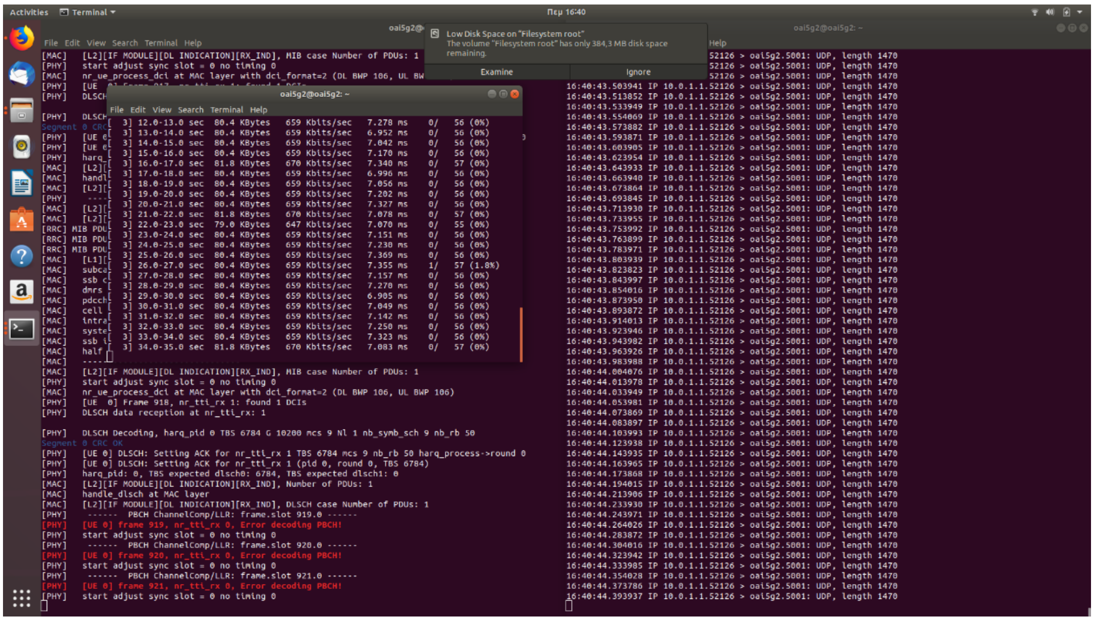

Figure 7 Ping and iPerf tests between OAI gNB and OAI nr-UE

Mobile Core Network

In release C of the portable demonstrator, the noS1 mode was replaced with the integration of the Eurecom's OAI Core Network solution as Mobile Core Network of the Portable Demonstrator. The code is implementing all basic functions of the Long-Term Evolution (LTE) core components (Mobility Management Entity (MME), Home Subscriber Server (HSS), Serving PDN GateWay (SPGW)). OAI Core Network solution is divided in two projects:

- openair-cn, implementing HSS and MME functions
- openair-cn-cups, implementing the separation of user and control plane functions of SPGW (SPGWU, SPGWC).

OAI implements the core network components and the respective interfaces. In the Portable Demonstrator, in order to follow the principles of Network Slicing concept, every core component is thought as a separate VNF. As a result, all core components are deployed on different virtual machines.

Performance Evaluation of NSA 5G Portable Demonstrator

The OAI end-to-end NSA setup is composed from the eNB and gNB components, the OAI CN and a 5G NSA supporting COTS UE, which in this case is the Google Pixel 5. The different performance evaluation measurements are based on testing with different Modulation Coding Schemes (MCS) , which have a direct impact on the Downlink (DL) throughput performance. The current release of the portable demonstrator reaches up to 75 Mbps for MCS 24 for DL (Table 4). This performance ranges around the theoretical expected values, considering the configurations made. The Uplink (UL) throughput is currently up to 7.15 Mbps regardless of the MCS scheme. Same for Round-Trip-Time (RTT) latency measurements with ping which was measured on average 14-14.5 ms.

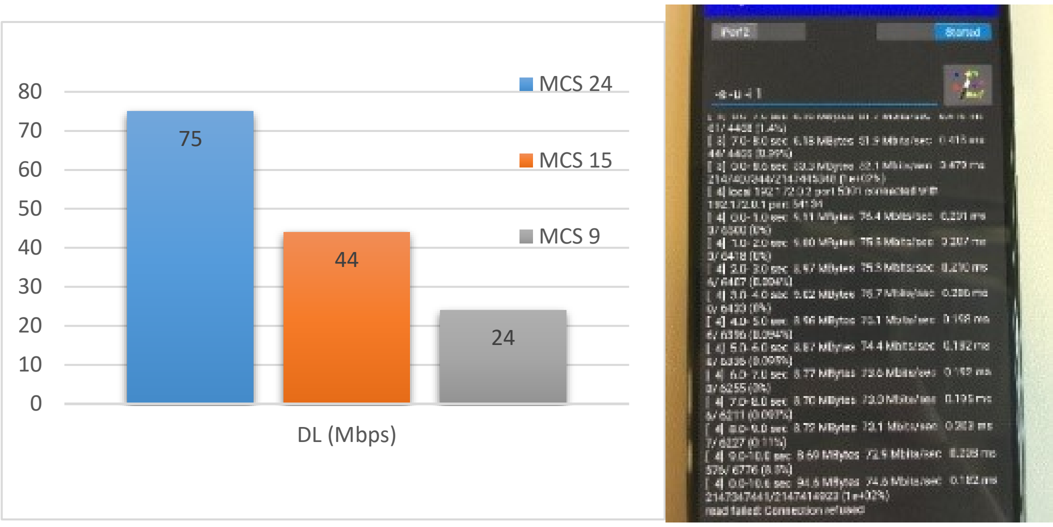

Figure 8 DL (Mbps) assessment at MCS 24/15/9

Regarding the setup, this is on Frequency Range 1 (FR1, band 78) for the gNB based on Time Division Duplex (TDD), 30kHz subcarrier spacing, 106 PRB (40MHz), Single-Input Single-Output (SISO).

Table 4 Performance Assessment Configuration

CS	Qm (Modulation Order)	Modulation Scheme	DL Throughput
9	2	QPSK	24 Mbps
15	4	16-QAM	44 Mbps
24	6	64-QAM	75 Mbps

2.2.1.2. Commercial 5G SA/NSA setup

(a) Amarisoft Callbox Classic

As already mentioned, a key principle of the 5GENESIS portable demonstrator is to examine multiple set-ups in a modular way to enhance the variety of test cases and experiments that the 5GENESIS portable demonstrator can support. The Amarisoft Callbox Classic is one of the commercial solutions deployed in the Athens Platform and provides the capability of demonstrating a complete 5G implementation. In phase 2 the NSA configuration had fully deployed and tested, while in phase 3 the SA configuration was also provided and properly validated with both COTS UEs and open-source CPEs/UEs. On top of this implementation 5GENESIS-specific features are being added to enable slice management and automated experimentation capabilities. In addition, the currently available web interface for monitoring the parameters of the system, is being enriched with Grafana and Prometheus tools.

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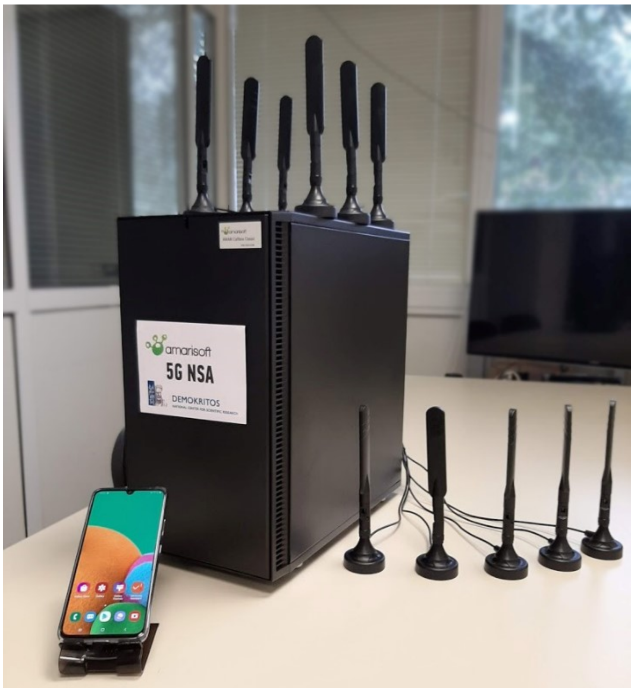

Figure 9 Amarisoft Callbox Classic and Samsung A90 5G

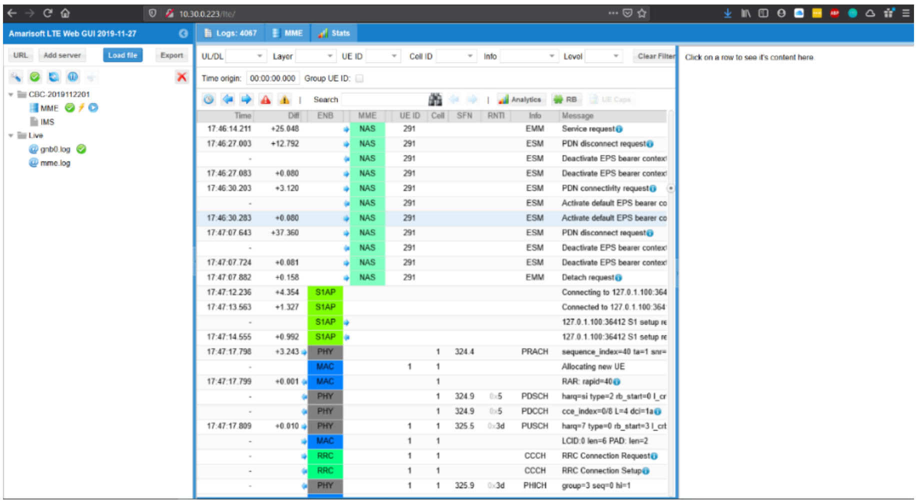

Figure 10 Amarisoft Web Interface

(b) Amarisoft Callbox mini

Packaged in a plug and play integrated PC, AMARI Callbox Mini is an ideal solution for 4G/5G testing of all types of UEs with advanced configuration. It acts as a 3rd Generation Partnership Project (3GPP) compliant eNodeB, gNodeB, EPC and 5GC allowing functional and performance testing of NR (SA mode), LTE, LTE-A, LTE-M and NB-IoT devices.

Figure 11 Amarisoft Callbox Mini

An integrated IMS server as well as an Evolved Multimedia Broadcast Multicast Services (eMBMS) gateway for VoLTE and eMBMS testing is also available, enhancing further the capabilities of the ultra-portable branch of the 5GENESIS demonstrator for supporting various use-cases and showcasing events in the field. AMARI Callbox Mini is a very compact solution, designed to be used everywhere. From lab to exhibition show, this is the ideal product for NB-IoT, CATM1, CAT0 to CAT4 UEs testing.

(c) Raspberry Pi-based SA/NSA 5G UE

This 5G/4G/3G Raspberry Pi communication HAT adopts SIMCom 5G module SIM8200EA-M2, supporting 5G NSA and SA networking and data rates up to 2.4 Gbps (DL) / 500 Mbps (UL).

Figure 12 SIM8200EA-M2 5G HAT UE

The base board features standard M2 connector, allows connecting with different 4G or 5G communication module with M2 package. There are also USB3.1 port, audio jack and decoder, SIM card slot, etc. Allowing the deployment of configurations script and programming code, the "open" SA/NSA UE allows the demonstration and showcasing of various apps and modules with 5G connection. 5G HAT supports a wide range of the frequency bands, both at SA and NSA mode:

Sub-6G (SA): n1, n2, n3, n5, n7, n8, n12, n20, n28, n38, n40, n41, n48, n66, n71, n77, n78, n79
Sub-6G (NSA) n41, n77, n78, n79

(d) 5G CPE

Figure 13 Qualcomm Snapdragon X55 CPE

The 5G CPE wireless router uses the Qualcomm Snapdragon X55 modem and converts 5G network into Gigabit Ethernet, USB 3.1, and WiFi 6, allowing the 5G connectivity with products that are not providing a 5G model as an option, but other network interfaces are available, such as ethernet, USB, wifi etc. The Qualcomm Snapdragon X55 5G Modem-RF System is a comprehensive modem-to-antenna solution designed to allow OEMs to build 5G multimode devices. The 5G CPE supports 5G SA and NSA and global multiple frequency band. Suitability for experimentation where high speed 5G network access are required, like: AI robot/drone, industrial IoT, outdoor live streaming, automotive devices.

(e) DualBand Small Cell Panel Antenna combined with PAs/LNAs

In order to enhance the coverage capabilities of the 5GENESIS portable demonstrator in the field, there is also the option of using an external small cell antenna together with PAs and LNAs. The CCI Dualband 65° x 65° array is an eight port Small Cell antenna, with four wide band ports covering 1695-2690 MHz and four wide band ports covering 3400-3800 MHz.

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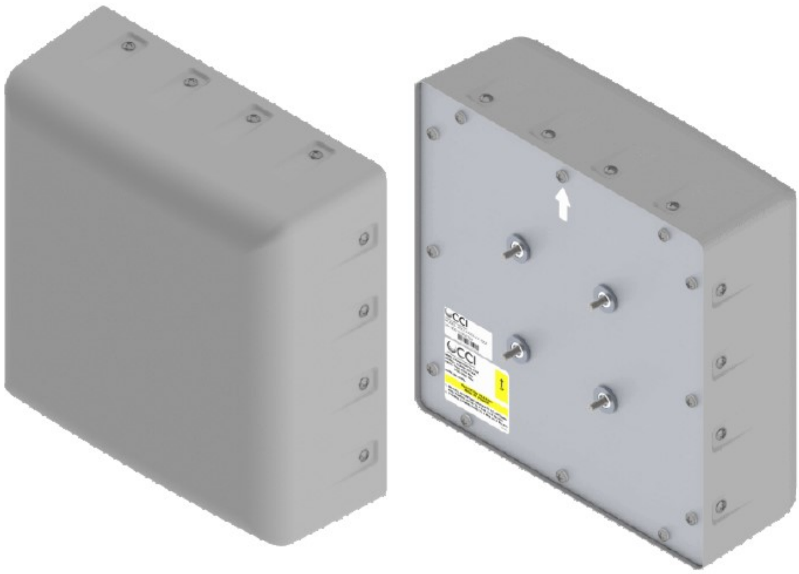

Figure 14 DualBand Small Cell Panel Antenna

The CCI 65° x 65° Small Cell antenna provides two independent sets of 2x2 Multiple-input-Multiple-output (MIMO) functionality across the 1695-2690 MHz and 3400-3800 MHz ports.

Table 5 DualBand Small Cell Panel Antenna Specifications

Ports	4 x High Band Ports for 1695-2690 MHz					4 x High Band Ports for 3400-3800 MHz
Frequency Range	1695-1880 MHz	1850-1990 MHz	1920-2180 MHz	2300-2400 MHz	2496-2690 MHz	3400-3800 MHz
Gain[1]	10.9 dBi	11.0 dBi	11.2 dBi	11.3 dBi	11.5 dBi	7.8 dBi
Gain (Average)[2]	9.5 dBi	9.6 dBi	9.9 dBi	10.3 dBi	10.5 dBi	7.4 dBi
Azimuth Beamwidth (-3dB)	67°	69°	69°	70°	71°	73°
Elevation Beamwidth (-3dB)	47°	45°	43°	38°	34°	72°
Electrical Downtilt	4°	4°	4°	4°	4°	0°
Elevation Sidelobes (1st Upper)	< -18 dB	< -19 dB	< -18 dB	< -12 dB	< -11 dB	NA
Cross-Polar Discrimination (at Peak)	> 21 dB	> 19 dB	> 20 dB	> 19 dB	> 19 dB	> 19 dB
Front-to-Back Ratio @180°	> 35 dB	> 34 dB	> 35 dB	> 35 dB	> 35 dB	> 35 dB
Cross-Polar Port-to-Port Isolation	> 25 dB	> 25 dB	> 25 dB	> 25 dB	> 25 dB	> 25 dB
Voltage Standing Wave Ratio(VSWR)	< 1.5:1	< 1.5:1	< 1.5:1	< 1.5:1	< 1.5:1	< 1.5:1
Passive Intermodulation (2x20W)	≤ -153 dBc	≤ -153 dBc	≤ -153 dBc	≤ -153 dBc	≤ -153 dBc	NA
Input Power Continuous Wave (CW)	100 watts	100 watts	100 watts	100 watts	100 watts	50 watts
Polarization	Dual Pol 45°	Dual Pol 45°	Dual Pol 45°	Dual Pol 45°	Dual Pol 45°	Dual Pol 45°
Input Impedance	50 ohms	50 ohms	50 ohms	50 ohms	50 ohms	50 ohms
Lightning Protection	DC Ground	DC Ground	DC Ground	DC Ground	DC Ground	DC Ground

[1]*Peak gain across sub-bands.*
[2]*Electrical specifications follow document "Recommendation on Base Station Antenna Standards" (BASTA) V9.6.*

The pattern of the antenna covers a wide area both at the vertical and horizontal axis.

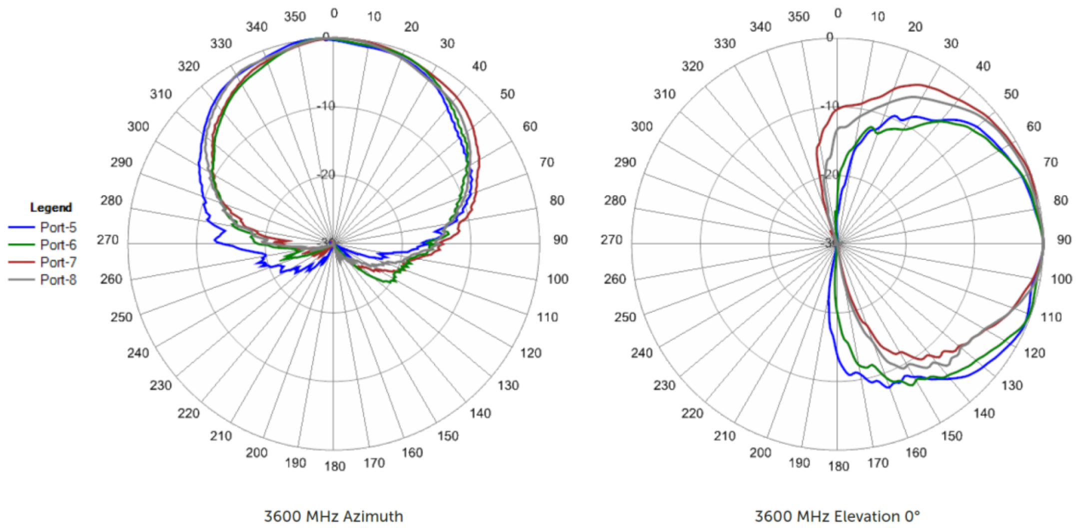

Figure 15 Typical Pattern of the DualBand Small Cell Panel Antenna at 3.6GHz

Moreover, the power of the 5G signal can be amplified by using a portable set of Power Amplifiers (PA) and Low Noise Amplifiers (LNA) that have been properly set up within a portable case. The PA amplifies when the 5G system transmitting, while the LNA amplifies when the system is receiving. For duplexed signal, passive duplexer shifts between the two on Rx/Tx.

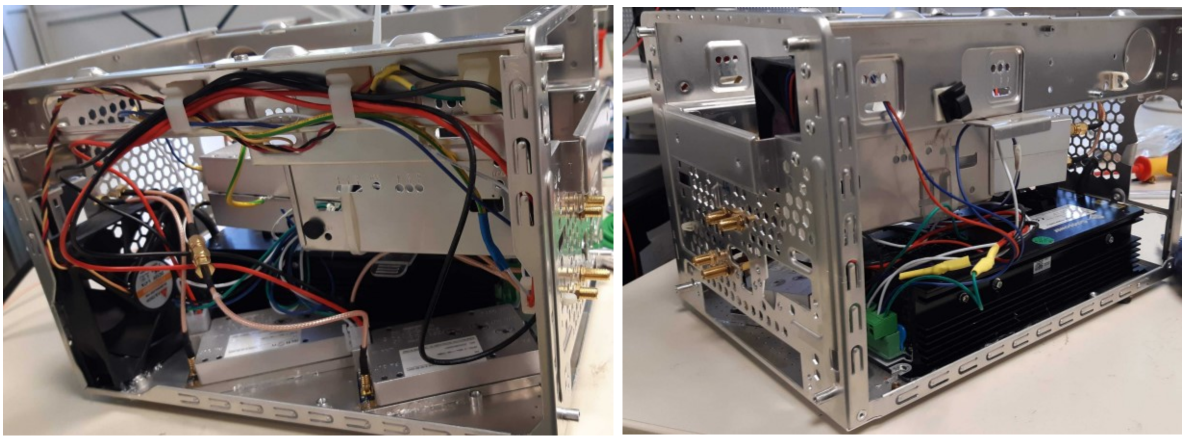

Figure 16 PAs and LNAs configured within the portable case

2.2.1.3. OAI-based End-to-End 4G setup

RAN features

The 4G RAN of the Portable Demonstrator is implemented with the open-source OpenAirInterface RAN (OAI-RAN) solution, provided from Eurecom. The 4G eNB component consists of an ETTUS USRP B210 SDR[4], with VERT 900 antennas attached, connected via USB3.0 to an Intel Core i7-8550U CPU @ 1.80GHz x 4 Dell laptop, deploying OAI RAN functions[5]. All

[4] The version of software driver for the USRP used is 3.13.1.
[5] The code is taken from Eurecom's "openairinterface5g" repo (master branch, commit "7af84127")

functions are running on Ubuntu 18.04 operating system with Linux 4.15.0-72 low latency kernel. The eNB node uses a physical interface through which it is connected to the OAI EPC.

Figure 17 The end-to-end 4G set up

The 4G UEs are implemented with COTS mobile phones and dongles (Figure 18). The UE is registered to the OAI EPC using (U)SIM cards provided by Sysmocom. The cards have been configured / programmed using pySim-prog, a command line utility that is used to modify identities and private key data in SIM cards. A list of the available COTS UEs used in our implementation, and the adopted frequencies for transmission are outlined below, in Table 6 and Table 7, respectively.

Table 6 UE features used in the end-to-end 4G setup

UEs	Features
1 x Huawei E3372 (USB Dongle)	Cat4 (DL: 150 Mbps/UL: 50 Mbps at 20 MHz), LTE FDD Bands: 800/900/1800/2100/2600
1 x Samsung Galaxy S4	Cat3 compatible Smart Phones (100/50)
1 x Samsung Galaxy Note 3	Cat4 compatible Smart Phones (150/50)

Table 7 eNB parameters for the end-to-end 4G setup

eNB parameters	Values
LTE Band	7
DL Frequency (MHz)	2685
UL Frequency (MHz)	2565
DL NRB	25

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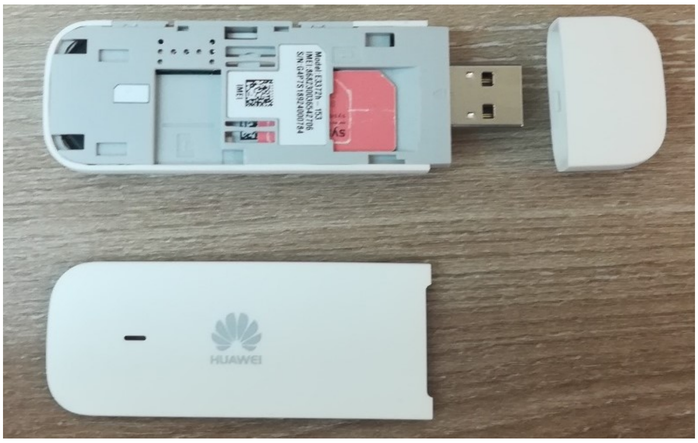


Figure 18 The LTE dongle used in the 4G set up

UE attachment

To attach a UE in the network, we first have to set our network's Access Point Name (APN) on the device. In the case of the Huawei dongle, we configure the APN from the dongle's portal. The portal can be accessed when the USB is attached to the machine. Otherwise, if an LTE smart phone is used, then the APN can be added from the phone settings. When the APN is set, the device scans for LTE networks nearby, and then the user decides to which networks she/he wants to be connected. The figure provided below depicts the dongle's portal results when the device connects to our network.

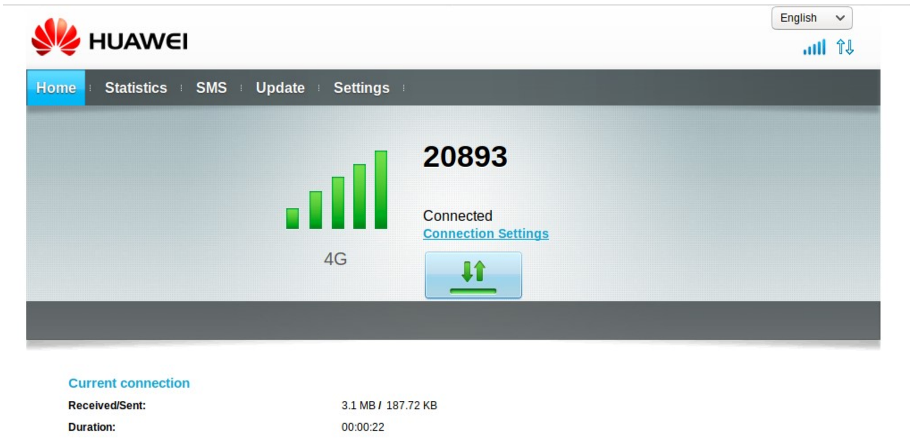


Figure 19 The established connection from the LTE Dongle in the 4G setup

RAN Monitoring

The OAI T-Tracer has been used for monitoring purposes. The figure below depicts T-Tracer results from the eNB, providing information on the received signal, uplink and downlink channels, as well as the packets of the network layers transmitted and received.

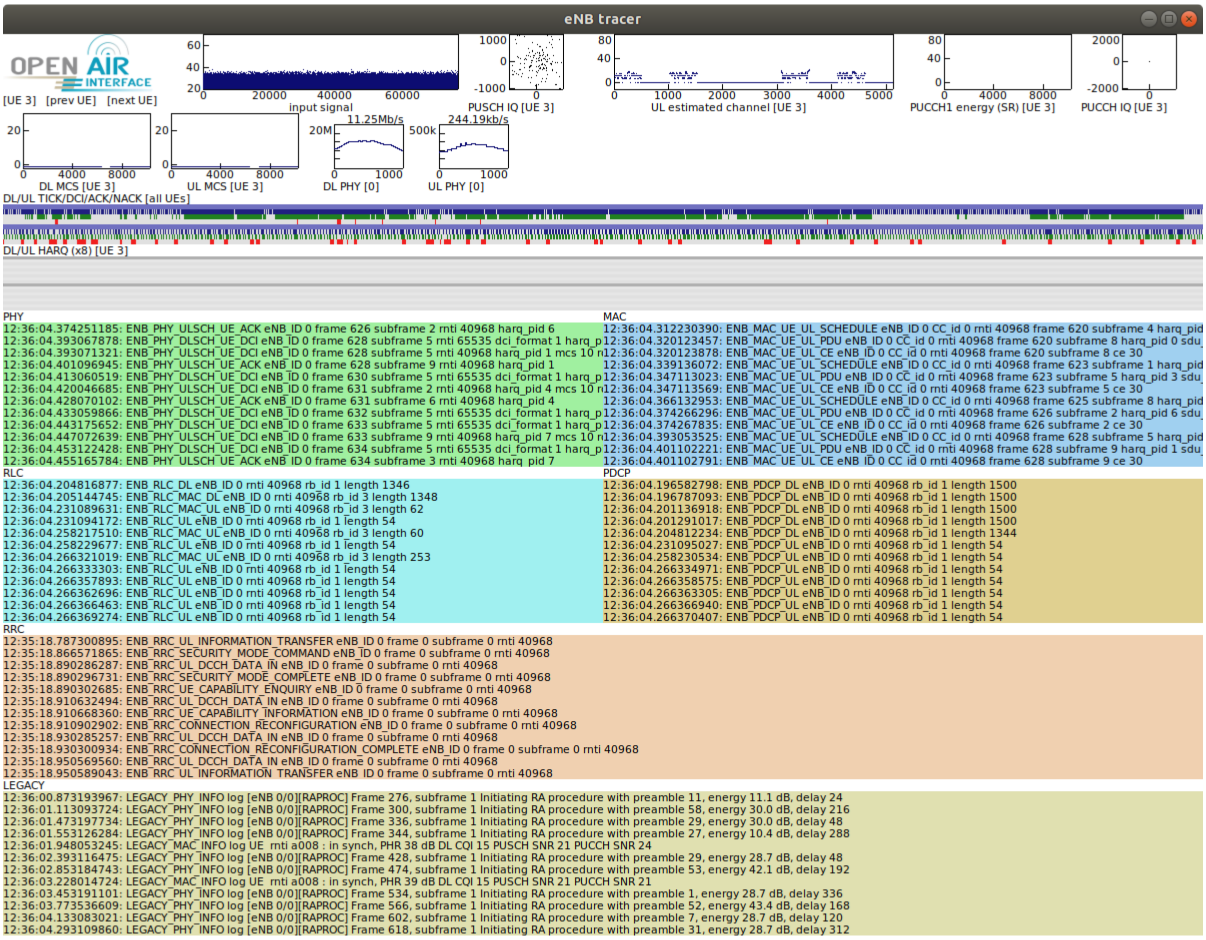


Figure 20 The T-tracer results as retrieved from the eNB

Features of the Mobile Core Network

The Mobile Core Network of the Portable Demonstrator is integrated by the open-source Eurecom's OAI Core Network solution. The code is implementing all basic functions of the LTE core components (MME, HSS, SPGW). OAI Core Network solution is divided in two projects:

- openair-cn, implementing HSS and MME functions
- openair-cn-cups, implementing the separation of user and control plane functions of SPGW (SPGWU, SPGWC)

OAI implements the core network components and respective interfaces, as shown in the figure below.

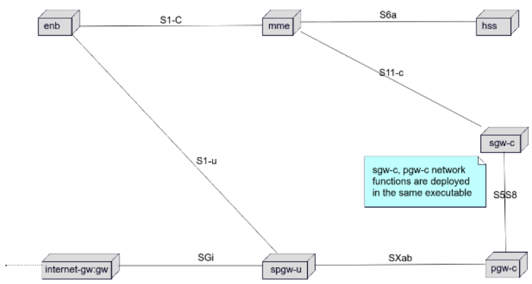


Figure 21 The components and the interfaces of the setup as provided by OAI

The MME, SPGWC, SPGWU and HSS communicate with each other via the following interfaces:

- MME and SGWC via S11-c
- MME and HSS via S6-a
- SGWC with PGWC via S5/S8
- SPGWU with PGWC via SXab
- SPGWU with eNB via S1-u
- SPGWU uses the SGi interface for internet connectivity

The hardware and software specifications of the OAI EPC deployment are detailed below:

- Dell Vostro 3470 (Intel i7-8700 CPU @ 3.20 GHz x 12, 16 GB RAM, 1TB Disk storage)
- CentOS Linux 7

In the Portable Demonstrator, in order to follow the principles of Network Slicing concept, every core component is thought as a separate VNF. As a result, all core components are deployed on different virtual machines. To accomplish this task, we use Openstack as NFV Infrastructure at out Dell host machine. The following guest Virtual Machines (VMs) were established:

- HSS
  - Ubuntu 18.04.03 LTS
  - Linux Kernel 4.15.0-74-generic
  - 1 VCPU, 2GB RAM, 20 GB Disk
  - openair-cn master branch (commit “d1d0e45”)
- MME
  - Ubuntu 18.04.03 LTS
  - Linux Kernel 4.15.0-74-generic
  - 2 VCPU, 4GB RAM, 40 GB Disk
  - openair-cn master branch (commit “d1d0e45”)
- SPGWC
  - Ubuntu 18.04.02 LTS
  - Linux Kernel 4.15.0-74-generic
  - 2 VCPU, 4GB RAM, 40 GB Disk
  - openair-cn-cups develop branch (commit “ec7a30c”)
- SPGWU
  - Ubuntu 18.04.02 LTS
  - Linux Kernel 4.15.0-74-generic
  - 2 VCPU, 4GB RAM, 40 GB Disk
  - openair-cn-cups develop branch (commit “ec7a30c”)

Core virtual machines have one network interface each, in order to communicate with every other component. This interface is connected to the external network, provided by a physical router, giving our host machine internet access. Core LTE interfaces (S11, S6-a etc), are using the components’ external addresses to communicate. Interface S5/S8 is implemented by defining a couple of virtual network interfaces in SPGWC VM. The figure below depicts the network topology of the core network.

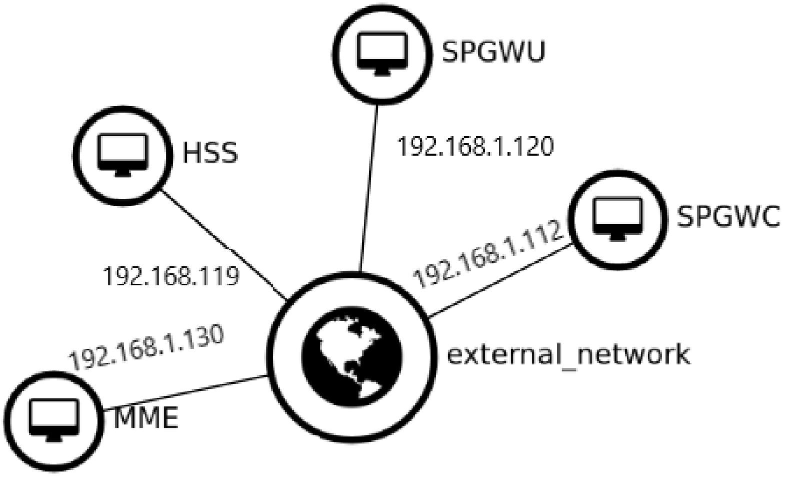
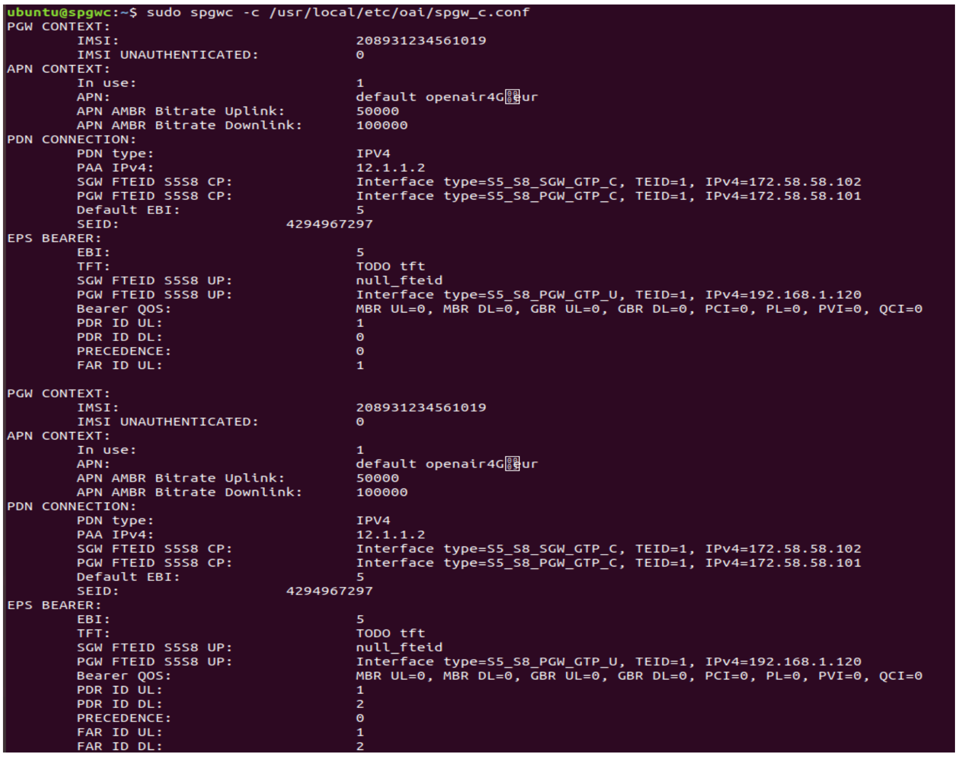


Figure 22 The integrated network topology with the IPs used

A screenshot of the console, depicting the data flow in the core network, having all the core network components up and running, is provided in Figure 23.



```
ubuntu@spgwc:~$ sudo spgwc -c /usr/local/etc/oai/spgw_c.conf
PGW CONTEXT:
        IMSI:                           208931234561019
        IMSI UNAUTHENTICATED:           0
APN CONTEXT:
        In use:                         1
        APN:                            default openair4G?ur
        APN AMBR Bitrate Uplink:        50000
        APN AMBR Bitrate Downlink:      100000
PDN CONNECTION:
        PDN type:                       IPV4
        PAA IPv4:                       12.1.1.2
        SGW FTEID S5S8 CP:              Interface type=S5_S8_SGW_GTP_C, TEID=1, IPv4=172.58.58.102
        PGW FTEID S5S8 CP:              Interface type=S5_S8_PGW_GTP_C, TEID=1, IPv4=172.58.58.101
        Default EBI:                    5
        SEID:                   4294967297
EPS BEARER:
        EBI:                            5
        TFT:                            TODO tft
        SGW FTEID S5S8 UP:              null_fteid
        PGW FTEID S5S8 UP:              Interface type=S5_S8_PGW_GTP_U, TEID=1, IPv4=192.168.1.120
        Bearer QOS:                     MBR UL=0, MBR DL=0, GBR UL=0, GBR DL=0, PCI=0, PL=0, PVI=0, QCI=0
        PDR ID UL:                      1
        PDR ID DL:                      0
        PRECEDENCE:                     0
        FAR ID UL:                      1

PGW CONTEXT:
        IMSI:                           208931234561019
        IMSI UNAUTHENTICATED:           0
APN CONTEXT:
        In use:                         1
        APN:                            default openair4G?ur
        APN AMBR Bitrate Uplink:        50000
        APN AMBR Bitrate Downlink:      100000
PDN CONNECTION:
        PDN type:                       IPV4
        PAA IPv4:                       12.1.1.2
        SGW FTEID S5S8 CP:              Interface type=S5_S8_SGW_GTP_C, TEID=1, IPv4=172.58.58.102
        PGW FTEID S5S8 CP:              Interface type=S5_S8_PGW_GTP_C, TEID=1, IPv4=172.58.58.101
        Default EBI:                    5
        SEID:                   4294967297
EPS BEARER:
        EBI:                            5
        TFT:                            TODO tft
        SGW FTEID S5S8 UP:              null_fteid
        PGW FTEID S5S8 UP:              Interface type=S5_S8_PGW_GTP_U, TEID=1, IPv4=192.168.1.120
        Bearer QOS:                     MBR UL=0, MBR DL=0, GBR UL=0, GBR DL=0, PCI=0, PL=0, PVI=0, QCI=0
        PDR ID UL:                      1
        PDR ID DL:                      2
        PRECEDENCE:                     0
        FAR ID UL:                      1
        FAR ID DL:                      2
```

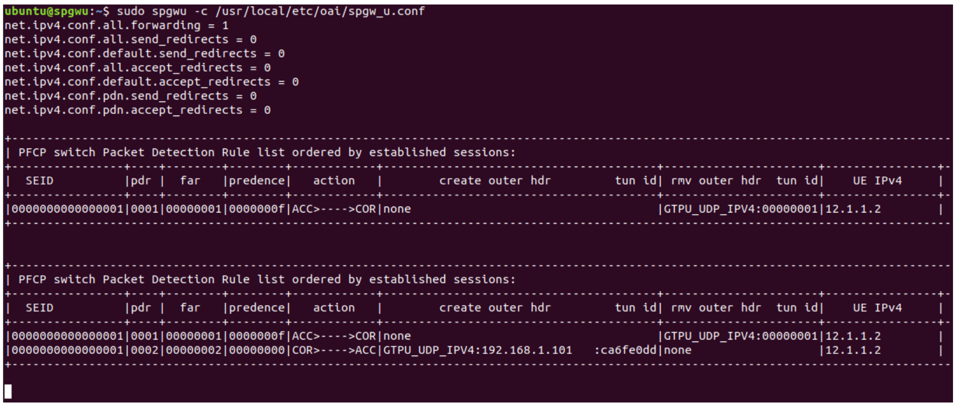


Figure 23 Console screenshots depicting the data flow in the core network

2.2.2. Transport Network

2.2.2.1. OpenDaylight-based emulator

The Portable 5G Demonstrator includes a WAN Emulator based on Mininet v2.2.2[6] for emulating the transport network. The WAN emulator is utilized for demonstrating SDN capabilities and allowing the deployment of various WAN topologies within a single node. The following figure depicts an example topology implemented with Mininet and OpenDayLight as the SDN controller:

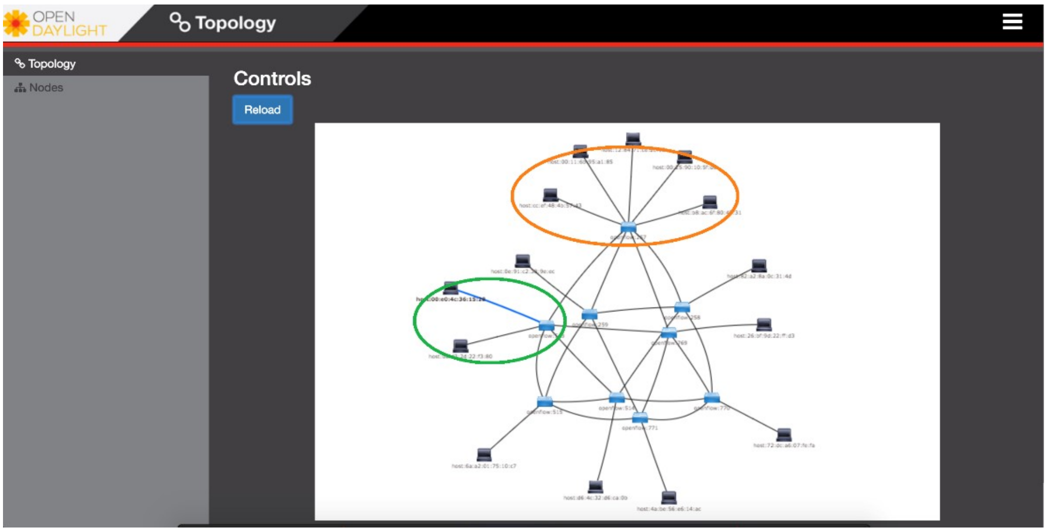


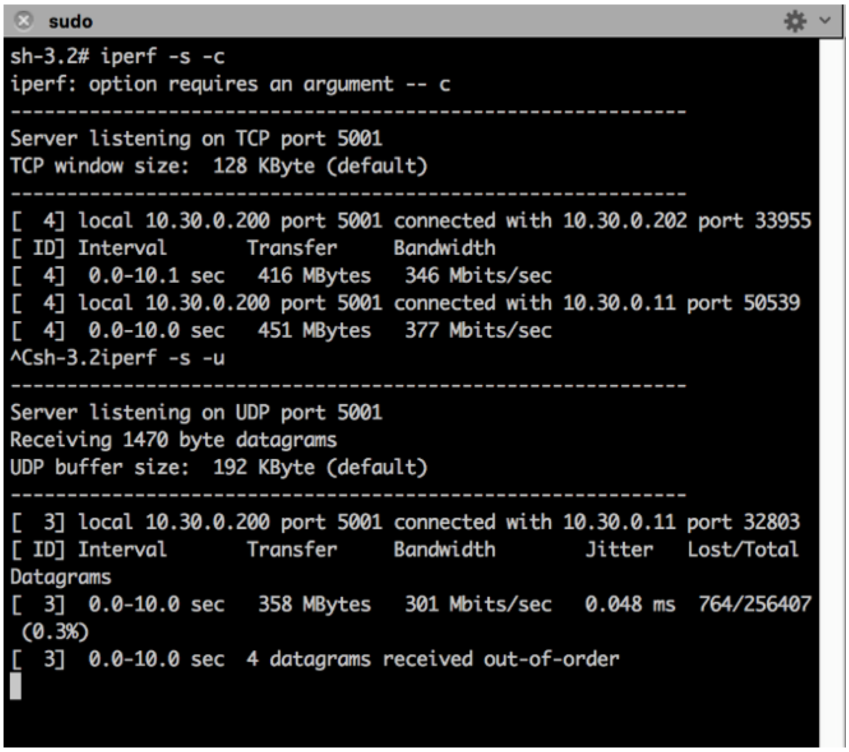
Figure 24 An example of Torus Topology in Mininet with ODL as external SDN Controller.

The physical machine (Intel NUC6i7KYK) runs Ubuntu Server and has three network interfaces. Two of them are assigned to Mininet in order to provide communication with external hosts and the third one is the Management interface.

Figure 25 demonstrates network traffic between Mininet hosts and physical machines deployed. The terminal depicts the physical host, acting as iPerf server while responding to

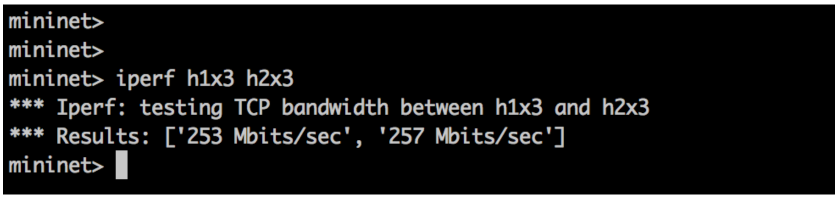
[6] Mininet Emulator: http://mininet.org/

requests made by the Mininet host and another physical hosts. It is also possible to conduct iPerf measurements between two virtual Mininet hosts, as shown in Figure 26.



```
sudo
sh-3.2# iperf -s -c
iperf: option requires an argument -- c
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  128 KByte (default)
------------------------------------------------------------
[  4] local 10.30.0.200 port 5001 connected with 10.30.0.202 port 33955
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0-10.1 sec   416 MBytes   346 Mbits/sec
[  4] local 10.30.0.200 port 5001 connected with 10.30.0.11 port 50539
[  4]  0.0-10.0 sec   451 MBytes   377 Mbits/sec
^Csh-3.2iperf -s -u
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size:  192 KByte (default)
------------------------------------------------------------
[  3] local 10.30.0.200 port 5001 connected with 10.30.0.11 port 32803
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total
Datagrams
[  3]  0.0-10.0 sec   358 MBytes   301 Mbits/sec   0.048 ms  764/256407
 (0.3%)
[  3]  0.0-10.0 sec  4 datagrams received out-of-order
```

Figure 25: Traffic passing through Mininet



```
mininet>
mininet>
mininet> iperf h1x3 h2x3
*** Iperf: testing TCP bandwidth between h1x3 and h2x3
*** Results: ['253 Mbits/sec', '257 Mbits/sec']
mininet>
```

Figure 26 Mininet Console

2.2.2.2. Onos-based emulator with FOGUS SDN testbox

Apart from the OpenDayLight WAN Emulator, the portable 5G Demonstrator offers an Onos-based emulator with the addition of FOGUS SDN TestBox (Figure 27), that was developed during the third phase of the project. Its main functionality is the demonstration of a Software Defined Network with an interconnection between internet and physical nodes through a Mininet network. It provides network customization options regarding the parameters of the links and paths between the nodes, in order to simulate events and monitor the behavior of the network in an efficient way. The statistics for the network are shown in real-time views and stored in InfluxDB.

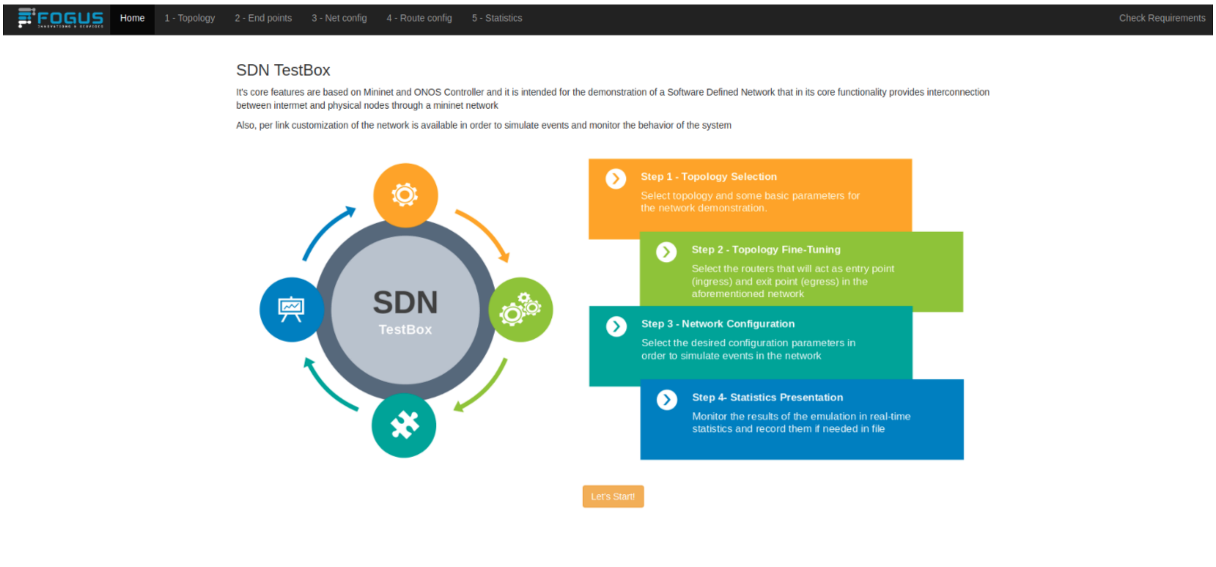


Figure 27 FOGUS SDN TestBox Start Page

The entire system runs on a Dell OptiPlex with Ubuntu 18.04 OS. The minimum requirements for running the system are 2 core CPUs, 8GB RAM, 50GB Disk Space and 2 NICs (for the interconnection of physical nodes).

The Figures below show the steps of SDN TestBox. At first (Figure 28), the user has the option of choosing between 3 different topologies for the desired network (Linear, Tree, Torus). Then (Figure 29), the network is created and the user chooses, which switch will be the Ingress and which the Egress in the network. In the steps 3 and 4 (Figure 30 & Figure 31), the user can configure the characteristics of each link, changing the values of parameters like the Bandwidth of the link and its Delay and/or change the path between the nodes of the network. In the final step, the user can monitor the network and see real-time statistics of each switch.

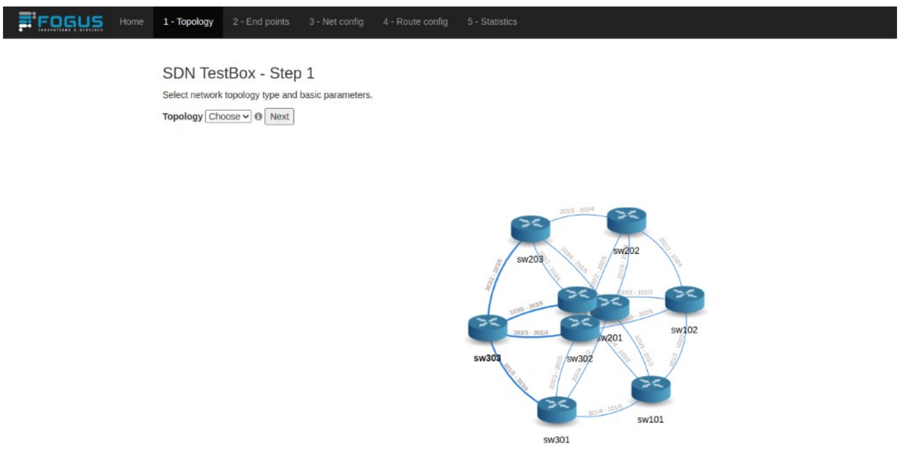


Figure 28 FOGUS SDN TestBox Topology Selection

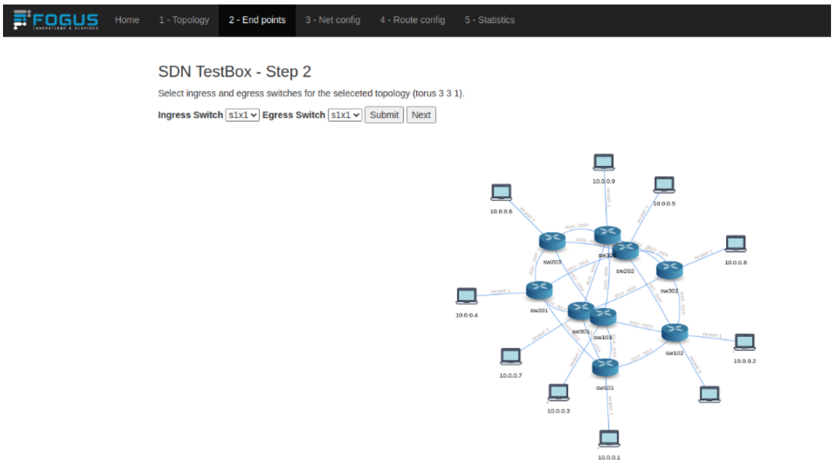


Figure 29 FOGUS SDN TestBox Ingress & Egress Switch Selection

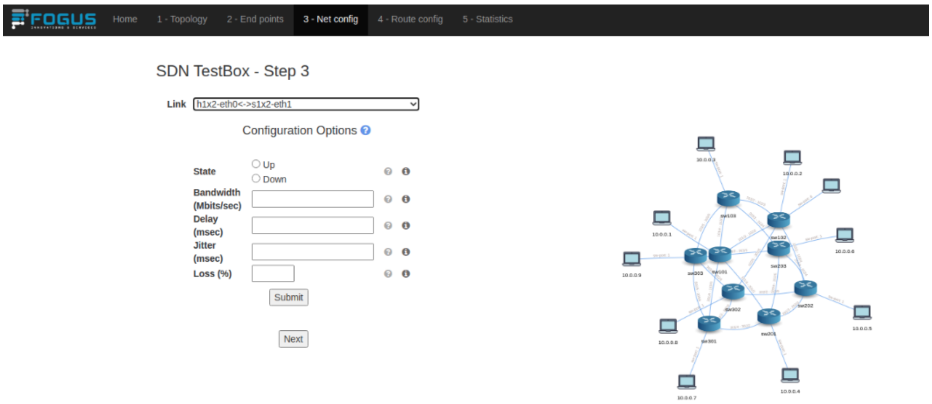


Figure 30 FOGUS SDN TestBox Link Configuration

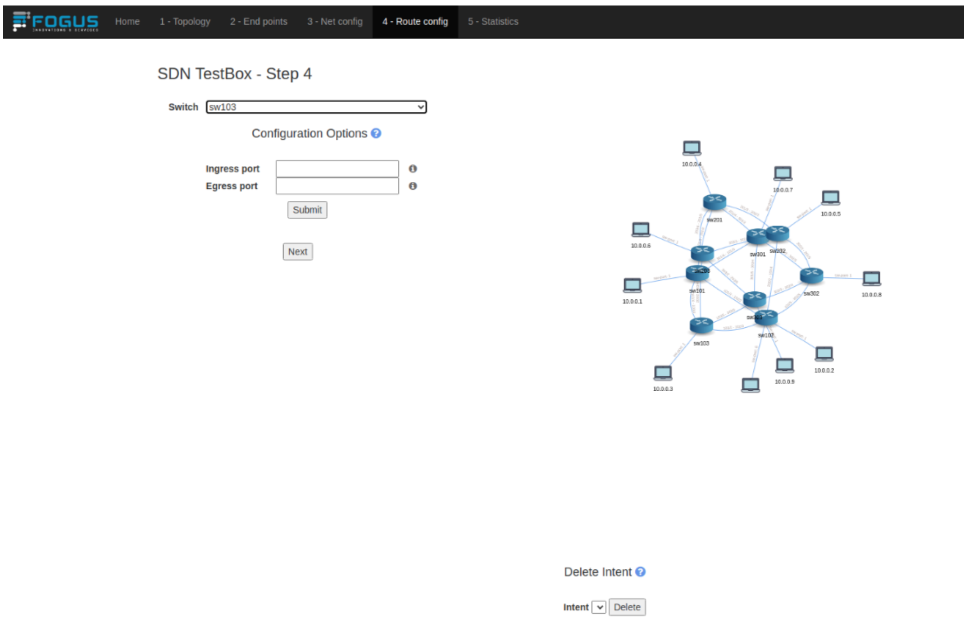


Figure 31 FOGUS SDN TestBox Switch Configuration

The Statistics are, also, available to be seen on InfluxDB Dashboard (Figure 32), while the entire Topology can be seen, also, on ONOS GUI (Figure 33).

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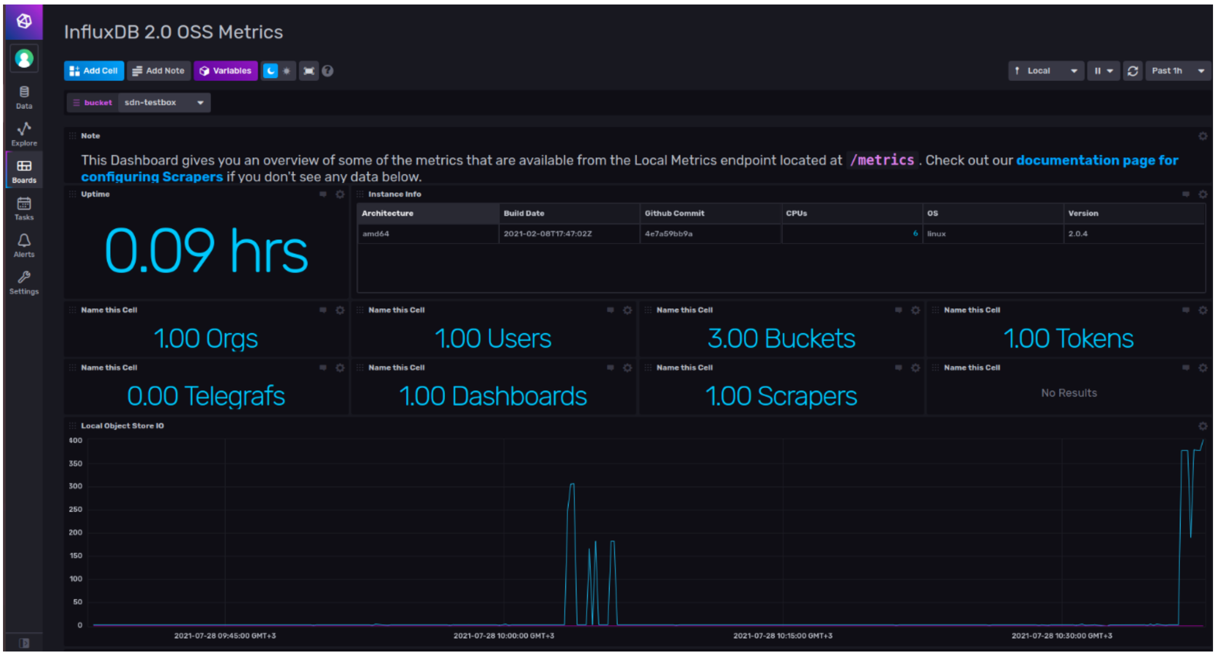

Figure 32 FOGUS SDN TestBox Statistics in InfluxDB

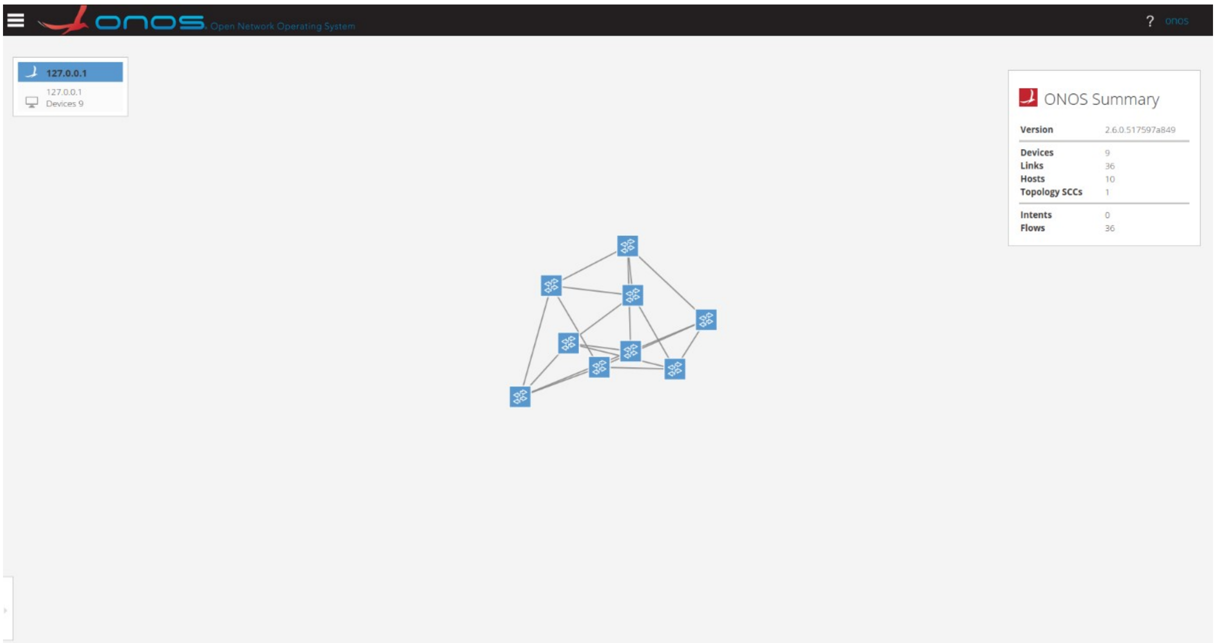

Figure 33 FOGUS SDN TestBox ONOS GUI

2.3. Management and Orchestration Layer

The Management and Orchestration layer of the portable demonstrator is responsible for the following actions:

- Creation of virtual network instances upon the physical network by using the resources and the functionality of the infrastructure layer.
- Mapping of network functions to virtualized network instances so that they build a service chain with the association of network function and virtualization layer.

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- Maintaining communication between service/application, coordination layer and the network slicing framework to manage the lifecycle of virtual network instances and dynamically adapt or scale the virtualized resources according to the changing experimental context.

Table 8 Management and Orchestration Layer components

Component	Product/Technology
Katana Slice Manager	Release A implementation of the 5Genesis reference architecture Slice Manager implementation (WP3 component)
NFV MANO OSM	OSM[7] is an open source MANO aligned with the ETSI framework for NFV. OSM is an orchestration and management system which manages life-cycle, and configuration aspects of the hosted VNFs that are deployed on the wide number of supported NFV Infrastructure (NFVI) platforms. These MANO capabilities are critical to implement the sophisticated services expected by the 5G communication systems and utilize the underline management systems and tools. For the purpose of the 5GENESIS platform, the deployed OSM is of release 5 and is already integrated with the Element management systems and monitoring tools as well as the Virtualization Infrastructure Managers (Openstack).
Prometheus	Prometheus servers deployed in hierarchical mode are collecting aggregated time series data from a large number of subordinated servers and can be used to take measurements from any device on the platform by creating custom exporters that use the SNMP protocol
Grafana	Used for the visualization and analytics of the Prometheus metrics and supports a lot of presentation dashboards.
iPerf	Network Performance tool supporting modelling and replay of network traffic

Regarding the above technologies of the MANO Layer, the below hardware and software was used:

Host PC:

- Dell Vostro 3470
- CPU: Intel Core i7-8700 3.2GHz
- OS: Ubuntu 16.04.06 LTS

In the host pc, 3 VMs was created via the VM Manager for hosting all the MANO Layer's and Coordination Layer's components. The software and hardware that was selected and used in the 3 VMs, in listed below. Also, a set of figures is provided depicting the actual instances of the VMs (Figure 34), the OSM (Figure 35) and the Slice Manager (Figure 36).

[7] OSM, https://osm.etsi.org/

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VM for Katana Slice Manager:

- OS: Ubuntu 16.04.06 LTS
- Hardware: 2 vCPUs, 4GB RAM, 60GB Storage

VM for OSMv5:

- OS: Ubuntu 16.04.06 LTS
- Hardware: 2 vCPUs, 4GB RAM, 60GB Storage

VM for Coordination Layer, Prometheus, iPerf and Grafana:

- OS: Windows 10 Pro x64
- Hardware: 2 vCPUs, 2GB RAM, 50GB Storage

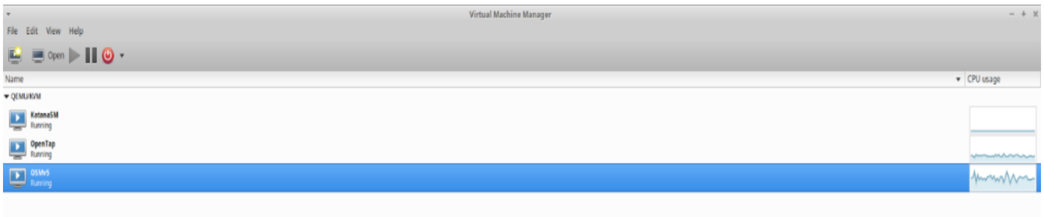

Figure 34 MANO Layer VMs

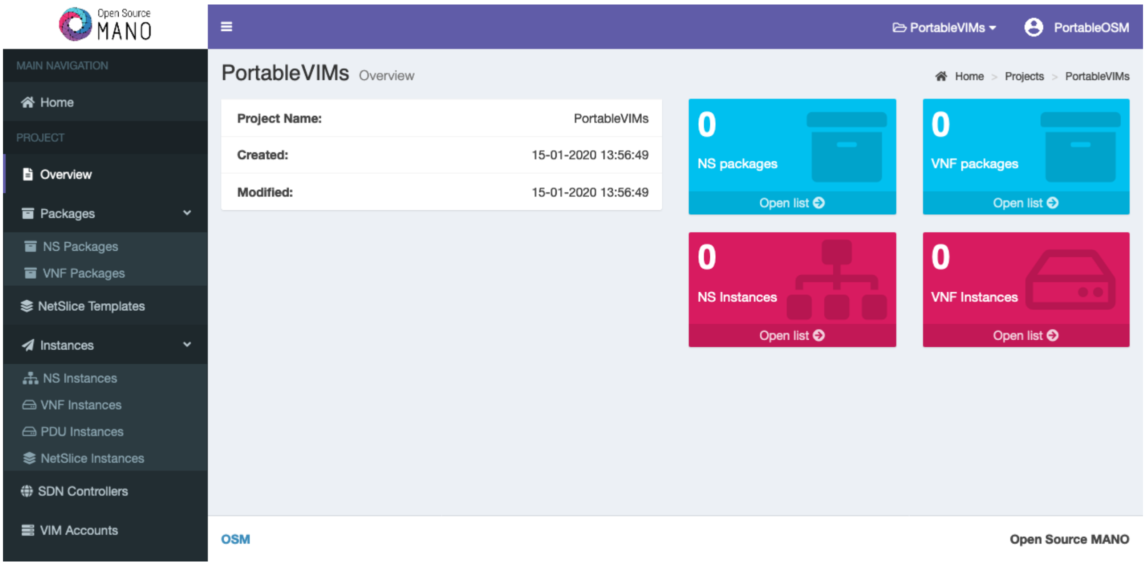

Figure 35 NFV MANO OSM

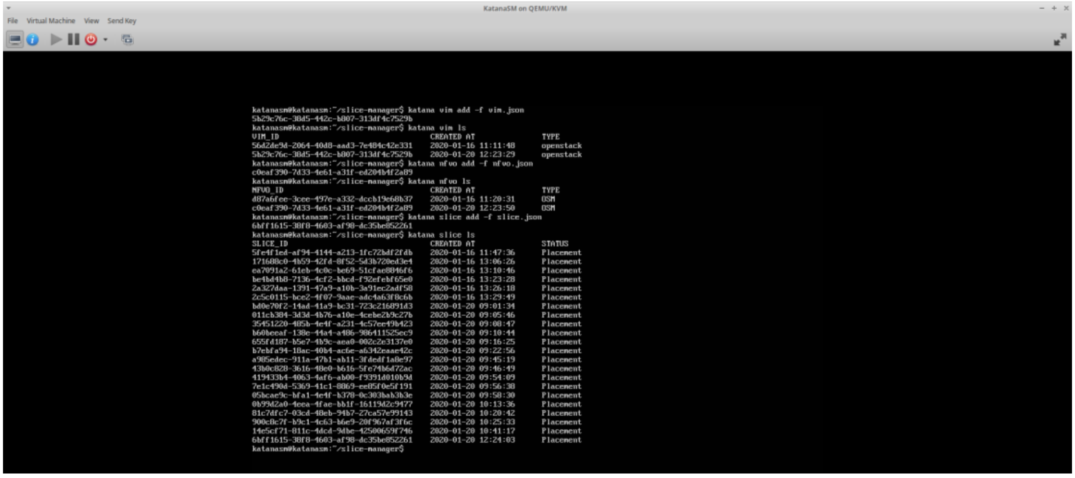

Figure 36 Katana Slice Manager

2.4. Coordination Layer

The Coordination Layer is common for all 5GENESIS platforms as defined in WP2 towards forming a Pan-European 5G Experimental Facility and this homogeneity applies also to the portable 5G demonstrator as well. The software components of the coordination layer are solely instantiated at each platform, i.e., an instance of them runs autonomously and independently at each platform, although their functional and architectural features remain the same, creating the basis towards a common 5GENESIS facility across the foreseen sites.

In order for the Portable Demonstrator to be self-contained, the Coordination Layer has also been included, providing the set of functionalities that would allow demonstrations of real-life tests to interested vertical industries and experimenters.

More details on the architectural components and functionalities of the coordination layer will be provided in WP3 and the corresponding deliverables. Regarding the activities of integrating the Coordination Layer in the portable demonstrator, the components depicted in the following table were installed in a single VM (one of the 3 VMs mentioned above, at Section 2.3)

Table 9 the coordination layer components

Component	Description
5GENESIS Portal	Release A implementation of the 5GENESIS reference architecture. 5GENESIS Portal implementation (WP3 component)
Experiment Life Cycle Management	Release A implementation of the 5Genesis reference architecture ELCM implementation (WP3 component)
Keysight OpenTAP	Keysight’s TAP commercial-off-the-self testing automation tool is used to implement the experiment life cycle management activities that are triggered by the vertical’s requests through the portal or the open API.

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Results Repository / InfluxDB	InfluxDB is the open-source storage engine provided within the InfluxData framework, and handles in particular time series data and is used to store all monitoring events and metrics that are necessary for the generation of the end-reports and KPIs validation.

The Figures below show an overall presentation of the Coordination Layer starting from the Portal/ELCM interaction through testing, analyzing, storing and displaying data.

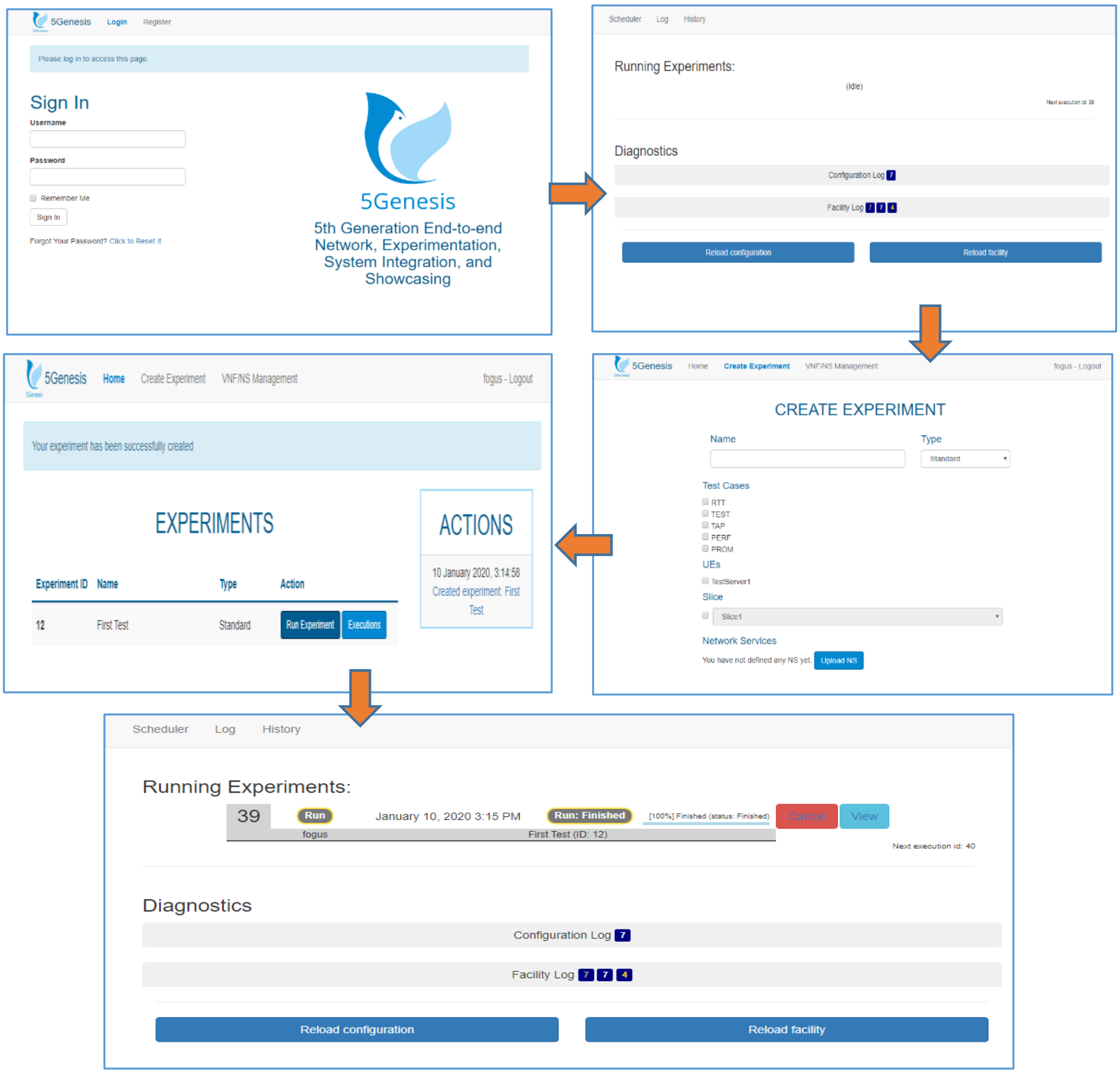

Figure 37 Set of screens depicting the steps for setting an experiment in the Portable Demonstrator

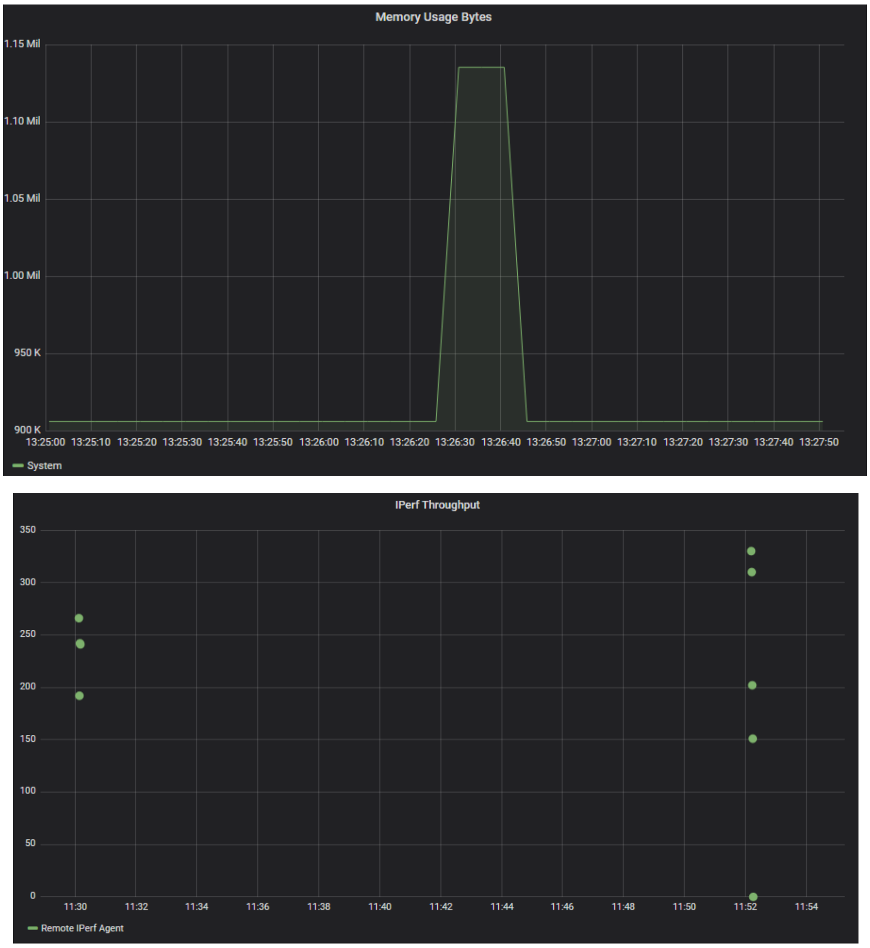

Figure 38 Memory usage and Throughput screens from the Grafana component

3. Portable Demonstrator Evolution in 5GENESIS

3.1. Evolution timeline

During the first integration cycle, specific actions have been taken towards a well-packaging of the components to serve a set of experiments that will convey easily the 5G performance capabilities to non-expert audience. Mainly, the following activities have been performed:

- The major infrastructure for the wireless part was prepared. It is composed of OAI-compliant (Open Air Interface Compliant) SDR hardware and general-purpose computers/servers that will host 5G RAN and core functionalities in the next phases.
- The first release of e2e monitoring tool has been integrated, providing RAN monitoring during the first integration phase.
- The first release of the transport network emulator has been integrated, providing the capability of emulating complex WAN topologies.
- NFVI infrastructure is in place based on INTEL NUC computing devices, together with the necessary cloud computing platform (Openstack) and OSM on top of it.

In summary, Figure 39 indicates in blue the components that have been chained to provide a first round of proof of concept experiments.

During the second integration cycle, specific actions have been taken capitalizing on the integrations made during the first integration cycle. Mainly, the following activities have been performed:

- Integration of the coordination layer components and pass the tests defined in project level for all the 5GENESIS platforms.
- Integration of three setups for the infrastructure part of the demonstrator, using open source (research oriented) components as well as commercial ones.

In summary, Figure 39 indicates in orange the components that have been chained to provide the second release of the 5GENESIS portable demonstrator. As can be observed in Figure 39, the major infrastructure part of the demonstrator was implemented, including also the Release B components of the coordination layer (Portal, ELCM, Slice Manager, Monitoring), which is also an advance in comparison to the intermediate release of the demonstrator.

The 5GENESIS portable demonstrator follows the general functional architecture of 5GENESIS, as defined in Deliverable D2.2 [2].

The figure below visualizes the per-phase instantiation of the 5GENESIS architectural blueprint in the 5GENESIS Portable demonstrator. It shows the functional blocks implemented and integrated in Phases 1 & 2, as well as the functionalities that integrated in the last Phase 3.

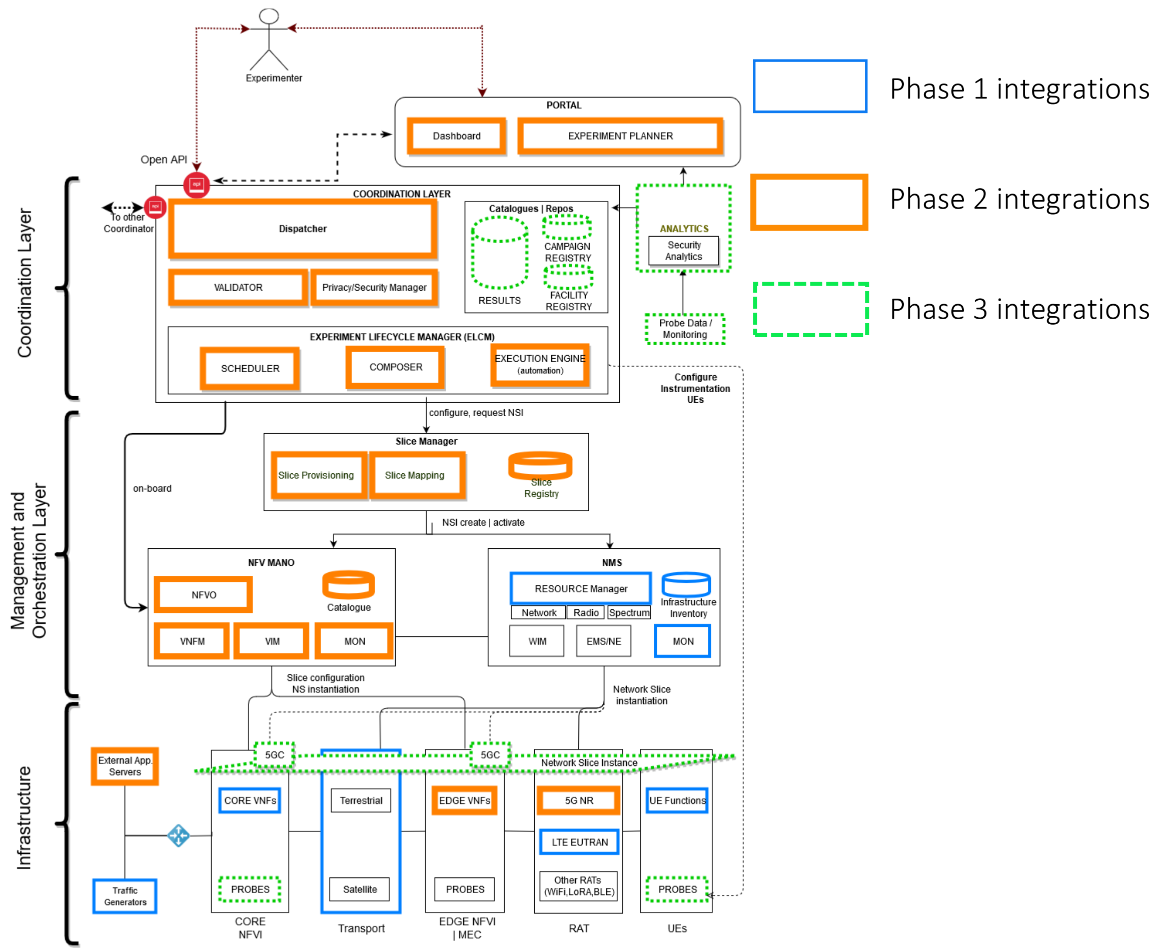

Figure 39 Instantiation of the 5GENESIS Architecture during integration cycle 3 (phase 3)

3.1.1. 4G Deployment Configurations

Table 10 presents the currently supported deployment configurations based on 4G technologies.

Table 10 The 4G deployment configurations

Deployment Parameters	Products/Technologies Options
ID	DEMO.E2E4G
Description	Opensource E2E deployment of experimentation environment with 4G infrastructure
Core Cloud	YES - Openstack
Edge Cloud	NA
# Edge Locations	NA
WAN/Network	SDN
Slice Manager	YES - Katana
MANO	OSM v6

NMS	eNB EMS
Monitoring	Prometheus
3GPP Technology	4G LTE+
3GPP Option	NA
Non-3GPP Technology	NA
Core Network	OAI vEPC
RAN	OAI eNB
UE	COTS Cat.12 (600/300) / Huawei LTE Dongle
Relevant Use Cases	To be defined

3.1.2. 5G Deployment Configurations

Table 11 presents the currently supported deployment configurations based on 5G technologies.

Table 11 The 5G deployment configurations

Deployment Parameters	Products/Technologies Options		
ID	DEMO.5GNR	DEMO.5Gcots	DEMO.E2E5G
Description	5GNR setup	5GNSA setup	Opensource/Commercial E2E experimentation environment with 5G infrastructure
Core Cloud	NA	NA	OpenStack
Edge Cloud	NA	NA	B2B Openstack
# Edge Locations	NA	NA	1
WAN/Network	NA	NA	WAN emulator/SDN
Slice Manager	NA	Katana	Katana
MANO	NA	NA	OSM
NMS	NA	NA	OAI gNB NMS
Monitoring	NA	Amarisoft	Open5GENESIS Suite/Prometheus
3GPP Technology	5G	5G	5G
3GPP Option	noS1	NSA/SA	NSA
Non-3GPP Technology	NA	NA	NA
Core Network	NA	Amarisoft	OAI
RAN	OAI NR	Amarisoft gNB (SDR)	OAI NR

UE	OAI	Samsung A90 5G	OAI/Google Pixel 5
Relevant Use Cases	To be defined	UAV field trials	Benchmarking tests

Finally, the aim of Phase 3 was to complete the implementation of the open 5GENESIS suite on its whole and to deliver a full-stack, end-to-end 5G experimental portable demonstrator with all the added-value features associated with the 5GENESIS. Phase 3 further evolved the 5G configuration, by employing fully functional 5G NR with both commercial and experimental UEs and 5G core functions. Moreover, the upper layer, namely the experimentation layer i.e., the Open5GENESIS suite, has been upgraded to the latest components, feature-rich versions.

More specifically, the following developments were achieved during Phase 3:

- ✓ 5G NR support evolution and stand-alone (SA) support
- ✓ Addition of 5G SA UEs, both COTS and Experimental ones.
- ✓ Integration of 5G CPEs.
- ✓ Upgrade of Open5Genesis Release B
- ✓ UC-specific developments (i.e., UAV specific additions, as described in Section 3.2.3)

These achievements are presented in detail in the sections to follow.

3.2. Phase 3 accomplishments

A constant updating of the demonstrator is performed after the implementation freezing for releasing the 5GENESIS portable demonstrator after the third integration cycle of the project. In Phase 3 we reflected the evolutions not only of the 5GENESIS Portable Demonstrator, but also of the whole project, incorporating the most recent (and relevant) technical advances and project outcomes, specifically Open 5GENESIS release B.

In Phase 3 the migration from 4G to 5G Mobile Network during 5GENESIS performed for the OAI-based setup, where the target is the integration of the 5G Standalone Architecture (SA) infrastructure have also achieved.

3.2.1. 5G NR support evolution and SA support

During Phase 3 the 5G portable demonstrator platform was enhanced with the Amarisoft Amari Callbox Classic (CBC) product, which implements a “5G-in-a-box” solution, integrating within a single compute node SDR-based radio as well as core. This enabled full 5G NR support and compatibility with both commercial and experimental UEs. The table below summarises the key 5G NR parameters which were mostly used for the integration and tests.

Table 12. 5G NR configuration in the Portable Demonstrator

Parameter	Value
3GPP release	Rel. 15
Bandwidth	100 MHz
DL MIMO config	4x4

Duplex mode	TDD
Network mode	NSA (Option 3), SA (Option 2)
Band	N78 (3490 MHz)/Configurable
Service type	eMBB

The table below shows the commercial UEs which have been successfully tested with the gNB in portable demonstrator

Table 13. Tested 5G UEs

Model	Modem (SoC)	Tested modes
Samsung A90 5G	Qualcomm SM8150 Snapdragon 855	NSA
Huawei P40 Lite 5G	Kirin 820 5G	NSA
Waveshare SIM8200EA-M2 5G Hat	Qualcomm Snapdragon X55	NSA & SA

3.2.2. Integration of Open5GENESIS Release B

During phase 3, most components of the Open5GENESIS experimentation suite have been deployed in their Release B version. Infrastructure related components including Influx DB, Grafana and testing probes were not affected, while OSM (NFVO) upgraded to version 7.

Release B components include:

- 5Genesis Portal
- 5Genesis Experiment Lifecycle Manager (ELCM)
- Slice Manager
- Dispatcher
- Analytics

Proper integration of Release B components is covered by a set of test cases illustrated in Deliverable D5.2. All components are running inside VMs, as stated at Section 2.3.

Firstly, the ELCM (Figure 40), the Scheduler of 5Genesis Platform, upgraded with the addition of Resources and Scenarios options for each experiment, as well as the connection to 5Genesis Dispatcher.

The Dispatcher, then, is added to the experiment execution flow, by adding a layer of authentication between the Portal requests and the ELCM and also the communication with MANO Layer.

The updated version of the Portal is enhanced with VNF/NS onboarding option on selected cloud location (edge or core)(Figure 41) and option for using the experiment results with Analytics tool (Figure 42).

Finally, Katana Slice Manager updated in order to support the creation and management of Network Slices.

An overview of the components interfaces is depicted below:

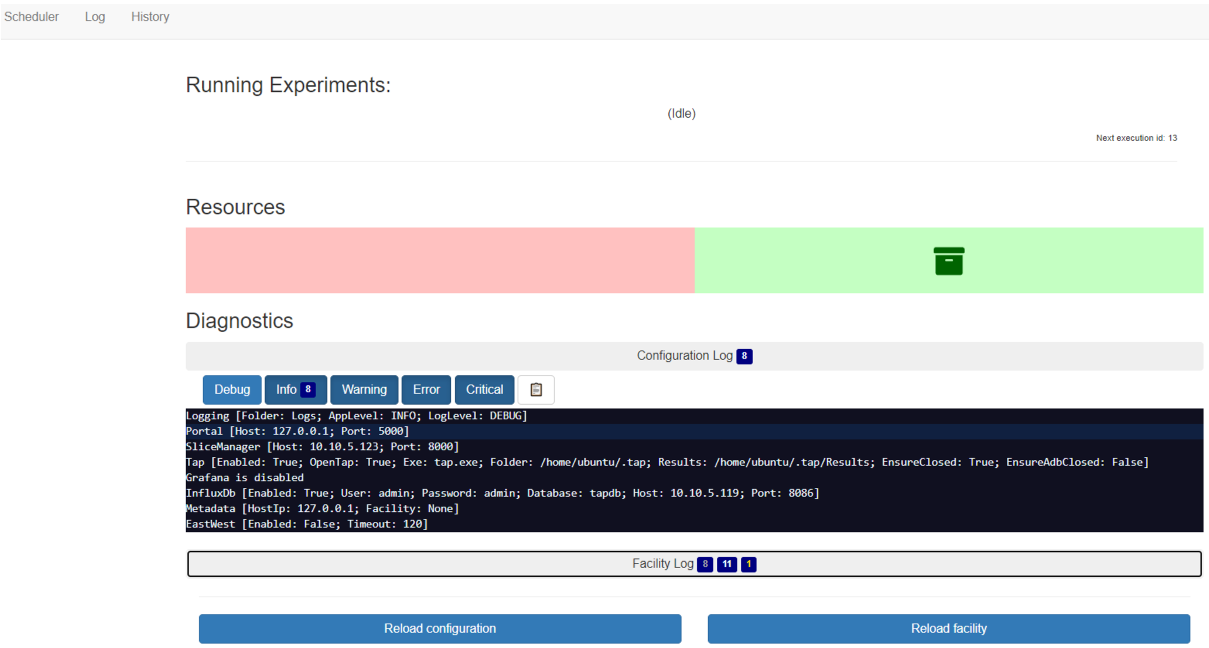

Figure 40. ELCM Release B Dashboard

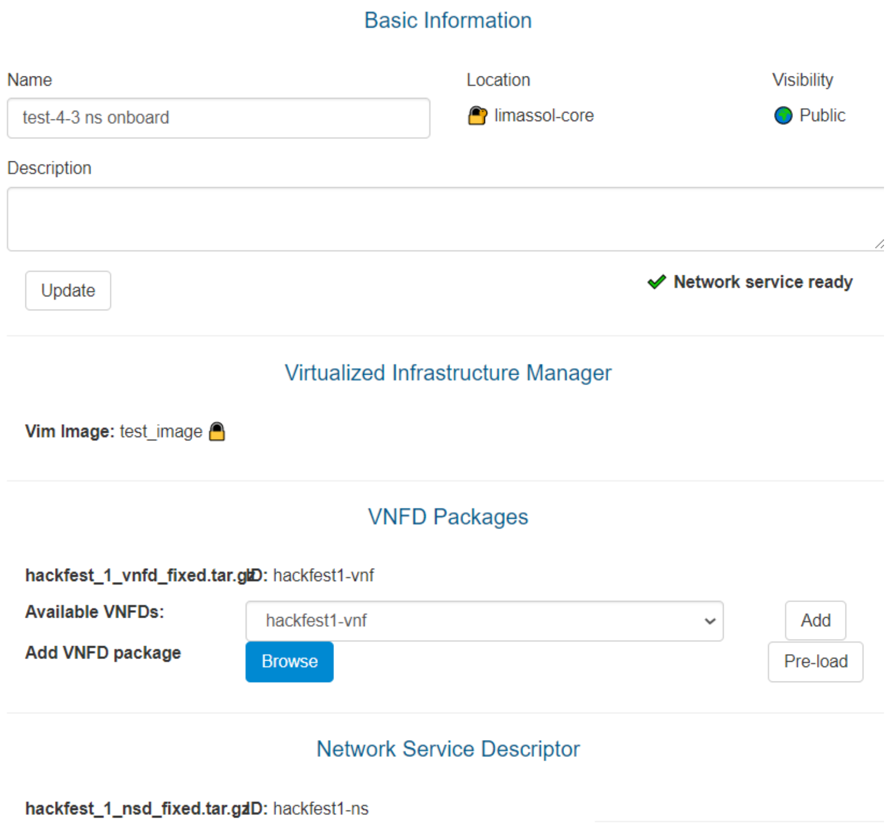

Figure 41. VNF onboarding through Portal UI

Figure 42 Portal Release B with additional features

3.2.3. Use of 5GENESIS portable demonstrator for video streaming test cases

Portable Demonstrator offers a plethora of test cases in coordination with its components. Figure 43 shows some of them. An experimenter can run a test case through the Portal or by using an App in a device and the results are depicted in Grafana and are stored in InfluxDB databases while the automation is handled by OpenTAP. The Test Cases, therefore, can be categorized as Prometheus Test Cases, Application Test Cases, SDN Test Cases and TAP Test Cases.

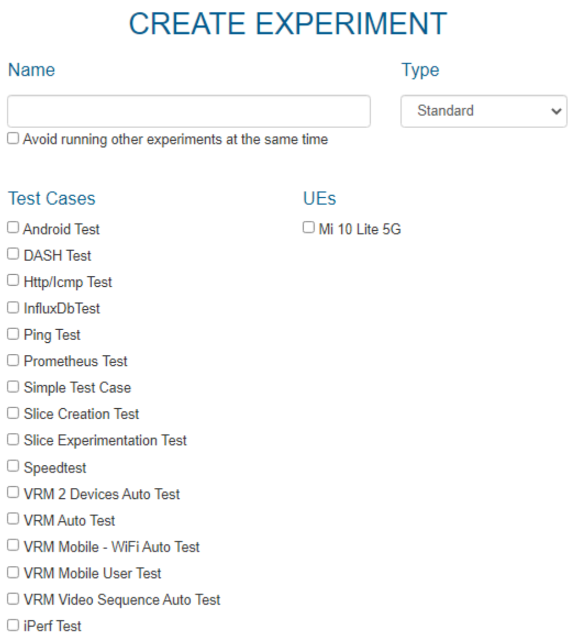

Figure 43 Portable Demonstrator Experiment List

The first category consists of Experiments, that use Prometheus exporters like Blackbox and Node in order to monitor network statistics or statistics of specific network node. Figure 44 shows an execution of a test case using Node exporter.

Figure 44 Node Exporter Results using Portable Demonstrator

In the second category, the Demonstrator executes an experiment with the use of an application. These applications are the UMA (IPerf, Ping, Resource Agent) and FOGUS (VRM) NetApps. The Android applications have been integrated with the platform in order to monitor devices' performance upon a network such as the CPU and RAM usage or the ping delay. While the FOGUS VRM App can monitor the main network traffic, system performance, video information and video's metadata. Figure 44 and Figure 46 show the functionality of the apps and their results in Grafana.

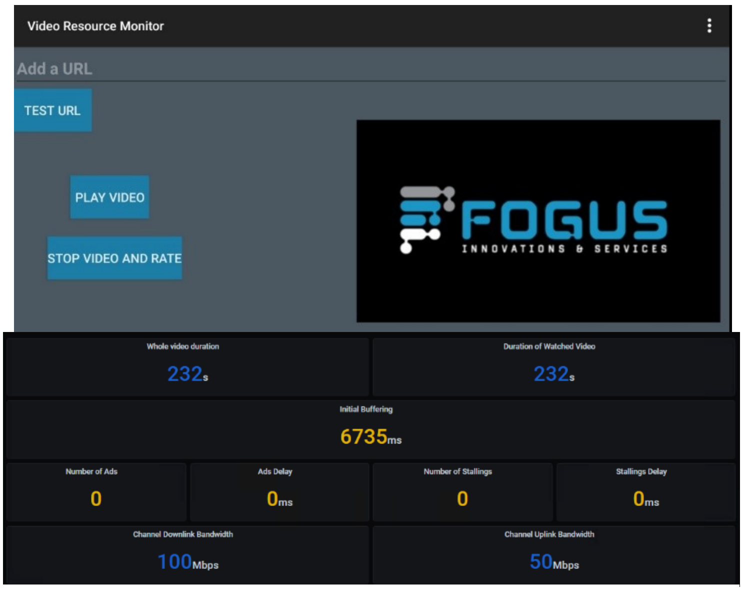

Figure 45 VRM FOGUS App

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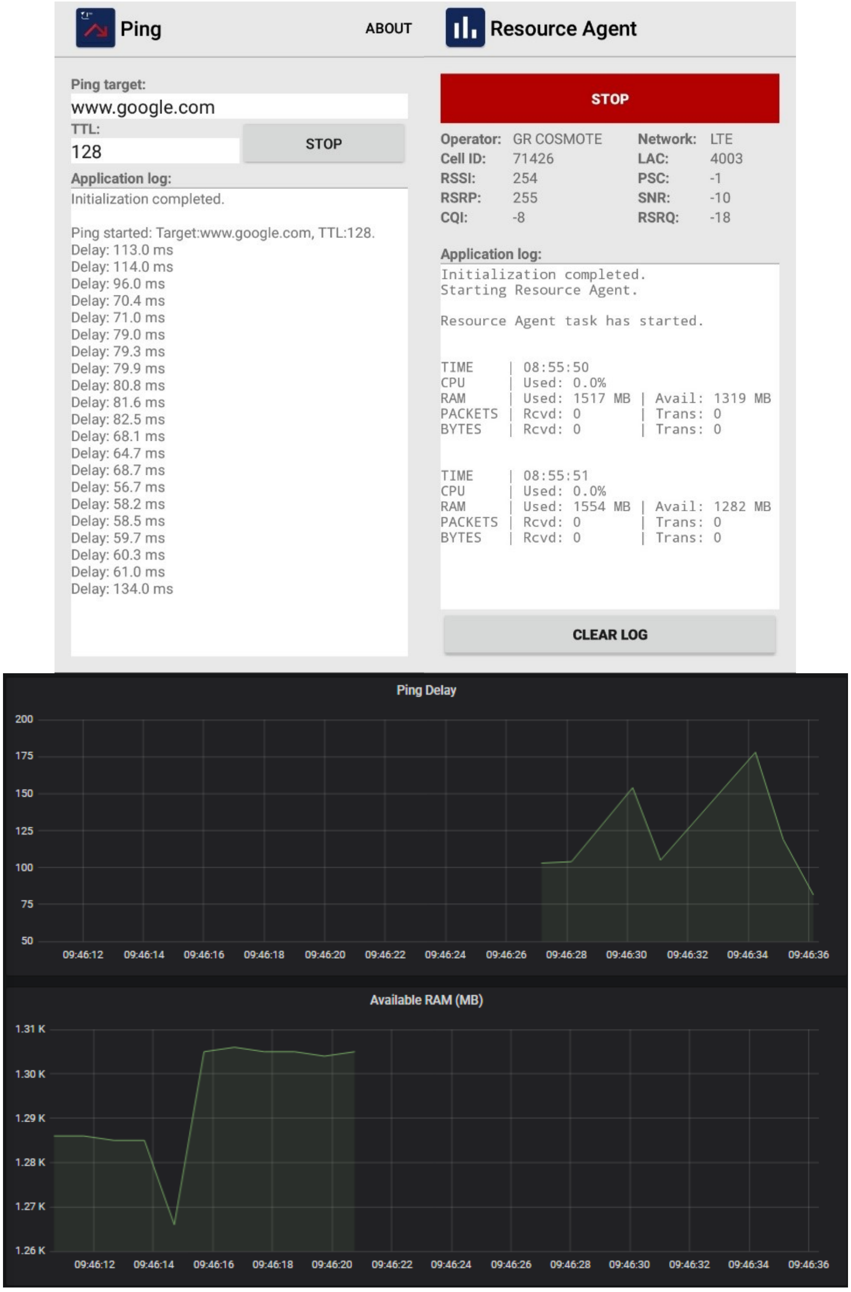

Figure 46 UMA Apps

The third category consists of the test cases using the WAN Emulator and the SDN TestBox. With the integration of these tools, an experimenter can create a network topology and test and monitor the network under selected conditions.

The final category consists of test cases, which use Test Probes and TAP Plugins from 5Genesis OpenSuite. With Test Agents like IPerf, Ping and DASH Agents installed, configured and executed and the configuration of TAP Plugins, a user can run an experiment using the Agents remotely from the machine that are installed. Figure 47 and Figure 48 show the execution of a Test Case using the DASH Client Agent and its results.

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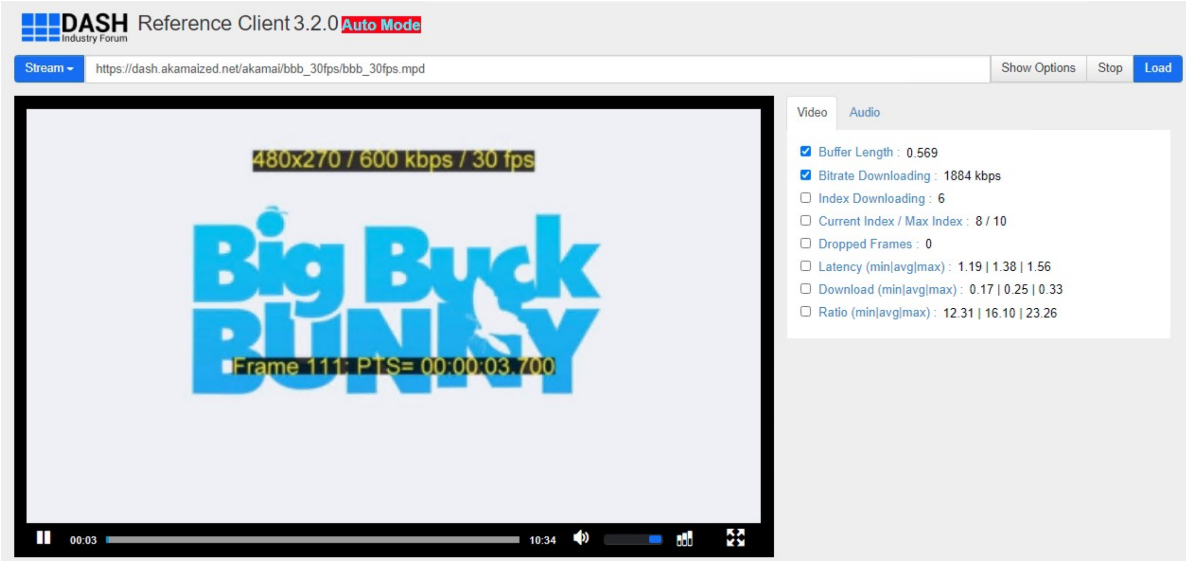

Figure 47 FOGUS DASH Client UI

Figure 48 DASH Client Results

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3.2.4. Use of 5GENESIS portable demonstrator for 5G-enabled UAV field trials

To cover the needs of the rapidly growing sector of UAVs, the 3GPP Working Groups (WGs) are active towards the mapping of the 5G system and the connectivity requirements of Unmanned Aerial Systems (UAS). In Release 15 of their standard LTE Aerial, 3GPP has conducted studies on the consequences of serving low altitude UAVs using LTE radio. The result of the studies was the publication of report 36.777 Enhanced LTE Support for Aerial Vehicles [8], on January 2018. The main focus of the specific report is to investigate the efficiency of the LTE radio networks to provide services to low altitude UAVs and moreover how the LTE performance can be affected by the use of User Equipment (UE) in UAVs.

A preliminary analysis focusing on the service criteria for UAV identification is included in Release 16 entitled Remote Identification of UAS (FS_ID_UAS) [9]. A final report 22.825 Study on Remote Identification of UAS was generated as a result of this work [10]. Following this report the primary aim of the Release 16 UAV study is to define standards for UAV operators, law enforcement, regulatory bodies, and Original Equipment Manufacturers (OEMs) around the world. The research is focused on the idea of defining a UAV by using control data that can be sent over the 3GPP network.

The transmission may take place between a UAV or a UAV controller and a network-based UAV Traffic Management system [11]. Release 17, enhancements for UAVs (FS_EAV), describes the Key Performance Indicators (KPIs) related to UAVs and the enhanced requirements for the UAV services [12]. Furthermore, the objective of this research is to come up with new scenarios that cover both commercial and hobbyist UAV applications.

Regarding the communication aspects between the UAV and the Ground Control Station (GCS) and taking into consideration the diversity of the applications that can be benefited by the deployment of UAVs, they can be classified into two main categories: the command and control (C2) and the payload communication, which both of them have been tested using the 5GENESIS portable demonstrator deployed at an open space like Egaleo Stadium, shown in the following figure.

Figure 49 5GENESIS portable demonstrator at Egaleo Stadium supporting 5G-enabled UAV trials

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3.2.4.1. C2 Link

The C2 link establishes communication between the UAV & the GCS or other ground systems such as the radio controller. It must facilitate highly efficient, low-latency, and bidirectional secure communications, usually with low data rate requirements, so that critical information can be shared between the UAV flight controller and the ground control station.

Table 14. KPIs for c2 link

Traffic Type for C2	Bandwidth	Latency
Command and Control	0.001 Mbps	VLOS: 10 ms Non-VLOS: 360 ms
Telemetry	0.012 Mbps w/o video	1 sec
Real-Time	0.06 Mbps w/o video	100 ms
Video Streaming	4 Mbps for 720p video 9 Mbps for 1080p video [30 Mbps for 4K Video]: optional	100 ms
Situation Aware report	1 Mbps	10-100 ms

The C2 link does not include, or interact with payload related data, such as cameras, LIDAR, etc. There can be various types of C2 links to connect the GCS or radio controller to the UAV. Some of the options are 433 MHz (Europe), 915 MHz (USA), 868 MHz, 2.4 GHz, 5.8 GHz, LTE band, and more recently, 5G bands. 3GPP has recommended specific KPIs for the C2 link communication for various types of data shared between the UAV and the ground control systems.

Through several experiments, the latency for various C2 bands have been identified and validated as illustrated in the following figure. For example, the 868 MHz band showed an RTL (Round Trip Latency) of 110 to 600 ms. The 2.4 GHz has an average latency ranging from 22 to 310 ms, while the LTE band has an average latency of around 200 ms.

3.2.4.2. Payload Communications

On the other hand, the payload communication link is used for transmitting data applications and usually supports high data rates, thus requiring high throughput. The type of data may include image, video, relaying or backhauling data packets, heavy LIDAR data in LAS format, etc. The application scenario each time indicates the type of payload communication to be used, as well as the capacity requirements.

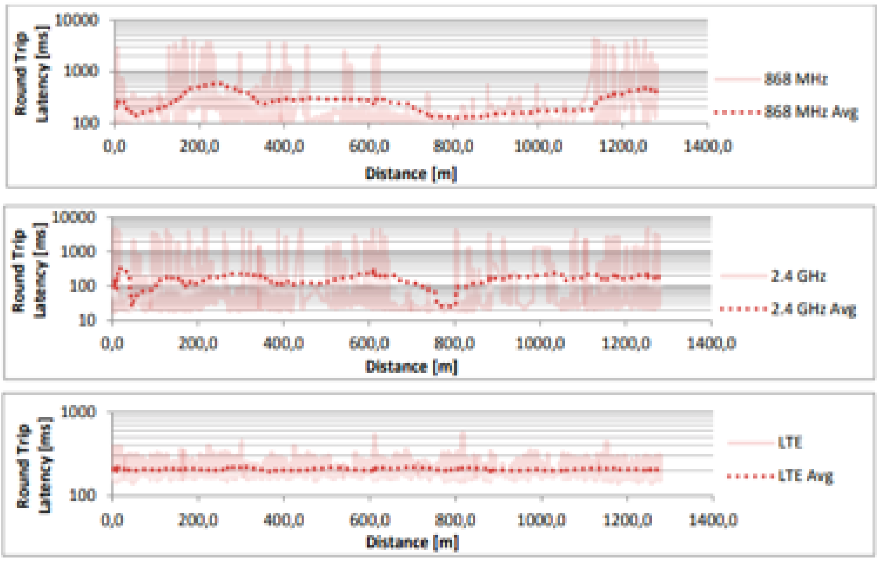

Figure 50. Round trip latency for C2 link and LTE

Moreover, these types of links are usually characterized by higher tolerance and security requirements in comparison to the C2 communication links. To cite an instance, in case of an application that requires video capturing, the UAV will transmit the captured video to the end users via payload communication.

Table 15. Data rates for payload communications

	Value	***Application***
Data Rate	UL 4 Mbps	1080p video transmission
	UL 30 Mbps	4K HD video
	UL 60 Mbps	8K HD video
	UL 1 Gbps	AR/VR

To transmit a full high-definition video from a UAV to a GCS the transmission rate requires several Mb/s, while the transmission rate for a 4K video can exceed 40 Mb/s. For supporting an application with wireless backhauling the UAV communication requirements can be in the scale of Gb/s. Table II summarizes the requirements regarding the data rates for the payload communication. For a typical transmission of an image or video the end-to-end latency can potentially include delays regarding coding decoding and processing. Moreover, latency includes the air-interface as well the latency of the core network. The indicative values related to the latency for image or video transmission are illustrated in the next table.

Table 16. Latency For Payload Communications

	End to end latency	***Network***	***Application***
Latency	<400ms	<40ms	Image/Video Transmission

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3.2.4.3. QoS and UAS Services

Based on the 3GPP requirements, Command and Control indicates the consideration of safety concerns, including the risk of collision or the risk of loss of control of a UAV. Therefore, to avoid the safety risks, when considering the 5G network as the transport network, it is important to provide Quality of Service (QoS) for the C2 communication towards UAV services. The new enablers that the 5G cellular networks introduce, can provide an end-to-end QoS system consisting of characteristics such as network slicing that has the potential to respond better to the needs of the increasingly diverse UAVs' applications. Each slice created on top of a physical infrastructure stands for a complete logical network consisting of network capabilities as well as associated resources which can provide specific end-to-end enhanced service capabilities.

In the light of the above by allocating a dedicated slice for the connected UAV, we can separate the service and the radio resource management for the UAV from those allocated for the terrestrial infrastructure. Moreover, it is possible to provide service differentiation for a diversity of UAVs' operations, for example by using different slices to support control signaling and applications for specific data services (image/video transmission).

3.2.4.4. 5G-Enabled UAS Architecture

This section provides details on the use-case specific components that used for the needs of this trials in order to realize the deployment of the scenario and further validate the feasibility of delivering the C2 connectivity to the UAV over 5G. The elements of the UAS along with the 5G portable demonstrator, are comprised of the UAS deployed in the Edge cloud, the Unmanned Traffic Management (UTM) deployed off-site, the Streaming server deployed in a private cloud and two drones, one for patrolling and one for infrastructure. DJI MAVIC drone dedicated for patrolling was used to measure the radio network quality (QoS). The infrastructure drone was a tethered custom-made drone which offers unlimited power supply and secured data transfer for safer operations.

Ground Control Station

The amount and the complexity of the UAV missions require the remote pilot to use not only a joystick for the real-time navigation, but to utilize a GCS for accessing, analysing and editing all the required data, applying sophisticated piloting mechanisms, based on AI mechanisms and Decision Support Systems (DSS). The GCS of the 5G-enabled UAV prototype consists of a USB joystick/gamepad for the real-time manual UAV control and a Graphical User Interface (GUI) software, running at the edge computing node of the 5G network, for supporting more complex applications and autonomous flying. "QGroundControl" is the open-source GCS software that is used for the needs of the 5G-enabled UAV prototype, which supports sending joystick/manually-generated piloting commands to the UAV, but also automated generated from a respective autonomous flying application. Additionally, further configurations are supported, such as adjusting the parameters of the UAV flight controller, tracking the UAV position on a map, viewing telemetry data (e.g. battery level, temperature, speed etc.), sending special navigation commands (e.g. loiter, mission etc.) and accessing the flight log as is illustrated in the following figure.

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Figure 51 QGroundControl software deployed at the edge of the 5G system

The software has also the capability of embedding the UAV video stream, allowing the user to view all the data (i.e. telemetry and video) in one screen. Alternatively, the video stream can open to a new window or even to a new device (e.g., another laptop connected to the 5G network), so other people can watch.

3.2.4.5. Field Trials and Results

Feasibility trials of UAV flight with 5G network were conducted at the Stavros Mavrothalassitis stadium of the Municipality of Egaleo. The realization of the 5G enabled UAS is presented in the following figure. UAV drone flight control (C2) software UGCS [13] was installed on a 5G Edge server and a flight mission was sent to the drone controller over the 5G network [14-15]. In addition, C2 system was connected to UTM test system, which in real life distributes drone locations to air traffic services and other drone operators. In this way, UAVs can fly together simultaneously, in the common airspace, avoiding collisions and accidents.

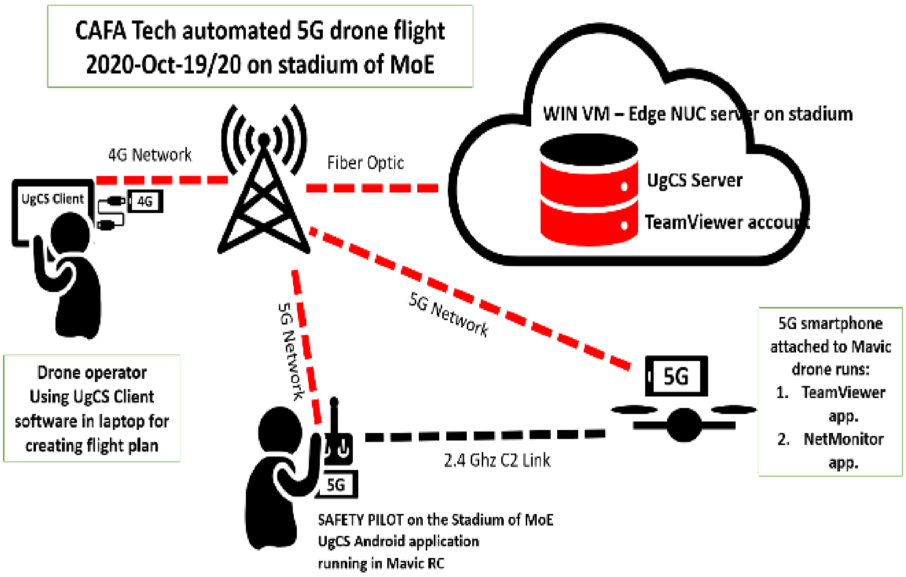

Figure 52. 5G-UAS Architecture of automated flight trials

Moreover, based on policy enforcements, the UTM via its integration with the 5G system, can mandate instantly the UAV landing, if a security incident occurs or a regulation bans flights over a specific location. Afterwards, experimental measurements at the height of 10m were performed in order to assess the coverage of the 5G network and the impact of the antenna pitch to the flight performance and accuracy of the UAV. The 5G coverage measurements were performed using a 5G-enabled smartphone attached to the patrolling drone, and utilizing the Ookla Speedtest application, to assess the uplink and downlink rates. The next figure visualizes the experimental results of the coverage of an automated flight following a circular trajectory around the center of the stadium.

Figure 53. Coverage area with uplink and downlink values

The greener the spots, the better the reception quality and the 5G coverage, while the yellow spots refer to medium reception quality and finally the red ones at bad reception quality. The different coverage levels are also depicted in the respective throughput rates in the uplink and downlink, where the maximum download rate in a good coverage point was 142 Mbps, while the respective value was significantly lower, in a bad reception point, i.e., 13 Mbps. Respectively, the uplink rate was measured from 37 Mbps, down to 22 Mbps as illustrated in the next figure.

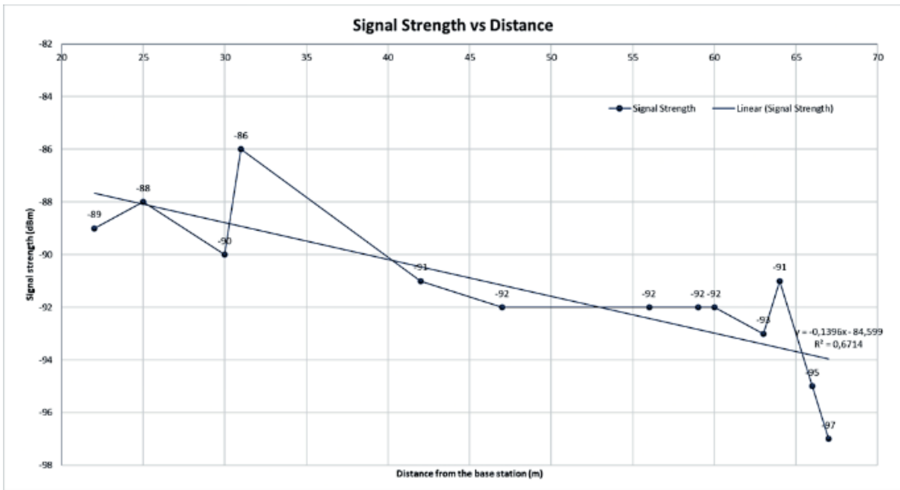

Figure 54. Signal strength vs gNB distance

Moreover, the average latency of the C2 signals over the 5G channel, was measured and found equal to approx. 30ms, which is a significant improvement in comparison to the respective round-trip latency measured for C2 link over LTE. Measurements of the signal strength were performed using the NetMonitor application. The deduced plots the signal strength as a function of the distance from the gNB during the automated flight. As we can see, there is a smooth decay of the signal strength as the drone moves away from the base station. It is also important to note that the UTM integration worked smoothly and the location of the Patrolling drone was visible in real time in the UTM system.

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4. CONCLUSIONS

This document presented the third release of the 5GENESIS portable demonstrator, as well as the activities conducted for the evolution of the demonstrator towards its final implementation.

During this third integration cycle of the project, the infrastructure part of the demonstrator was implemented, following a modular approach that resulted to three setups, namely, the OAI-based 4G set up, the OAI-based NSA 5G set up, and the commercial 5G SA/NSA set up. Also, the integration of the Release B components of the coordination layer (Portal, Dispatcher, ELCM, Slice Manager, Monitoring) and an upgrade of the transport network emulator with the FOGUS SDN testbox was completed successfully.

The configuration made and the activities conducted for the utilisation of the 5GENESIS portable demonstrator in lab-based tests (i.e., the video streaming test case) and in field trials (i.e., the UAV control in a stadium) are also presented in this document.

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