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

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Deliverable D4.9

The Limassol Platform – Release C

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LIST OF ACRONYMS

Acronym	Meaning
5G PPP	5G Infrastructure Public Private Partnership
5G-IA	The 5G Infrastructure Public Private Partnership
5GC	5G Core
AES	Advanced Encryption Standard
AR	Augmented Reality
CSP	Content Service Provider
CUPS	Control and User Plane Separation
eNB	eNodeB, evolved NodeB, LTE eq. of base station
EU	European Union
EPC	Evolved Packet Core
EUTRAN	Evolved Universal Terrestrial Access network
FDD	Frequency Division Duplexing
GES	Gateway Earth Station
gNB	gNodeB, 5G NR, next generation NR eq. of base station
IOT	Internet of Things
KPI	Key Performance Indicator
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution - Advanced
MANO	NFV MANagement and Organisation
MEC	Mobile Edge Computing
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine Type Communications-5G Generic Service
MONROE	Measuring Mobile Broadband Networks in Europe.
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NMS	Network Management Systems
NSMF	Network Slice Management Function
NR	New Radio
OAI	Open Air Interface
OAM	Operations, Administration & Management
OSM	Open-Source MANO
PoP	Point of Presence
P-GW	Packet Data Node Gateway
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RRH	Remote Radio Head
RRM	Radio Resource management
RU	Radio Unit
SCPC	Single Carrier Per Channel
SDN	Software Defined Network

Acronym	Meaning
SDR	Software Defined Radio
SoC	System-on-Chip
UE	User Equipment
uRLLC	Ultra-Reliable, Low-Latency Communications
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal

Executive Summary

The 5GENESIS project is building a facility composed by six 5G experimental platforms in Europe to validate the KPIs (Key Performance Indicators) defined by 5GPPP, like latency, throughput, speed, capacity, etc. These platforms in Athens, Berlin, Limassol, Málaga and Surrey, plus a portable version, are instances of a common reference architecture already defined in deliverable D2.2 "Initial overall facility design and specifications" in response to the project requirements identified in deliverable D2.1 "Requirements of the facility". This deliverable focuses on the specific instantiation of the reference architecture to construct the 5GENESIS Limassol platform.

The Limassol 5G platform integrates several infrastructures in the city of Limassol, Cyprus, in order to form an interoperable multi-radio facility, combining terrestrial and satellite communications with the ultimate aim of efficiently extending 5G coverage to underserved areas. To that end, the Limassol 5G platform employs NFV-/SDN-enabled satellite communications as well as tight integration of different access and backhaul technologies.

The implementation of the Limassol platform has been organised in three consecutive phases, according to the 5GENESIS project plan, resulting in three platform releases correspondingly (A, B and C). The aim of Phase 1 has been to deliver an end-to-end 4G network which utilizes satellite backhauling and is NFV/SDN capable, also featuring edge computing capabilities. The aim of Phase 2 has been: i) to upgrade from 4G to 5G, by switching from EUTRAN to a first version of 5GNR; ii) to integrate the secondary backhaul (terrestrial) and demonstrate link aggregation via the appropriate VNFs at the core and edge and iii) demonstrate the basic coordination layer capabilities, allowing automated experiment execution, configured using the Portal.

The present document focuses on the Release C (final) of the platform, as it was implemented during the third implementation phase. The aim of Phase 3 has been to complete the implementation of the 5GENESIS architecture on its whole and to deliver a full-stack, end-to-end 5G experimental testbed with all the added-value features associated with the Limassol platform specificities. Phase 3 further evolved the 5G configuration, by employing fully functional 5G NR with commercial terminals and 5G core functions and upgraded the upper layer (Open5GENESIS) components with their latest, feature-rich versions.

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

- ✓ 5G NR support evolution and stand-alone (SA) support
- ✓ Integration of the 5G mobile hotspot
- ✓ Integration of virtualised 5GC based on Open5GS and satellite 5G backhauling
- ✓ Study and implementation of mechanisms for satellite network slicing
- ✓ Upgrade of MANO to support Docker/Kubernetes
- ✓ Upgrade of Open5Genesis and Security Analytics to Release B
- ✓ Evolution of spectrum allocation mechanisms
- ✓ UC-specific developments (implementation of UC applications and integration with experimentation framework)

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

During the next months, extensive tests will be performed to ensure that all the newly integrated services and components work as expected and, in parallel, the platform partners will continue their efforts towards fine-tuning and optimising the operation of the platform.

The Release C of the platform will be used for the third round of experiments during Q3/Q4 2021, and the report on the KPIs will be available in deliverable D6.3 in December 2021.

Table of Contents

1. Introduction

1.1. Purpose of the document

This deliverable provides a detailed description of the expected layout and functionalities of the 5G experimental platform to be built in the city of Limassol in the context of the H2020 project 5GENESIS. The project aims to validate the relevant 5G KPIs identified by 5GPPP building realistic 5G platforms and 5G use cases. In the previous deliverables, the project has identified the specific requirements [1] for the platforms and a common reference architecture [2] which is being instantiated in Athens, Berlin, Limassol, Málaga and Surrey, plus a portable version.

The document is the second of a series of three deliverables to report on the status of the 5GENESIS Limassol platform in line with the three experimentation cycles defined in the project: April-June 2019, January-March 2020, October 2020-June 2021. Each experimentation cycle is preceded by an integration phase of components to add more subsystems with the final target of validating the relevant 5G KPIs in a full end-to-end network with real users.

1.2. Structure of the document

Following the present introduction, this document proceeds in Section 2 with a brief overview of the target topology of the platform, the platform sites as well as the technologies used for the platform components at the three logical layers (coordination layer, MANO layer, infrastructure layer).

Section 3 is devoted to the two use cases that are demonstrated on the platform, describing their components, the scenarios of utilization and the expected outcome.

Section 4 presents the progress which was achieved during the third implementation phase, the developments and the upgrades done towards finalizing the platform.

Finally, Section 5 concludes the document.

1.3. Target Audience

This deliverable is released to the public, with the intention to expose the technical approach, the advancements as well as the capabilities of the Limassol platform, potentially attracting experimenters.

2. Limassol Platform Overview

2.1. Platform Sites Topology

The Limassol 5G platform integrates several infrastructures in the city of Limassol, Cyprus, in order to form an interoperable multi-radio facility, combining terrestrial and satellite communications with the ultimate aim of efficiently extending 5G coverage to underserved areas. As shown in Figure 1 below, the key infrastructures on which the platform is built are:

- **The Primetel R&D experimental testbed in Limassol**. It is located in the company's central building close to the Limassol port. The PLC testbed acts as the core node of the platform by: i) hosting, in its private Data Centre, all the management components and services for the platform, ii) providing the interconnection to the Satellite Gateway and the Internet, as well as to the other 5GENESIS platforms.
- **The Avanti Satellite Gateway at Makarios Earth Station.** The Avanti Ground Earth Station facility in Cyprus is used to provide managed SATCOM services over its HYLAS 2 and HYLAS 4 satellites using a professional grade network platform supporting efficient transport of cellular traffic, as well as management interfaces and APIs via its cloud operational support system (OSS) and network platform (NMS).
- **A remote network, constituting the mobile 5G hotspot.** This is a mobile/portable platform, used to connect to the satellite (and/or terrestrial backhaul), host the edge computing equipment as well as the RAT assets in order to provide localized 5G coverage.

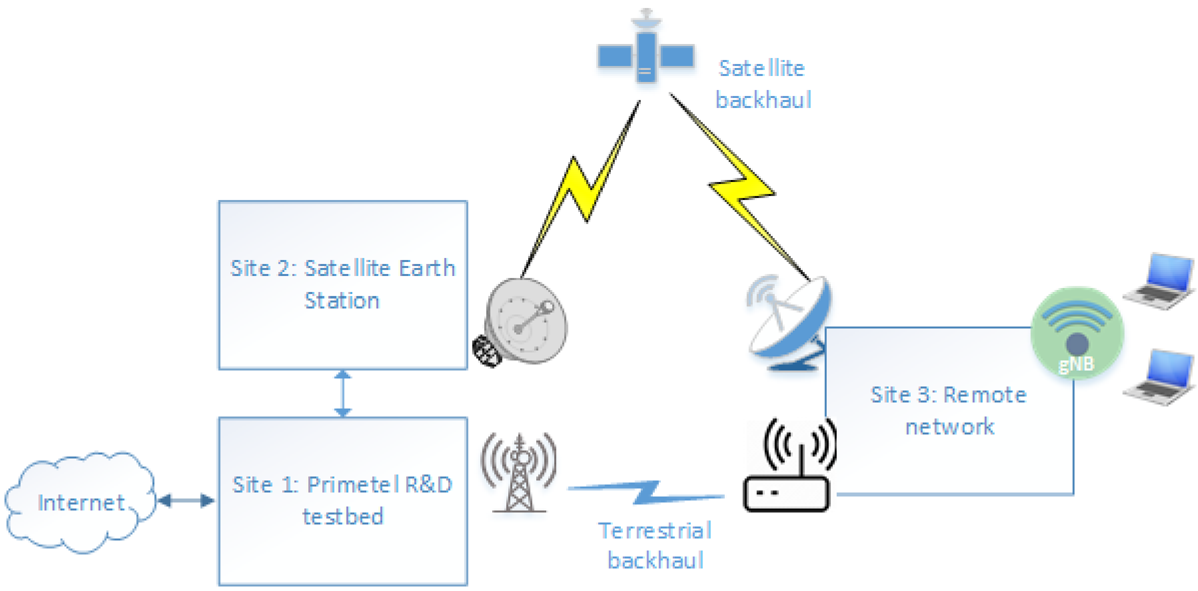

Figure 1. High-level topology of the Limassol testbed

The sections to follow present briefly the infrastructure and assets already available at the three sites. For a more detailed presentation of the sites, please refer to D4.7 [4]

2.2. Platform Deployment Setups

2.2.1. Site 1 – PrimeTel R&D testbed

As a network operator and service provider, PLC owns and operates 5 privately-owned ISO certified data centres in Cyprus, which offer reliable, uninterrupted operation and the use of a high-capacity 10 Gbps network.

The 5GENESIS hardware is collocated at the Limassol data centre, on R&D department rack space. There, PLC hosts the mobile network EPC/5GC, the compute nodes and the monitoring functions, as shown in Figure 2 below. The network and the interconnections are managed by PLC. In addition, PLC has deployed a L3 VPN in order to connect the management network to other partners' infrastructure and the cloud.

Figure 2. R&D department rack space hosting 5GENESIS equipment

The operation of the 5GENESIS platform also requires COTS 4G networking as well as international connectivity.

PLC operates its own private 4G mobile network and the largest privately-owned fibre optic network in Cyprus, offering a variety of complete communication solutions to personal, business and wholesale customers. High-speed 4G connectivity is offered to all major metro and rural areas through own equipment.

Furthermore, PLC owns and operates an international network, spanning across United Kingdom, Russia, Germany and Greece. This provides network connectivity, data communications and IP-based services. PLC holds high-capacity rights on all major submarine cable systems terminated in Cyprus with full diversity which allows interconnection with all major Points-of-Presence (PoPs) and Disaster Recovery Centers all around the world. PLC, in cooperation with Reliance Globalcom, has set-up the next-generation network (NGN) submarine cable system 'Hawk' with capacity of 20 Tbps at PLC's privately-owned landing station in Paphos.

PLC operates the core VPN infrastructure of the Limassol platform. This is the central hub connecting to 1) the Avanti Satellite Earth Station (over an IPSec tunnel), 2) the remote 5G hotspot (over an L2TP tunnel) and 3) remote clients for development, integration and monitoring purposes (over a WireGuard-based infrastructure).

2.2.2. Site 2 – Avanti Satellite Earth Station

The satellite earth station at Makarios (Cyprus) is used to support the SATCOM component of the Limassol platform.

The Makarios Ground Earth Station (GES), operates with a diverse site at Pera (Cyprus). In the event of heavy rainfall or other extreme weather conditions when the signal-to-noise-ratio (SNR) drops below a predefined threshold, the diverse site at Pera takes over without having to replicate the complete GES (only the antenna and RF system). Both sites employ a 9.2 m antenna and are physically connected via an RF-over-fibre link. Both antennas (and feeds) cover the full Ka-band for maximum flexibility: Transmit Band at 27.5-31 GHz and Receive Band at 17.70-21.20 GHz.

Figure 3. Makarios (Cyprus) GES

The data centre of the earth station has an area of 116 square meters with 50 42U racks grouped in 3 cold aisle containments and are available for all RF & antenna control systems, baseband hubs and network equipment.

The data centre core network subsystem is deployed on several racks. Its functionality is to provide networking services to interconnect the different subsystems including those of third-party users and provide all routing, traffic shaping and network security to the backhaul. The core network is composed of switches, routers, firewalls and other supporting equipment like servers, storage, and traffic shapers.

Similar to the data center network, the broadband network subsystem is also deployed on several racks. It has the purpose of providing all the necessary infrastructure for the deployment of broadband services over the HYLAS 2 High Throughput Satellite (HTS). The broadband network is based on satellite internet hub infrastructure (e.g. iDirect, Hughes, Newtec) that interfaces between the Earth Station and the internet with the purpose of providing data services to users located in the areas covered by the HYLAS 2 beams.

The Limassol platform is backhauled through HYLAS 2 satellite and Makarios GES. The Cyprus GES is connected via Ethernet (L2) over fibre to Avanti's WAN PoPs in London (primary) and Frankfurt (secondary) and subsequently to the internet through TIER-1 transit providers. In the framework of 5GENESIS, the Cyprus GES is connected to Primetel's facility (where the orchestrator, core network and NFVs/SDN are based) via a L3 VPN connection.

A dedicated router (Figure 4) has been installed in Makarios GES, to which all traffic from the 5GENESIS satellite terminal(s) is routed. This router connects to the Primetel data centre over IPSec. This configuration allows us to deploy nodes behind the satellite modem within the 5GENESIS private IP address space, without the need for a VPN tunnel over satellite, which would degrade the performance of the satcom link.

Figure 4. Colocation router installed for 5GENESIS at Makarios Earth Station

The GES broadband subsystem is based on satellite internet hub infrastructure supplied by iDirect and Hughes. In 5GENESIS we opted for iDirect hubs due to higher data rate capabilities and support of terminal mobility. An iDirect Evolution type hub, shown in Figure 5, installed at Makarios (Cyprus) GES is employed to provide the satellite backhaul connectivity to the Limassol platform.

An iDirect network is a satellite network with a Star topology in which a Time Division Multiplexed (TDM) broadcast downstream channel from a central hub location is shared by a number of remote sites. Each remote site transmits to the hub either on a shared Deterministic – Time Division Multiple Access (D – TDMA) upstream channel with dynamic time slot assignments or on a dedicated Single Carrier Per Channel (SCPC) return channel. iDirect supports L3 TCP/IP over the satellite link in Avanti's network.

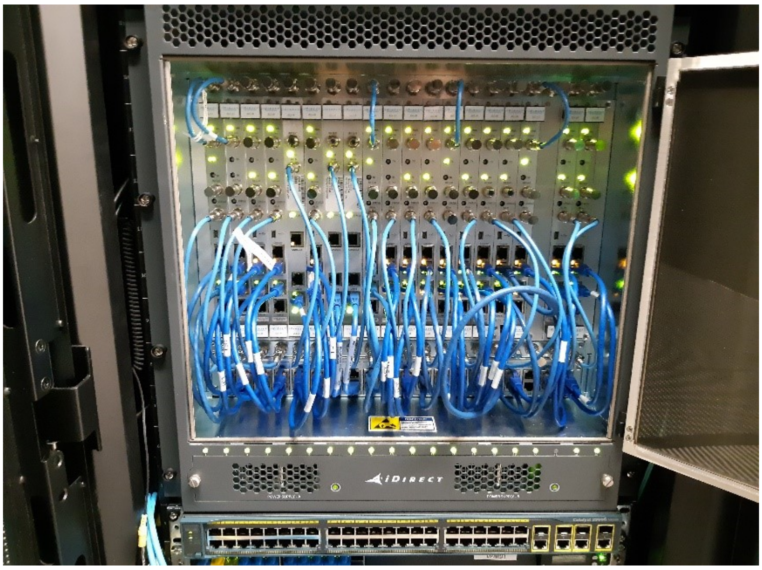

Figure 5. iDirect Evolution Hub

The iDirect software has flexible controls for configuring Quality of Service (QoS) and other traffic – engineered solutions based on end – user requirements and operator service plans. Network configuration, control, and monitoring functions are provided by the integrated NMS.

2.2.3. Site 3 – Remote 5G hotspot

The aim of the remote 5G hotspot is to provide ad-hoc 5G connectivity in a deployable manner in mobile use scenarios or undercovered areas. Its key elements are:

- The satellite and 4G antennas
- The 4G router (backhaul)
- The satellite terminal
- The edge computing equipment
- The gNB
- Non-3GPP radio access points

Figure 6 below depicts the functional blocks 5G mobile hotspot, comprising the aforementioned components.

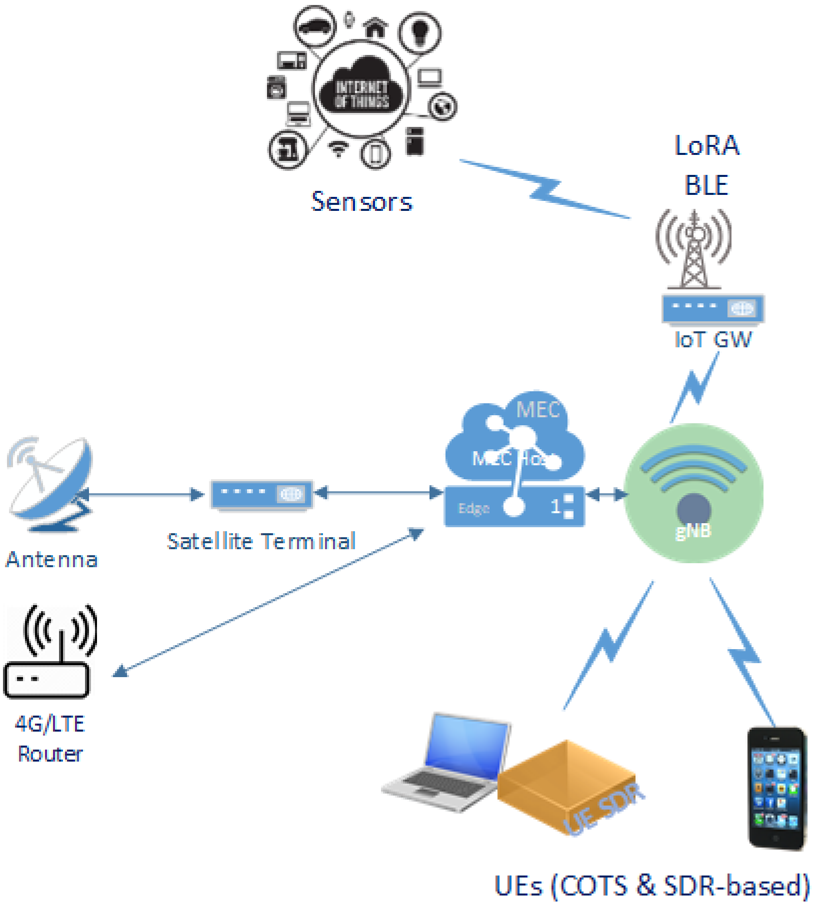

Figure 6. Key elements of the remote 5G hotspot

The 5G hotspot features computing assets in order to host the edge computing services. These are provided by a Dell Edge Gateway compute node, which is tailored for edge IoT applications.

Most assets of the mobile hot-spot have been housed in a small-factor portable rack, so that it can easily transported and installed on ad-hoc basis. See Sec. 4.2.2 for more details.

The 5G hotspot connects to the primary backhaul (satellite backhaul) using a satellite terminal. The iDirect X7 model is used for this purpose. This rack-mount model supports bandwidth-heavy business applications and multicast services like IP TV, distance learning, HD broadcast, digital signage and video. It also features an 8-port embedded switch for managing multiple user groups. It makes possible to serve a range of enterprise voice and data services while simultaneously receiving multicast channels over the same or a second transponder or satellite – even combining spot-beam HTS capacity and Ku- and C-band capacity.

Figure 7. iDirect X7 satellite terminal installed at 5GENESIS platform

The access radio network comprises of:

- A 5G gNB, based on the Amarisoft Amari Callbox Classic model. The gNB supports SA and NSA operation, 2x2 MIMO up to 50 MHz bandwidth.
- A 4G eNB, based on the OpenAirInterface suite and the setup provided by. The eNB is implemented using an ETTUS B210 SDR platform, driven by a laptop computer running the OAI software. The Amari Callbox can also be used as eNB.
- Non3GPP radio access points, including WiFi and LoRa.

For the satellite backhaul link, a standard fixed vSAT antenna is used, equipped with a 120 cm dish (Figure 8).

Figure 8. Fixed satellite antenna installed to backhaul the 5G hotspot

2.3. Platform Implementations

2.3.1. Platform Infrastructure Layer

Table 1 below provides an overview of the infrastructure layer components and associated technologies currently deployed in the Limassol platform.

Table 1. Infrastructure layer components and technologies in the 5GENESIS Limassol platform

Component	Products/Technologies Options	Mode of Implementation

Edge/Cloud Computing	OpenStack/OSM	Single instance
EPC/5GC	Amarisoft 5G Core Open5GS 5GC Athonet EPC NextEPC	Single instance
5GNR	Amari Callbox Classic gNB	HW
LTE EUTRAN	Eurecom OpenAirInterface, Amari Callbox Classic eNB	Single instance & SDR HW
Non-3GPP Access Networks	Fixed and wireless IoT devices (LoRa, BLE, PanStam and Arduino for first iteration), INTER-IoT physical/virtual network and an IoT platform and services.	Bespoke devices
Probes	OpenTAP agents	Multiple instances deployed across the network
Edge VNFs	5GC UPF, IoT interoperability function, IoT edge applications	Multiple instances deployed at the edge of the network
UEs	Commercial 5G terminals (Samsung A90 5G, Huawei P40 Lite 5G, Realme 7 5G, Waveshare 5G Hat for Raspberry Pi) Commercial 4G terminals (Galaxy Tab, Huawei E3372 USB dongle)	COTS devices

2.3.1.1. Main Data Center

The purpose of the core cloud domain is to host the NFV Infrastructure (NFVI) at the core of the network. In addition, the core cloud domain hosts higher-layer components, i.e. Management and Orchestration Layer as well as Coordination Layer functionalities.

In any case, the focus is on hosting the VNFs, the EPC/5GC functions and other functionalities operating on the data plane. For MANO/Coordination layer functionalities, as well as other control plane modules, in case of physical and logical resources shortage, the Limassol platform offers the capability to off-load them to a public cloud infrastructure (Microsoft Azure).

The core cloud domain is physically deployed in the Primetel R&D testbed. It is based a single Dell R430 server (Figure 9), which for the time being has enough resources for hosting all necessary services.

The server basic specifications are as following:

- Processor: 2x Intel Xeon E5-2630 10C/20T

- Memory: 192 GB RAM
- Disk 1: 240 GB SSD SATA
- Disk 2: 1 TB SATA
- Network I/F: 4x GbE

Figure 9. Dell R430 server, as building block of the Core Cloud Domain

The Core Cloud server is running on Ubuntu Linux 18.04LTS.

OpenStack (Rocky version) is used as cloud operating system and NFVI enabler.

2.3.1.2. Edge Data Center

The Limassol platform employs edge computing, in order to enable content and applications to be processed at the edge of the network, close to the end user, thereby improving the user experience and reducing the traffic that has to be sent over the network. The MEC can be used, for example, to optimize and cache video traffic close to the end user.

The Limassol platform particularly focuses on deploying services on the satellite edge. In this context, the alleviation of the satellite delay for traffic, which can be routed locally, is considered a major benefit from the application of edge in the Limassol platform. This feature is enabled by deploying a User Plane Function (UPF) instance at the satellite edge and/or custom user applications. Since the application data does not have to be backhauled to and then traverse the core EPC/5GC before being processed, the latency is significantly reduced.

Another benefit of edge computing in a satcom environment is the pre-processing/ aggregation/ compression of data before being sent over the satellite channel (such as e.g. IoT data). This further contributes to the reduction of the usage of the costly satellite backhaul.

The edge computing infrastructure is based on a Dell Edge Gateway 5100 (Figure 10).

Figure 10. Dell Edge Gateway 5100, used as edge node

Ubuntu Server 18.04 LTS, along with a full OpenStack installation (Rocky version) has been deployed at the edge host, excluding its dashboard service (Horizon). The OpenStack VIM is managed in turn by the central OSM at the core, which allows deployment of VNFs either at the core or the edge. As an alternative edge VIM, Kubernetes (See Sec. 4.2.5) has been set up.

2.3.1.3. Transport Network

Limassol platform uses a dual-backhaul approach, combining satellite and terrestrial backhauls using link aggregation techniques.

Satellite backhaul

Avanti operates a fleet of five Ka-band High Throughput Satellites (HTS), namely HYLAS 1, HYLAS 2, HYLAS 2B, HYLAS 3 and HYLAS 4. In 5GENESIS, backhaul bandwidth to the Limassol platform is provided though Makarios (Cyprus) GES and HYLAS 2 satellite the coverage of which is shown in Figure 11 (b).

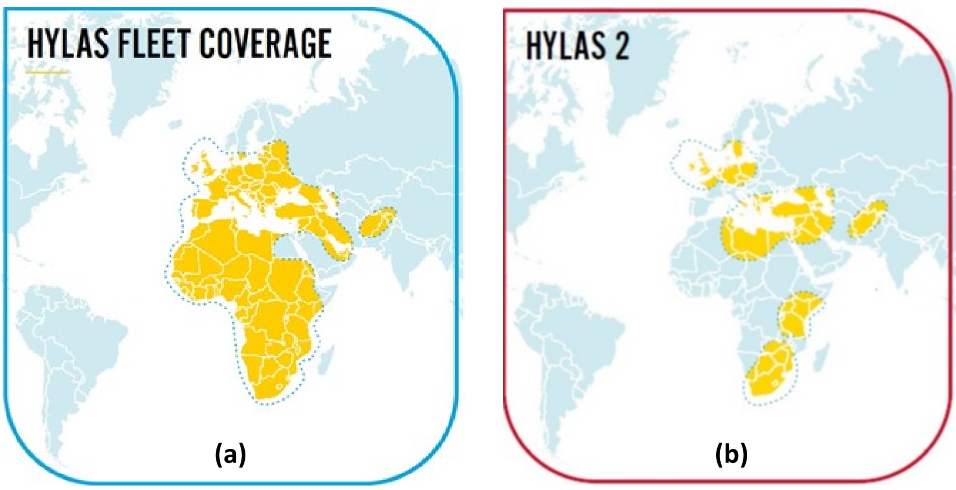

Figure 11. Avanti's (a) HYLAS Fleet coverage (b) HYLAS 2 coverage

HYLAS 2, operating from geostationary orbital slot 31° E, has a capacity of 11 GHz and provides coverage to 61 countries through 24 fixed beams and one steerable beam. The Limassol platform is covered from one spot beam over Cyprus with a dedicated 15 Mb/s download (downstream Forward Channel) and 5 Mb/s (Upstream Return Channel). For this service the iDirect Very Small Aperture Terminal (VSAT) network hub vendor is used. More specifically, an Evolution type hub is employed at the Earth Station (more details on this in section 2.1.3). At the terminal, a 120 cm terminal antenna including a 3 W transceiver is installed along with an iDirect X7 satellite router. Full mobility is supported by the hub for the terminal which will enable the next phase of the Limassol platform offshore, on board a vessel/boat. For this last phase of the Limassol platform, a 3-axis stabilized antenna, type approved by Avanti, will be employed. This antenna has the capability to track the satellite maintaining the optimum signal-to-noise ratio. In essence, Avanti provides an L3 interface to the Limassol platform at both the Gateway and terminal site. The X7 satellite router is the top end product of iDirect with maximum accelerated IP data rates of up to 59 Mb/s downstream and 16 Mb/s upstream. At the final stage of the trials, i.e. offshore (on board a vessel) and unserved/underserved rural 5G base station backhauling, Avanti will endeavour to provide these maximum downstream and upstream data rates for showcasing purposes.

Terrestrial backhaul

In the Limassol platform, the aim of the secondary (terrestrial) backhaul is to demonstrate and assess the functional features of satellite/terrestrial link aggregation. For such a purpose, a high-performance micro- or mm-Wave point-to-point connection is not necessary; in addition, the establishment of a point-to-point connection poses severe technical challenges in the mobile use scenario (especially the maritime communication one). The addressing of such challenges is not considered within the 5GENESIS scope.

For these reasons, the secondary terrestrial backhaul is based on OTS 4G data connection, which is more feasible to deploy and more relevant for the mobile use scenario. The 4G-based backhaul is provided by PLC.

PLC operates its own, independent 4G mobile network with nationwide coverage since March 2015, as a full mobile network operator (MNO). For the terrestrial backhaul, PLC’s commercial 4G network is used. This requires the use of SIM cards from PLC and a 4G modem at the edge of the network (on-board the vessel.) As part of its commercial 4G network, PLC offers the possibility for Plug n Play Broadband using a Huawei 4G modem, capable of speeds up to 150 Mbps.

Link aggregation

The Limassol platform has the particularity to include a 5G hybrid backhaul to support use cases where a terrestrial backhaul cannot deliver the performance expected by the 5G service. This is typically the case when a vessel equipped with a gNodeB leaves the harbour: the impact on services and users on the vessel will increase as the distance increases. The hybrid backhaul proposition adds a satellite link so that the backhaul traffic benefits from the consolidated links. The project therefore delivers a system coupling satellite and terrestrial links to be used for external experimentations.

The link aggregation system is based on two new Virtual Network Functions (VNF): an Edge Gateway integrated on the vessel next to its gNodeB and a Central Gateway integrated next to the mobile core.

Latency is a critical characteristic of the 5G technology, but the satellite signal travelling from earth to satellite and back to earth implies 600+ msec delays, too high to support a 5G backhaul. The solution that is deployed to address this challenge is based on research performed during the BATS, VITAL and SaT5G H2020 European projects that resulted in combining WAN Optimization, multilink algorithms such as Packet Selection Based on Object Length and real time links characteristics measurement. The system distributes the traffic to dynamically optimize the Quality of Experience. This means that the distribution of the traffic on the terrestrial and satellite links between the vessel gNodeB and the ground 5G network will be dynamically adapted as the distance to the harbour increases or decreases. Aside the known benefits of WAN Optimization on satellite traffic, its benefits on a 4G network have been studied when its utilization varies (number of users or bandwidth demand) as experience shows it can be over 100+ msec when highly used. As the same result is expected for 5G, WAN Optimization will be deployed on the 2 Limassol links: satellite and (4G) terrestrial.

GTP protocol support has been added to the WAN Optimization VNF for the satellite to carry 5G (GTP) backhaul traffic.

We also studied the recent QUIC transport protocol, proposed by Google to the IETF, in terms of performance and behaviour over satellite. QUIC's aim is to augment TCP by reducing the establishment of secure connections, and is expected to become very popular in the years to come. Our experimentation confirms that QUIC efficiency decreases badly on a high latency link. To address this, we have modified the QUIC code to include WAN Optimization principles such as quicker window increase, demonstrating positive results.

2.3.1.4. Mobile Network Technology

Radio Access: 5G NR

5G NR radio network is implemented using the Amarisoft Amari Callbox Classic (CBC) product. Amari CBC implements a “network-in-a-box” solution, integrating within a single compute node SDR-based radio as well as core. The Amari CBC gNB is Rel.15 compliant, operating in several FDD/TDD FR1 bands (sub-6GHz) in a bandwidth up to 50 MHz. It can support up to 2x2 MIMO in DL and supports all SSB/data subcarrier spacing combinations and all modulation schemes. It can operate in either NSA or SA mode. It exposes a standard NG (NGAP and GTP-U) interface to 5GC.

Figure 12. gNB based on Amari Callbox Classic

Radio Access: 4G LTE

The 4G LTE eNB is based on the OpenAirInterface RAN (OAI-RAN) solution provided from Eurecom, both for the g/eNB and the UE.

OpenAirInterface is an open-source software and hardware platform providing a standards-aligned implementation (3gpp Rel. 10/14) for the LTE UE and eNB. Currently, OAI is being extended to support 5G-NR UE and gNB [6], as per Rel.15 standards.

The OAI software is freely distributed by the OpenAirInterface Software Aliance (OSA) and it can be deployed using standard off-the-shelf Linux-based computing equipment (Intel x86 PC architecture) and standard RF equipment (e.g., National Instruments/Ettus USRP). In this context, OAI offers a flexible framework for experimentation with prototype 4G/5G implementations of the UE and base station components.

The hardware platform, provided by EURECOM, uses the ETTUS N300 boards together with a powerful Laptop with a Core i7-7900 8 core processor. A special adaptor is used to connect the Thunderbolt 3 interface of the laptop with the 2x10Gbit Ethernet interface of the USRP.

In addition to the 3GPP RAN, in the Limassol platform, non-3GPP access network is contemplated to support a credible Internet of Things scenario in a rural area deployment. Currently, the available non-3GPP radios are: LoRaWAN, Bluetooth and Panstamp. Fixed technologies are also available, such as RS232, as well as Modbus protocol.

The need of employing these access network technologies is clear when there is a need to include as many devices as possible in the IoT-5G environment, in order to cover more diverse use cases. As some devices are legacy or vendor specific and they are modifiable, we need to create the mechanisms/interfaces to also include non-3GPP access technologies.

Mobile Core: 5G 5GC

In the Limassol platform, for the Mobile 5G Core, the open-source Open5GS platform[1] is mainly used.

The Open5GS 5G SA Core is Rel.16 compliant and contains the following functions as discrete services:

- AMF - Access and Mobility Management Function
- SMF - Session Management Function
- UPF - User Plane Function
- AUSF - Authentication Server Function
- NRF - NF Repository Function
- UDM - Unified Data Management
- UDR - Unified Data Repository
- PCF - Policy and Charging Function
- NSSF - Network Slice Selection Function
- BSF - Binding Support Function

It is open-source, written in C, with a WebUI provided for testing purposes, which is implemented in Node.JS and React. Open5GS has been deployed as a VM on OpenStack, installed in Ubuntu 20.04 Server.

Alternatively to Open5GS, the integrated 5GC provided by Amari CBC (see previous section) can be used.

Mobile Core: 4G EPC

The Mobile Core Network (both EPC and 5GC) is based on Athonet product line. Athonet's mobile core is based on a highly efficient and effective software-only implementation. The expensive, proprietary, hardware centric capex of traditional mobile core solutions have been replaced with a wholly software-only product that runs on standard off-the-shelf servers or in a virtualized environment since its first release, in 2010. The solution has a reduced footprint that can run on x86-based as well as on ARM-based platforms.

The existing platform is a full 4G mobile core that implements 3GPP defined network functions including MME, PGW, SGW, PCRF and HSS. The mobile core provides support to roaming and 3G UMTS too. Being a commercial solution, it can be connected to commercial OSS/BSS systems which enforce regulatory obligations and billing by means of standard interfaces, i.e., X1, X2 and X3 for lawful intercept and Bx and Gy for charging.

2.3.2. Management & Orchestration Layer

Table 1 below provides an overview of the Management and Orchestration layer components and associated technologies deployed in the Limassol platform.

Table 2. MANO layer components and technologies in the 5GENESIS Limassol platform

Component	Products/Technologies Options	Mode of Implementation

[1] https://open5gs.org/

Slice Manager	Katana (developed in 5GENESIS)	Single instance
VIM	OpenStack & Kubernetes	Single instance
NFV Orchestrator	Open Source MANO	Single instance
SDN Controller	OpenDaylight	Single instance
Terrestrial NMS	LibreNMS	Single instance
Satellite NMS	iDirect Evolution hub	Single instance
gNB EMS	Amari CBC GUI / Open Air Interface Management	Single instance
EPC/5GC NMS	Athonet EMS	Single instance

2.3.2.1. Slice Manager

The slice manager is the component that manages the creation and provision of network slices over the infrastructure and is the binding element between the 5GENESIS Coordination layer and the actual infrastructure and management and orchestration layer. The Slice Manager receives the network slice template from the Coordination Layer and then provisions the slice, deploys the network services, configures all the physical and virtual elements of the slice and finally activates the end-to-end operation.

The Limassol platform integrates the Katana slice manager, as implemented in 5GENESIS for all project platforms. Release B of Katana is described in detail in Deliverable D3.4 [10]. In the Limassol platform, the slice manager manages the lifecycle of slices consisting of:

- VNFs and NSs at the core and satcom edge
- Network resources at the satellite and terrestrial backhaul

In this sense, the integration of slice management in the Limassol platform aims to constitute a definitive step towards integrated satellite/terrestrial network slicing in the 5G context.

2.3.2.2. NFV Management & Orchestration

The purpose of NFV Management and Orchestration component at the Limassol platform is to manage the NFV Infrastructure and control the lifecycle of all virtual network functions, at the core and the edge, including the satellite edge.

The VIM (Virtualised Infrastructure Management) component is based on the OpenStack cloud controller (Rocky version)[2]. OpenStack is currently the prevailing open-source cloud controller with a wide ecosystem of services and plug-ins. It is also the most widely used controller for NFV platforms, also a part of the OPNFV (Open Platform for NFV) suite.

[2] https://www.openstack.org/software/rocky

The NFV Orchestrator component is based on Open Source MANO, release six[3]. OSM is one of the most popular open-source platforms for NFV orchestration, and, being developed under the ETSI umbrella, is also aligned with the ETSI NFV specifications.

A more detailed description of OpenStack and OSM is beyond the scope of this document. However, we should here identify some focused adaptation/integration work which is specific to 5GENESIS and the Limassol testbed:

- Integration with the 5GENESIS management and coordination components and specifically with the Experiment Lifecycle Manager and the Slice Manager.
- Configuration and adaptation of OpenStack and OSM to manage the lifecycle of edge VNFs deployed at the satellite edge.
- Extension of service chaining features in order to support proper flow handling over the satellite backhaul.

During Phase 3, edge services are also deployed as Docker containers, so Kubernetes has also been adopted as alternative edge VIM (see Sec. 4.2.5)

2.3.2.3. Network Management Systems

5GENESIS employs and properly adapt existing NMSs for the terrestrial and satellite network segment, respectively. These NMSs are orchestrated by the Slice Manager and the SDN controller for the management, monitoring and control of federated satellite/terrestrial 5G network slices.

Terrestrial NMS

For the Limassol Platform and its terrestrial infrastructure, PLC engages a number of monitoring tools used for the commercial network as well as monitoring tools used within PLC's R&D department. These include open-source and commercial tools configured to monitor system and network activity, including: Zenoss, Prometheus, Graylog and LibreNMS.

In particular, LibreNMS is used at PLC as a composition of different tools/managers to provide a complete view of the flow of traffic across the network, as well as a map of the network and routes. LibreNMS is also used to track service availability and service routes, provide monitoring and alerting in the case of faults. LibreNMS's data feeds are dependent on SNMP, syslog and other agents.

Satellite NMS

For the management of the satellite network, Avanti uses the iDirect VSAT network hub for the satellite network segment of the Limassol platform. iDirect provides its custom made NMS to Avanti via the iBuilder and iMonitor components.

- iBuilder enables rapid, intuitive configuration of any iDirect network. It allows to easily add components to a network, change current configuration, and download configuration and software to network elements.
- iMonitor provides detailed information on real-time and historical performance of the network. Among its many capabilities, iMonitor allows to analyze bandwidth usage;

[3] https://osm.etsi.org/

view remote status; view network statistics; monitor performance of networks (e.g. latency, signal-to-noise-ratio), sub-networks and individual network elements; and manage alarms, warnings and network events.

2.3.2.4. Element Management Systems

Amari CBC EMS

The Amari Callbox Classic platform allows remote management mostly via Command-Line Interface (CLI) and YAML configuration files. It is possible to configure system parameters such as operating band, TDD/FDD mode, bandwidth, MIMO configuration etc. Real-time monitoring of the gNB is also possible via CLI as well as via a web-based GUI, which displays log configuration in real-time.

OAI EMS

Openairinterface configuration and execution

Openairinterface-RAN offers a flexible Command Line Interface (CLI) to launch and configure the two 4g/5g-RAN components: **eNB/gNB** and **UE**. The desired configuration can be provided through a wide range of parameters that are controlled through execution options or configuration files. The configured options are loaded when calling the target executable for the gNB or UE at runtime, as shown in the example below.

UE executable

Related with subcarrier spacing config

Number of Resource Blocks

PHY testing operation mode

```
sudo ./nr-uesoftmodem --numerology 1 -r 106 --phy-test -C 3510000000 --usrp-args "addr=192.168.30.2,clock_source=external,time_source=external"
```

Central carrier frequency

Figure 13. NR configuration from the CLI

This CLI can be easily accessible through external tools/applications/scripts (e.g., Keysight TAP) for remote execution and configuration within the platforms.

The availability of configuration options can be easily extended in parallel with the extensions in 5g-NR development in OAI and following the testing requirements of 5g-NR in the context of 5GENESIS platforms.

Openairinterface KPI measurement/monitoring tools

Openairinterface provides a logging interface per RAN layer (NAS, RRC, PDCP, RLC, MAC, PHY) that contains a wide range of logs for different purposes (e.g., procedures monitoring, radio link measurements monitoring, raw data that can be used for the extraction of KPI measurements like throughput). These logs can be easily exported to log files for ***post-processing*** within the platforms. The information provided from the logs can be easily extended according to the testing requirements of the 5GENESIS platforms.

OAI also provides tools that can be used and extended for scenarios where ***real-time monitoring*** of 5G-NR components is required for the needs of the platforms. T-tracer[4] is a separate monitoring framework for use with OAI only which integrates:

- An events collector integrated to the real-time processing
- A separate set of programs to receive, record, display, replay and analyze the events sent by the collector

Athonet 5GC/EPC EMS

Athonet has implemented a web-based Element Management System (EMS) that caters for performance, configuration and fault management. The EMS includes the following main features:

- System configuration for networking and 3GPP elements;
- User subscriber management and QoS profile assignment/management;
- Automated installation and insertion of license key;
- System configuration backup;
- Detailed user activity;
- Individual users monitoring and global system usage; historical data and statistics are also provided, based on different time granularity (daily/weekly/monthly/yearly);
- Secure access to the GUI via dual-authentication method based on TLS 1.2;
- Access and activity logging.

The following integration points are available for controlling the EPC can be controlled using 3rd party management systems through the following integration items:

- SNMP for KPI and performance monitoring;
- SNMP traps for alarm indication;

RESTful API for user provisioning and profile assignment in the HSS and other functions such as user enablement, examining users' CDRs (UL and DL traffic), enabling users for a certain traffic or time quota; the API is continuously evolving following customer requests and new functionalities are expected to be introduced.

2.3.2.5. Spectrum Management

One of the characteristics that differentiates the Limassol testbed from other 5GENESIS testbeds is the fact that it integrates terrestrial and satellite wireless backhauls. So, from the spectrum management perspective, it would be very useful that the testbed could be prepared to identify, in each moment and in each base station, what is the spectrum that is not being used at that location and use it to 'draw' a network of terrestrial and satellite backhaul links that would deliver the additional capacity to the base stations that are needing it.

For the terrestrial 4G backhaul, we use part of the 2GHz band (1920-1980 MHz; 2110-2170 MHz). This is a band that is licensed to mobile operators to deliver mobile broadband services. The challenge resulting from the adoption of this band is to identify, in a given moment and in each cell, the part of the band that is not being required by the access network, and use this

[4] "T-tracer tool"[Online], https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/T

unused spectrum to build a network of terrestrial backhaul links to enhance the capacity of other base stations that require additional capacity.

For the satellite backhaul network, we use the satellite band (17.7-19.7 GHz; 27.5-29.5 GHz). In Cyprus, as in many other European countries, this band is licensed to multiple applications like fixed-satellite service (FSS) links, fixed terrestrial links and feeder links for the broadcasting satellite service (BSS). Some parts of the band also include weather satellite and earth-exploration satellite services (EESS). Therefore, the challenge here is to identify, in a given moment, if this band can or cannot be used by each base station to provide satellite backhaul links to other base stations. It should be stressed that backhaul links will only be considered when these links do not interfere with other services using the same band.

Figure 14 illustrates the scenario under study. Here, the goal is to activate / deactivate / configure the terrestrial (depicted in orange) and satellite (depicted in blue) backhaul links, so that they can deliver the required capacity to specific base stations, while they do not interfere with other services using the same bands (links that are depicted in green).

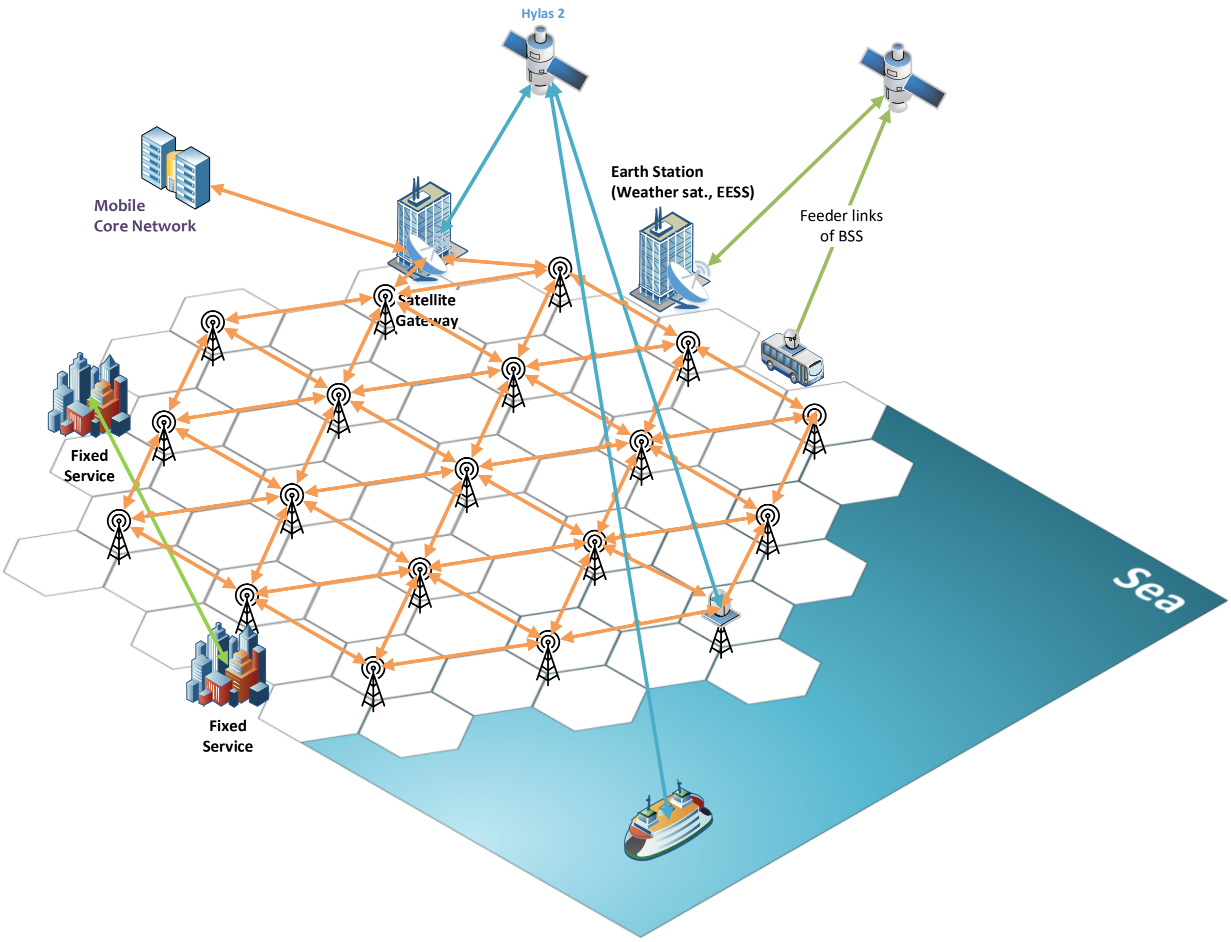

Figure 14. Wireless backhaul network comprising terrestrial (orange) and satellite (blue) links that do not interfere with other services (green) operating in the same bands and in the same area.

To achieve the proposed goal, 5GENESIS considers dynamic sharing of spectrum both in time and in geography.

The spectrum management scenario under study in the Limassol testbed allows to extend the state-of-art on spectrum sharing in the following aspects: i) reuse of spectrum by mobile operators according to channel plans that may vary over time and/or geography, ii) use the shared spectrum for backhaul purposes, iii) integrate satellite and terrestrial backhauls, iv) develop a method to automatically activate / deactivate / configure the terrestrial and satellite backhaul links using bands that are shared with other networks.

As far as the proponents of these solutions know, there is no commercial product available in the market that can actually implement the abovementioned features necessary to the deployment of the Limassol spectrum management scenario. However, the implementation of these features, among others, requires the use of a spectrum database to provide input data. Therefore, if such a database containing spectrum information for Cyprus is not available, we may have to use open-source data from another country to provide input to the developed spectrum sharing techniques.

As the testbed has limited geographical scope, the gains obtained from using shared spectrum in a wide backhaul network will be validated through simulation. IT is currently developing an in-house simulator aligned with the use cases being demonstrated in Limassol testbed. It should be stressed that no wide-scale experimentation of spectrum management techniques will be demonstrated in Limassol testbed.

If the experimenter desires to use the Limassol testbed to test spectrum management techniques, they would need to add the algorithms mentioned in section 4.2.9 to the network management function (NSMF) of the Slice Manager, ensure the Slice Manager is able to communicate the selected backhaul topology to the NMSs in charge of controlling the satellite and terrestrial backhaul links, provide any extra hardware required, and acquire the adequate spectrum licenses.

2.3.3. Coordination Layer

As decided at project level, the Limassol platform (as all other platforms), includes the coordination layer components which are developed in the frame of the project. These components are:

- The 5GENESIS Portal, used as a graphical user interface to the experimenter, facilitating configuration and monitoring of experiments, as well as access to their results.
- The 5GENESIS Experiment Lifecycle Manager (ELCM) for the lifecycle management of the experiments, which interfaces with the underlying element and network management functionalities for the orchestration of network components.
- The Dispatcher and Validator functionalities, for the proper routing and validation of API requests and experiment specifications.
- The monitoring subsystem, for the collection, processing and analysis of measurement results.
- The security framework, for performing advanced network insights and detecting and classifying anomalies at various parts of the network.

The design and implementation of all the above mentioned components has been described in WP3 deliverables.

3. Limassol Platform Use Cases - Specific Extensions

3.1. Use Cases Target Deployment

3.1.1. UC1: 5G Maritime Communications

The features of the Limassol platform, based on satcom and 5G integration, will be used to show how the 5G capabilities (massive throughput, edge services, slicing etc.) can be extended to cover vessels en route. This will be achieved by using the 5G-enabled satellite backhaul to bridge the on-board 5G network with the home (core) network. Scenarios to be tested include crew welfare and on-board communications as well as officer-to-office communications, leveraging edge computing, satellite/terrestrial link aggregation as well as slicing.

Another, more focused and vertical-specific scenario has been elaborated in the course of the project, with the aim of better demonstrating the added-value of 5G on board. This scenario is around AR-enabled hull inspection using 5G edge services. The aim of the inspection will be to quickly detect rust and corrosion in the ship's hull. The images captured by the AR glasses are transmitted in real-time over 5G to the edge node, on which the image processing application runs. More details on this application, which has been already implemented for the needs of the project, is provided in Sec. 4.2.9.

In order to realise the above-mentioned scenarios, the remote 5G hotspot will be installed on board a vessel. The plan has been to install it on a cargo vessel, provided by MARAN.

The exact installation and experimentation procedure and logistics will be defined and implemented during Q3 2021 and will be subject to the restrictions stemming from the planned route and schedule of the ship. It is also clarified that the installed platform components will not interfere at all with the operations network of the ship.

For the implementation of this use case, as seen in the figure below, almost all components of the Limassol platform will be engaged and orchestrated, including the core platform, the hybrid backhaul (satellite and terrestrial) and the 5G hotspot (including the stabilized satellite antenna, the edge computing and networking equipment and the New Radio front-end), to be installed on the vessel.

As for the user equipment, commercial 5G smartphones will be used.

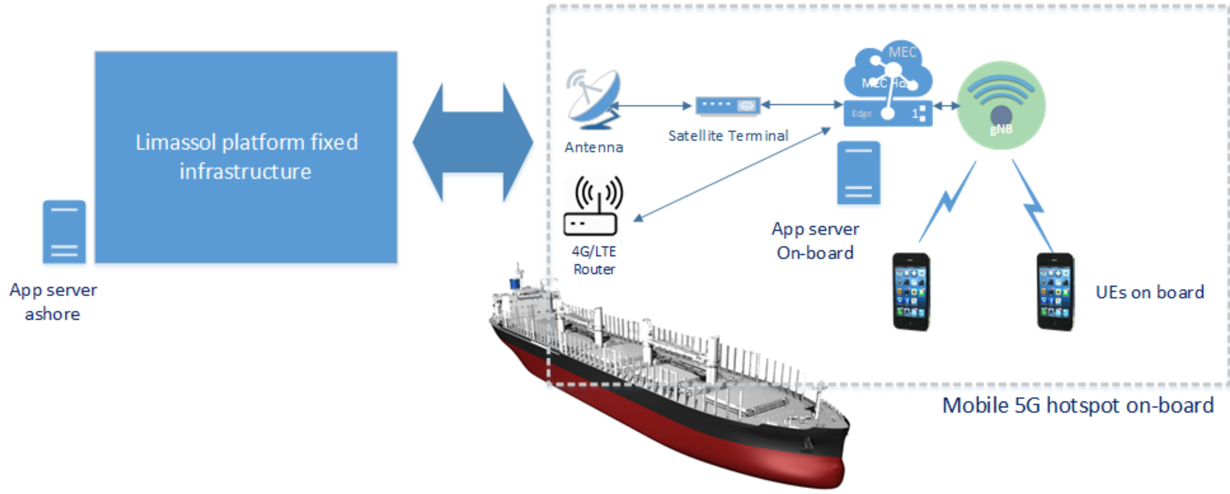

Figure 15. Configuration for the maritime communications scenario

3.1.2. UC2: 5G Rural applications

The use case targets the provision of 5G connectivity in rural (or underserved) areas. Being a key enabler in those areas, IoT services are offered at the top of the infrastructure created by the composition of the two aforementioned backhaul networks, i.e., the satellite and the terrestrial.

The first objective that was envisioned for this use case was the integration of Non-3GPP Access network within the 5G infrastructure. This objective was fulfilled during the first phase of the use case, thanks to the integration of the gateway developed within the framework of the INTER-IoT[5] project. This gateway facilitates the integration of several IoT Access Networks and protocols, being modular and customizable. It consists of two parts, a physical one (Physical-GW) and a virtual one (Virtual-GW) communicated via WebSockets over the Limassol infrastructure. The devices that hosted the Physical-GWs had a radio access to communicate with the 4G base station, using S1 interface, and could send data to its virtual counterpart which was deployed within the virtualized infrastructure.

To demonstrate that the solution was successful and could handle typical IoT protocols, the setup was completed with (a) a LoRaWAN extension for the Physical-GW, with a LoRa module to facilitate the communication with LoRaWAN devices, and (b) the development of a set of customized devices. In particular, the setup consisted in two Physical-GW (and their respective virtual ones), one connected to a LoRa device via LoRaWAN Access Network, which acted as a sensor device (temperature, pressure and humidity), and an Arduino device connected via serial that performed actuator operations. The logic for actuating was implemented via a Node-RED service, deployed in the virtualized infrastructure, and that leveraged the APIs of the Virtual-GWs to receive data and send commands.

During Phase 2, commercial LoRa devices were connected and tested. The LoRaWAN extension for the Physical-GW was updated to not just gather data from LoRa devices, but also to send commands through this access network. Besides, the IoT Virtual-GW was containerized in a

[5] https://inter-iot.eu/

VNF to facilitate its handling by the management and orchestrator components. Thus, the creation, deployment and testing of a VNF descriptor for the Virtual-GW and the creation of an NS descriptor to deploy the service by OSM were the main accomplishments for the second period.

The second objective consists in the implementation of IoT 5G edge applications that can be deployed in rural/underserved areas, to demonstrate the use of Open5GENESIS at those cases for facilitating their deployment and experimentation for KPI gathering. This objective has been addressed during Phase 3, with dedicated services and devices. In particular, two applications for precision farming are being developed:

- Smart irrigation.
- Autonomous weed detection and elimination.

The smart irrigation application consists of gathering data for different parts of field crops and combine this information with external sources of data in order to automate and optimise the irrigation of the field. The data collected by the sensors are sent to the IoT gateway by means of LoRaWAN technology, which is then sent to a 5G base station (in this case, the one of the 5G hotspot) and redirected to a server located at the edge or in a cloud facility. This server contains a custom Decision Support System that controls the utilisation of resources. The actuation logic could be either fully configured by the user or aided by sophisticated AI and/or Big Data methods, and may be supported by weather forecasts and other external services.

For implementing this application, two new devices have been developed (see Figure 16). The first one consists in an evolution of the environmental device from Phase 1, including additional sensors for measuring moisture and detecting whether it is raining or not. The second one consists of two elements, an actuator for letting water pass or not through the connected pipes (with an electrovalve), and a flow sensor to have the ability of monitoring whether water is flowing or not.

Figure 16. IoT devices developed for Phase 3

In the virtualized environment, apart from the Virtual-GW and the Node-RED (as business orchestrator engine), an IoT platform, based on FIWARE has been implemented. It is currently composed of four services: *Orion* Context Broker (OCB), which handles all current, updated data from the devices managed by the gateways, data that can be shared via API calls and subscriptions; *Comet* Short Term Historic (STH), which stores historical series of (subscribed) data; JSON agents, for integrating the data from the gateways to the context broker; and *Perseo* Complex Event Processor (CEP), which is monitoring context data and acting over predefined, modifiable rules.

Irrigation intelligence from Node-RED service has been (mostly) shifted towards the CEP, as it is subscribed to changes of data it can response faster. However, Node-RED flows are still useful for several reasons, like for applying middleware logic, for acting as an IoT agent, for adding more gateways and sensors to the platform, to change the irrigation logic from its flows, etc. (the two latter functionalities could be performed via API calls or from a Swagger as well, but from Node-RED interface is easier and faster for non-expert personnel). The following rules are applied:

1. No irrigation performed or rain detected in the last 5 minutes.
2. No rain is expected in the following 3 hours (making use of data from external platforms, gathered periodically via external API Calls and included in the OCB).
3. Temperature and soil humidity (moisture) values are found below the function depicted in Figure 17.
4. The water flow will be checked by the corresponding sensor, informing of an error to the user if there is flow of water when it should not be (or vice versa).
5. The irrigation valve will be closed after 1 minute.

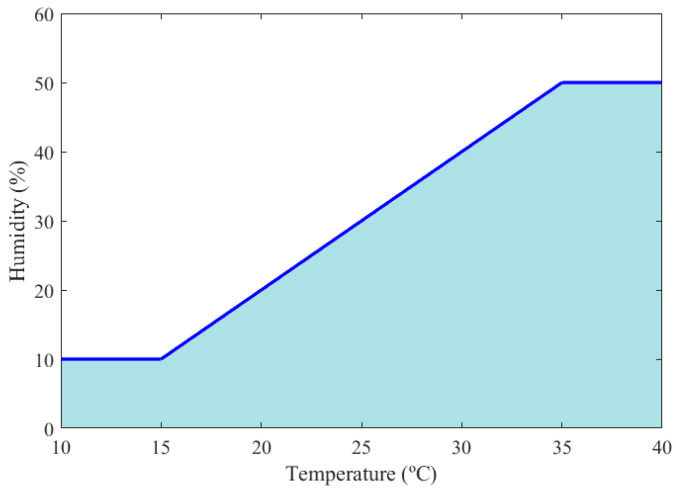

Figure 17. Irrigation depending on the temperature and soil humidity values

Besides, the second application consists in a smart farming application for detecting and eliminating unwanted weed. It considers the processing of video streams, provided by IP cameras, to detect the presence of unwanted weeds in crop fields. The video streams will be sent from the camera to the edge by means of cellular access, where they will be processed in a server. This server will contain an object recognition service, pre-trained to detect weeds among the crops in these streams, using additional technologies such as Deep Learning, OpenCV, and Python. For demonstration purposes, a custom pre-rained model will be used, although it could be trained at the hotspot itself or retrieved from cloud platforms.

The service is based on three main components: (1) a video client, installed in a user device with 5G connectivity, which can be custom (e.g., for a raspberry with a camera and a 5G Hat attached) or available by third parties (e.g., Android application for mobile phones); (2) a weed detection service with a trained AI model, deployable in the virtualized environment, for analysing the frames of the video stream in real time; (3) and a notification server, which receives the image with the outcomes of the weed detection server and informs to the connected clients (via web or mobile phone application).

The increased bandwidth and reduced latencies that 5G brings are very interesting for this application. On the one hand, higher bandwidth allows higher image resolution, which improves the accuracy of image detection algorithms. On the other hand, lower latencies allow much faster sweeps of the field, which in turn reduces the carbon footprint since the dedicated equipment (robot, drone, GPU, virtualized services, etc.) require less operating time for accomplishing the objective. Besides, local breakout configurations at the edge alongside reconfiguration capabilities offered by 5G enhance flexibility, latency and privacy aspects of the whole solution.

The key component is the weed detection service. It has been implemented considering Tensorflow as AI platform, SSD Inception v2 Deep neural network as AI model, and openCV for managing the video frames, among other required libraries. Once the application starts, a connection is established (either by the client or by the server, both options have been used) and either video or image frames are sent to the server and analyzed via this service. In case weed is found, a notification is sent to the clients connected to the notification server. In a market-ready deployment, the actual actuation depends on the target weed. For instance, for specific unwanted plants that grow in localized regions of a crop field (e.g., look examples), video can be captured via drones and a notified to the responsible, who can remove the plants or apply herbicide manually. In other cases, where unwanted weed is available within the whole field, it is more optimal to integrate the cameras with an autonomous robot that travels through it and applies herbicide where needed.

4. Limassol Platform Evolution in 5GENESIS

4.1. Evolution timeline

As with all platforms, the Limassol platform follows the general functional architecture of 5GENESIS, as defined in Deliverable D2.2. [2]

Figure 18 below visualizes the per-phase evolution of the implementation of the 5GENESIS architecture in the Limassol platform. It shows the functional blocks implemented and integrated in Phases 1 & 2, as well as the integrations and upgrades which took place during Phase 3.

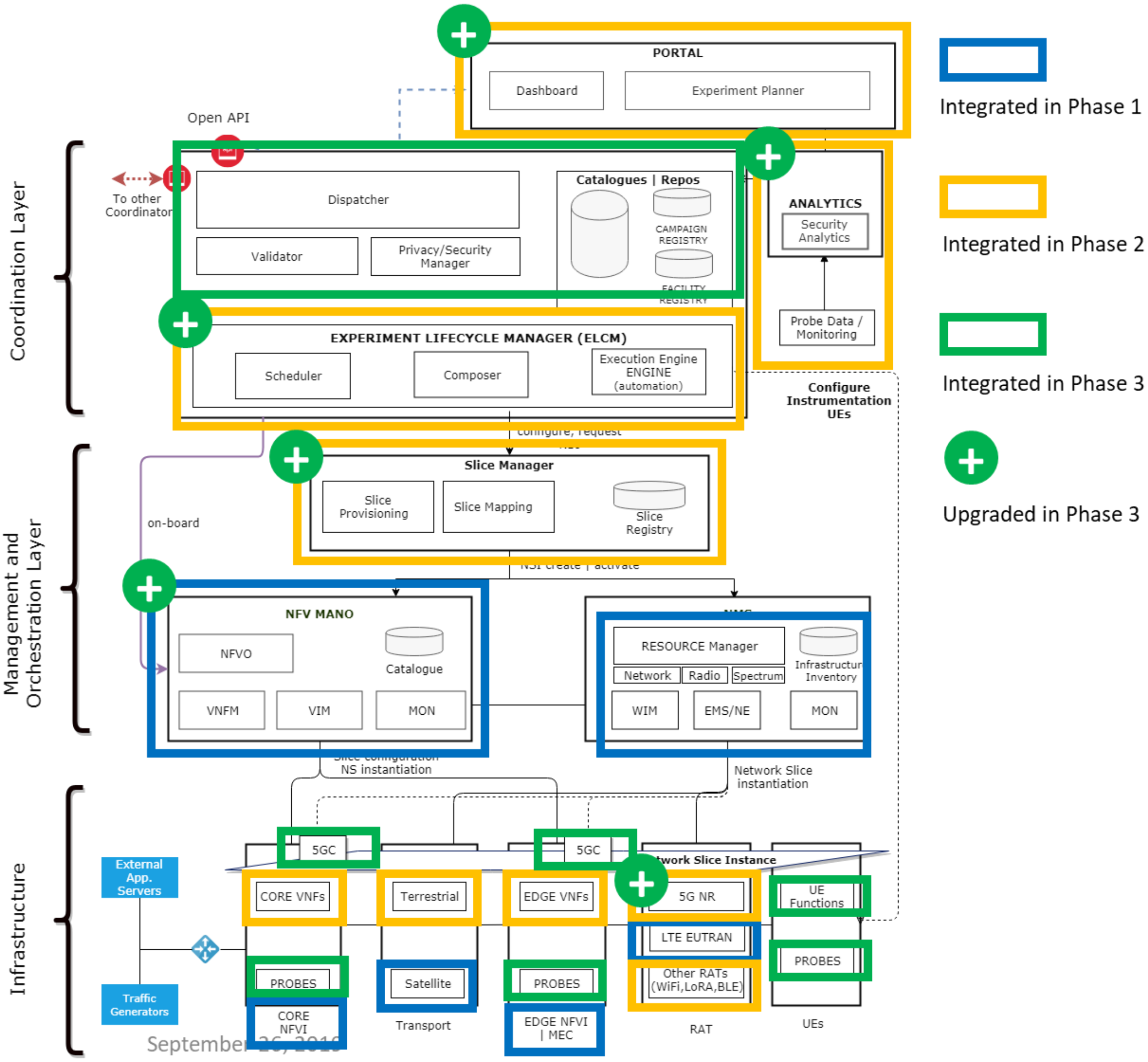

Figure 18. Per-phase evolution of the Limassol platform

The aim of Phase 1 was to deliver an end-to-end 4G network which utilizes satellite backhauling and is NFV/SDN capable, also featuring edge computing capabilities. To that end, Phase 1 focused on the deployment of the 4G core and radio components (EPC and EUTRAN), as well as the satellite backhaul network and the NFV MANO and Infrastructure – including the edge computing platform. Phase 1 also deployed a first version of the IoT use case.

The aim of Phase 2 was: i) to upgrade from 4G to 5G, by switching from EUTRAN to a first version of 5GNR; ii) to integrate the secondary backhaul (terrestrial) and demonstrate link aggregation via the appropriate VNFs at the core and edge and iii) demonstrate the basic coordination layer capabilities, allowing automated experiment execution, configured using the Portal. Phase 2 also demonstrates slicing features, using an early version of the Slice Manager and further upgrades/refines the IoT use case. Certain aspects of spectrum management were also integrated. Last, the integration of the monitoring and analytics components, as well as the Security Analytics framework were done in this phase.

Finally, the aim of Phase 3 was to complete the implementation of the 5GENESIS architecture on its whole and to deliver a full-stack, end-to-end 5G experimental testbed with all the added-value features associated with the Limassol platform specificities. Phase 3 further evolved the 5G configuration, by employing fully functional 5G NR with commercial terminals and 5G core functions and upgraded the upper layer (Open5GENESIS) components with their latest, feature-rich versions.

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

- ✓ 5G NR support evolution and stand-alone (SA) support
- ✓ Integration of the 5G mobile hotspot
- ✓ Integration of virtualised 5GC based on Open5GS and satellite 5G backhauling
- ✓ Study and implementation of mechanisms for satellite network slicing
- ✓ Upgrade of MANO to support Docker/Kubernetes
- ✓ Upgrade of Open5Genesis and Security Analytics to Release B
- ✓ Evolution of spectrum allocation mechanisms
- ✓ UC-specific developments (implementation of UC applications and integration with experimentation framework)

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

4.2. Phase 3 accomplishments

4.2.1. 5G NR support evolution and SA support

As stated in Sec. 2.3.1.4. during Phase 3 the Limassol platform was enhanced with the Amarisoft Amari Callbox Classic (CBC) product, which implements a “network-in-a-box” solution, integrating within a single compute node SDR-based radio as well as core. This enabled full 5G NR support in the Limassol platform and compatibility with commercial UEs. The table below summarises the key 5G NR parameters which were mostly used for the integration and tests.

Table 3. 5G NR configuration in the Limassol platform

Parameter	Value
3GPP release	Rel. 15
Bandwidth	50 MHz
Downlink MIMO config	2x2
Duplex mode	TDD
Network mode	NSA (Option 3), SA (Option 2)
Band	n78 (3490 MHz)
Service type	eMBB

The table below shows the commercial UEs which have been successfully tested with the gNB in the Limassol platform.

Table 4. Tested 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
Realme 7 5G	MediaTek MT6853 Dimensity 800U 5G	NSA & SA

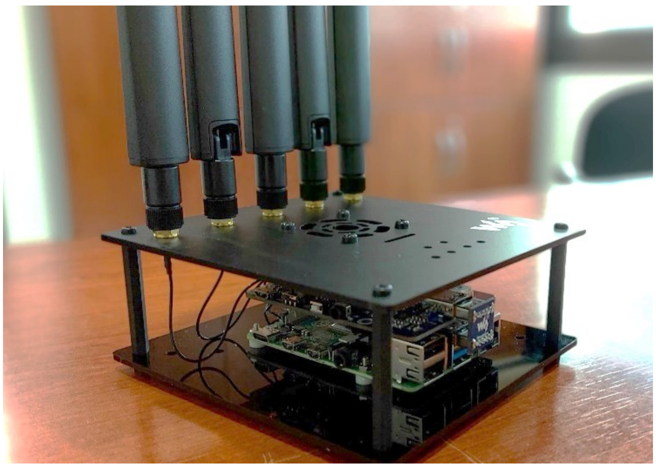

Figure 19. Waveshare SIM8200EA-M2 5G Hat on Raspberry Pi 4, operating in both 5G NSA and SA

4.2.2. Integration of 5G mobile hotspot

For portability and demonstration purposes, specific elements of the Limassol platform were mount in a portable 7U rack (flight case). These are:

- Amarisoft Callbox Classic gNB and integrated core
- Dell edge gateway 5000 (edge node)
- Samsung Galaxy Tab 3 tablet
- Gigabit Ethernet switch

The 7U flight case features rugged wheels, a telescopic handle and front/back detachable cover to facilitate transportation. Several modifications had to be made during the mounting to ensure a compact and secure installation, since none of the above-mentioned components is actually rack-mount.

The integration of these components implements an independent, full stack 5G mobile network which can be easily transported for demonstration purposes. Indoor omni antennas are used, which, combined with the built-in RF front-end of the gNB, enable 5G communication either indoors or outdoors in several tens of meters, always depending on the conditions. The mobile hotspot connects to the platform core in Limassol via either a terrestrial or satellite backhaul.

Figure 20 below shows the assembled 5G mobile hotspot in operation, where the tablet screen presents the Grafana dashboard of the monitoring framework (see Sec. 4.2.6), showing RAN and compute node metrics in real time.

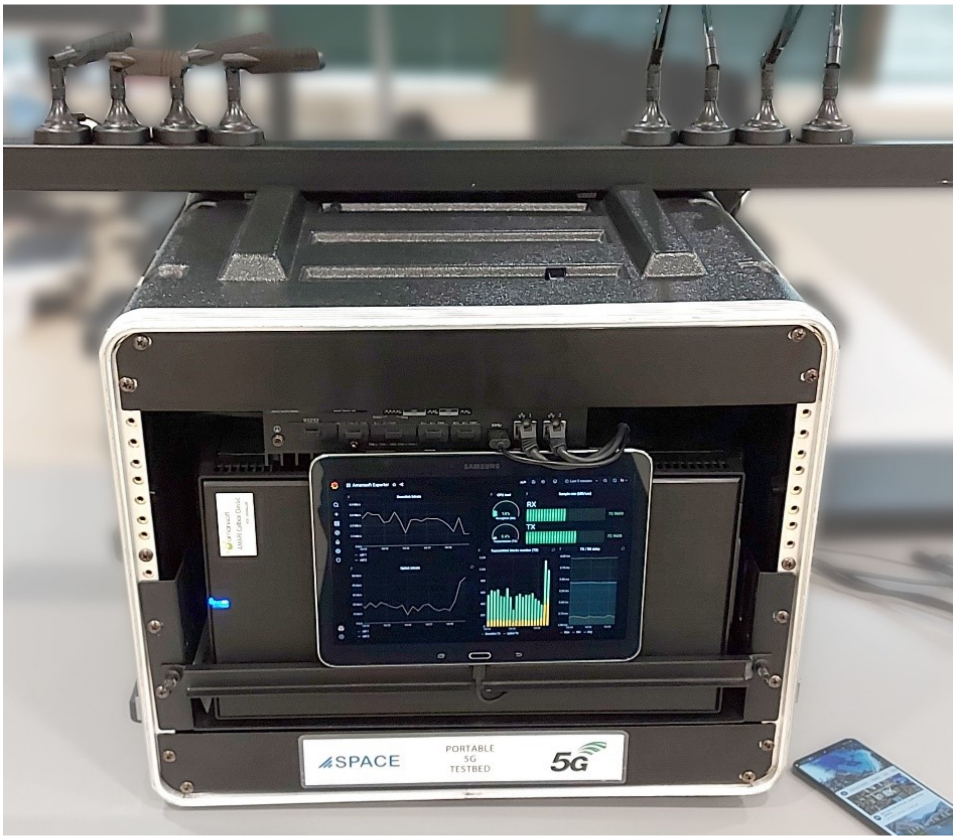

Figure 20. Integrated 5G mobile hotspot

4.2.3. Open5GS integration and satellite backhauling

Another very important achievement during Phase 3 has been the integration of Open5GS (see Sec. 2.3.1.4.). Open5GS is a C-language Open Source implementation for 5G Core (Rel.16) as well as EPC. Open5GS implements all 5G Core functions as discrete services, each of which can be deployed in a different host or VM. In our deployment, we deployed all functions of the core in a single VM, with the characteristics shown in the table below. The VM was initially deployed in an Oracle Virtualbox test environment for testing and configuration and then it was re-deployed in the OpenStack infrastructure of the Limassol platform.

Table 5. Open5GS VM deployment specs

Open5GS version	2.2.6
Underlying OS	Ubuntu 20.04 LTS (Focal Fossa), 64-bit
vCPUs	2
RAM	4GB
HDD	50 GB
Network interfaces	eth1: to gNB (N1, N2, N3) eth2: to data network (N6) eth3: management interface

Open5GS supports both SA and NSA operations. In our tests, we restricted to SA mode. In order to integrate it with the rest of the platform, we disabled the internal 5G core functions of the Amari Callbox platform and we configured the gNB to directly connect to the external Open5GS core. Under this configuration, Open5GS was successfully tested with the commercial UEs mentioned in Sec. 4.2.1.

Apart from the proper setup of the service IP addresses and the PLMN ID, no other special tuning was necessary in the Open5GS configuration. We used the GUI provided (Figure 21) to configure the subscriber parameters.

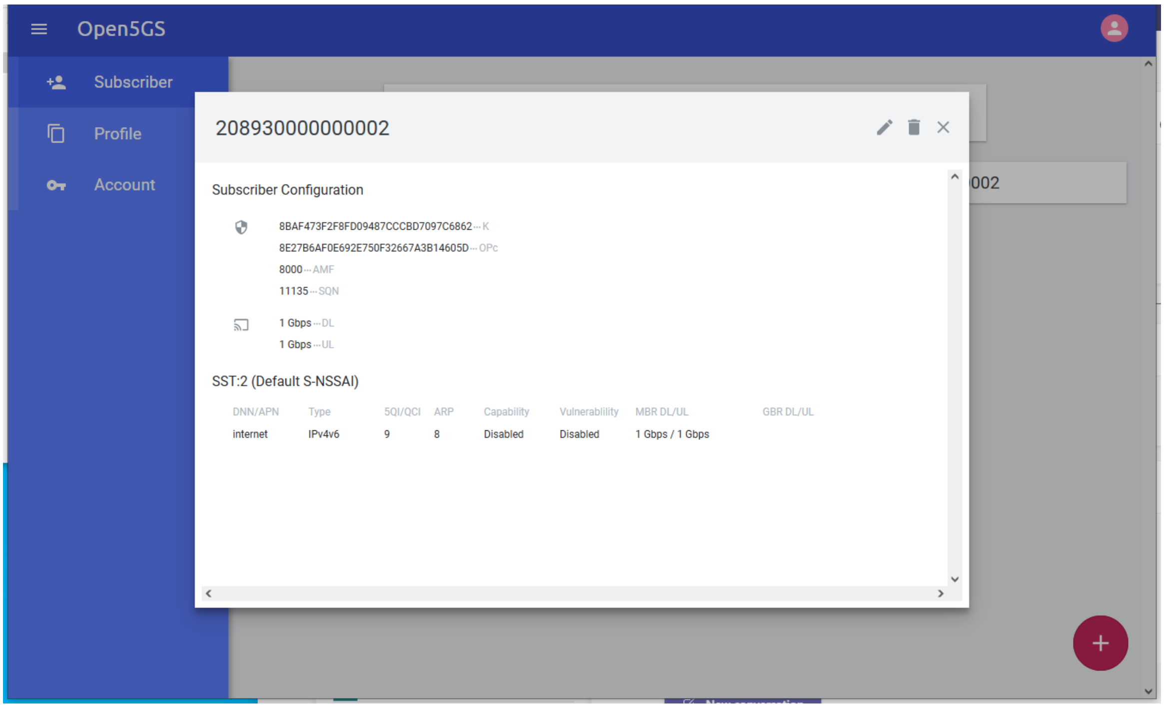

Figure 21. Subscriber configuration using the Open5GS GUI

Figure 22 below shows the AMF (Access and Mobility Management Function) log of the Open5GS reflecting the UE registration (Waveshare 5G Hat) in 5G SA mode.

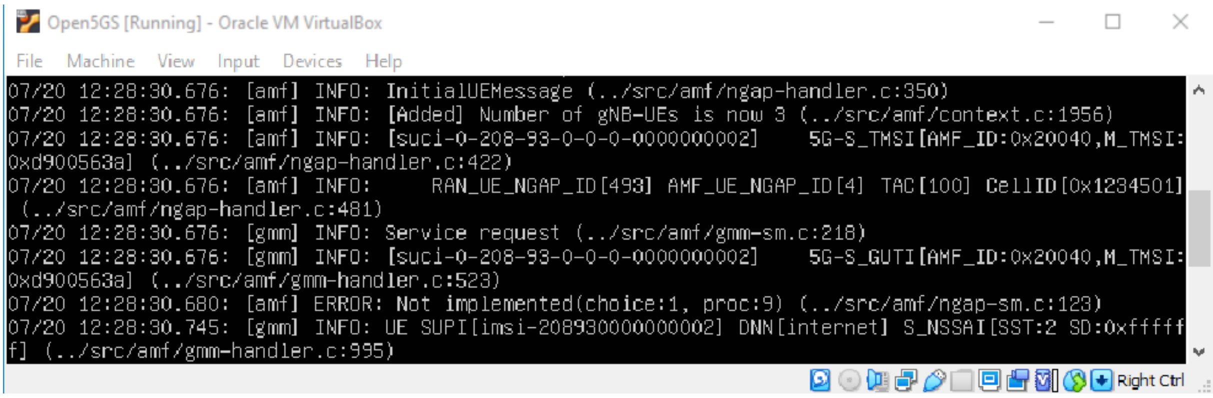

Figure 22. UE registration in Open5GS (AMF log)

The adoption of Open5GS allows to fully virtualise the 5G Core and deploy the 5GC functions at any point of the infrastructure. We eventually deployed the 5GC functions in the core data centre of the platform (connected to the satellite gateway), while the gNB was fed by the satellite terminal. In other words, the satellite link was used to convey the N1, N2 and N3 interfaces. Figure 23 shows the different 5G network functions and their mapping to specific components in the 5G SA satellite backhauling setup which was implemented in the Limassol platform.

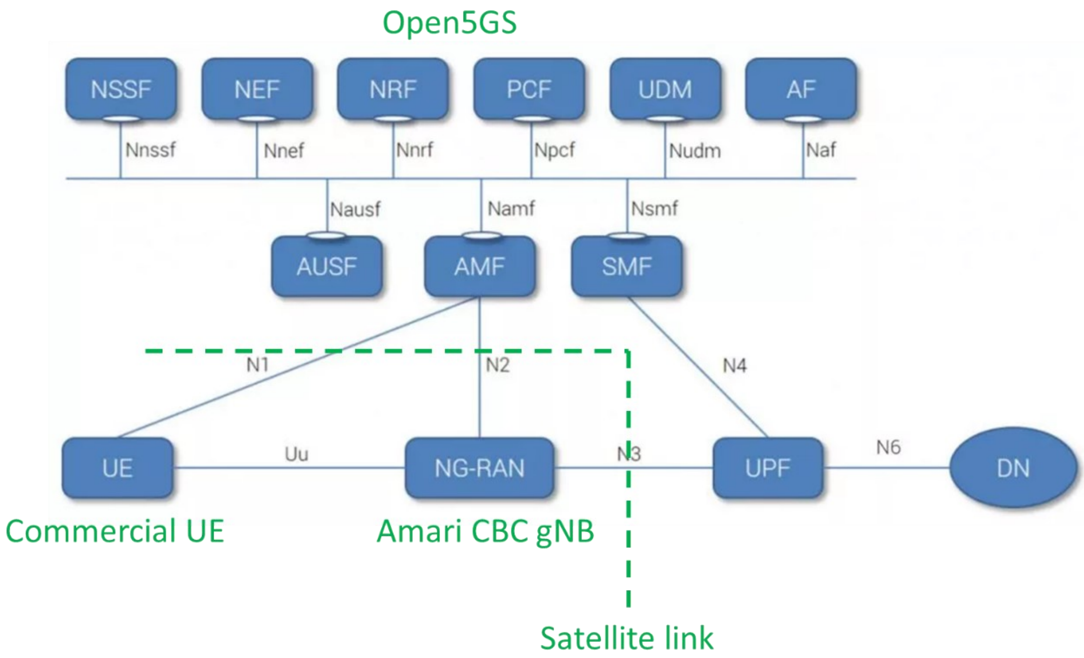

Figure 23. 5G network functions and assignment to specific components in the 5G SA satellite backhauling configuration

4.2.4. Satellite network slicing

Concept

The Satellite connection supporting Network Slicing is a transport solution for RAN and AN (access network) applications serving multiple 5G verticals.

The Network Slicing over Satellite solution will provide a service perspective, the 5G network (5G-NR and 5GC) is designed to support with a PDU Connectivity Service, with different QoS Flows, in a service that provides exchange of Protocol Data Units (PDUs) such as IPv4, IPv6, Ethernet or Unstructured data packets between a UE and an external data network reachable from the 5GC.

The PDU Connectivity Service is realized via the establishment of one or multiple PDU sessions, which are the logical associations created between the 5GC and the UE to handle the data packet exchanges.

Static implementation of slicing of the satellite network

As proposed in WP3 (D3.1), network slicing over the satellite can be enabled by supporting 5GQI/QoS with VLAN tagging.

Our interpretation of the network slicing standards in a satellite environment/ecosystem allowed us to identify that the service request starts from the 5G UE with a key point being the S-NSSAI: Single Network Slice Selection Assistance Information. S-NSSAI is an identifier for a Network Slice across the 5GC, 5G-RAN and the UE.

This request from the UE expresses the 5G vertical it requests specifically. An S-NSSAI consists of Slice/Service Type (SST) and Slice Differentiator (SD). Table 6 below shows which slice each SST value represents (source 3GPP TS 23.501 V16.6.0 table 5.15.2.2-1).

Table 6. Standardised SST values

SST value	Slice service type	Characteristics
1	eMBB	Slice suitable for the handling of 5G enhanced mobile broadband
2	URLLC	Slice suitable for the handling of ultra-reliable low-latency communication
3	mMTC	Slice suitable for the handling of massive IoT (massive machine type communication)
4	V2X	Slice suitable for the handling of vehicle to everything services

A S-NSSAI is used by the UE in the access network in the PLMN that the S-NSSAI is associated with Initial UE Message Registration request NSSAI/SST/SD.

The PDU session (transport services session) activated between a UE and a 5GC/PLMN network is associated with one and only one S-NSSAI so that the corresponding traffic flows (denoted as QoS flows in the 5G network) are handled according to whatever behaviour is pre-established for the selected S-NSSAI.

N1/N2 trace analysis

An N1/N2 trace of our 5G-SA satellite transport network (5G-NR – 5GC), in the initial context setup request S-NSSAI, shows an SST value of 1 which represents a request for an eMBB slice, see trace in Figure 24 below:

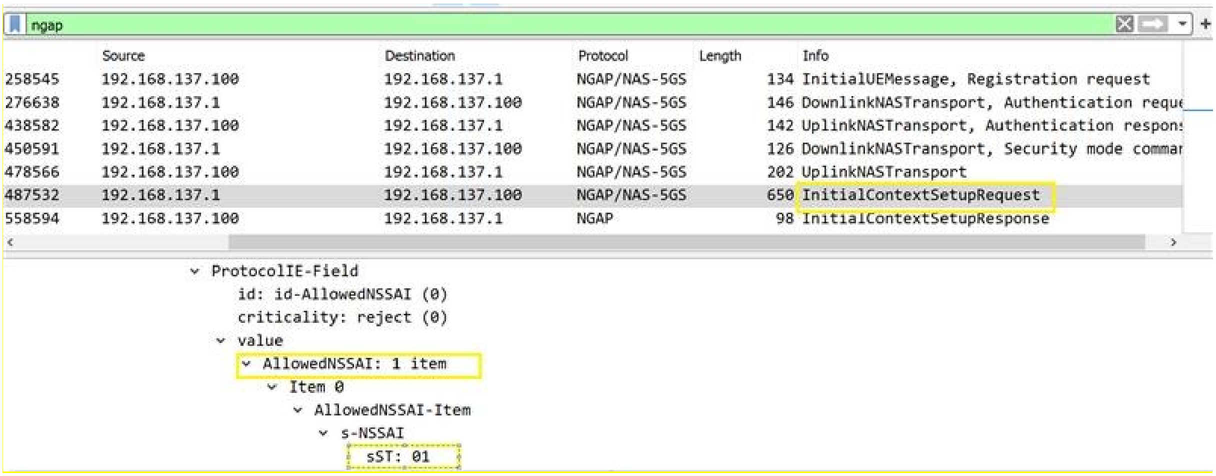

Figure 24. Slice request with SST=1

The SST value was then changed to SST=2 thereby requesting a URLLC slice. This was captured on the N1/N2 as shown in the trace on Figure 25 below:

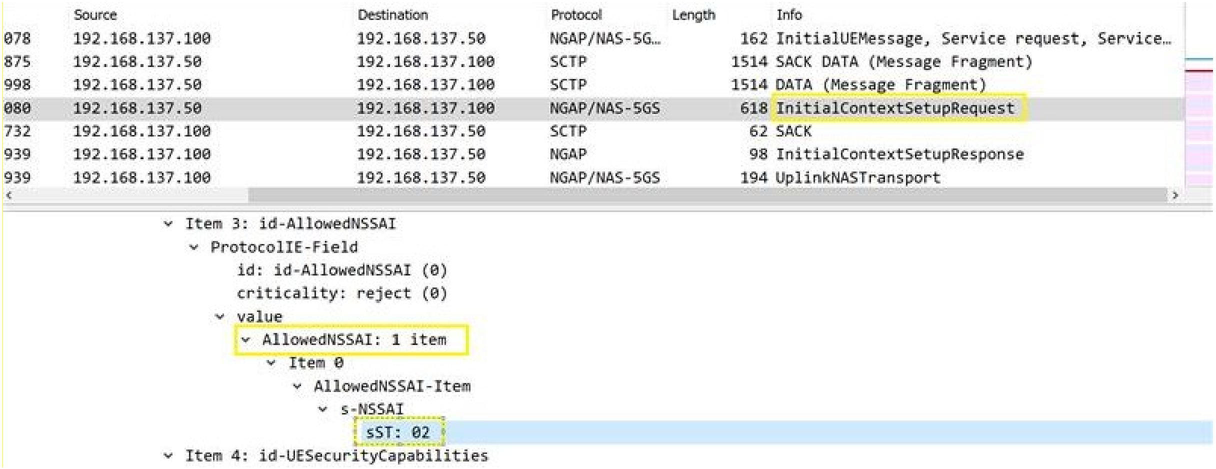

Figure 25. Slice request with SST=2

The UE is then able to request different slices, potentially serving multiple verticals. The satellite terminal is able to detect the DCSP value (IP) or VLAN tag associated with the CST level. The link between CST and these are described in 3GPP TS 23.501 V16.6.0 sections 5.7.6.2 (for IP connection) and section 5.7.6.3 for L2 satellite transport connections. This is further supported by section 5.8.2.4.2 that introduces traffic detection information roles.

There are a number of analyses looking at a more detailed mapping between 5G and IP, for example a paper by Nokia[6] "5QI to IP DSCP Mapping"; there is also a draft rfc[7] on Diffserv to QCI Mapping. The key aspect is that the 5G quality requirements can be mirrored at L3/L2 and thus managed by the satellite transport link.

The Amarisoft gNB used in the platform does not support URLLC slices (or MMTC) so is unable to set the CST value.

No traces have yet to made of the related user plane traffic (N3) – this will be looked at in follow-up work.

User plane functions

Where 5G network slices terminate on different user plane functions (UPFs – as is usual) then it is easy for the satellite network to provide separation (service and addressing) between these slices. The UPF IP address (or MAC address) being used to assign the data packet to the correct satellite VLAN.

The 5GC Service Based Architecture requires that the necessary functions are as close as possible to the edge of the network in order to support the application capabilities.

[6] https://www.researchgate.net/publication/344287398_5G_QoS_5QI_to_IP_DSCP_Mapping - 5G QoS: 5QI to IP DSCP Mapping, September 2020, Conference: Nokia White Paper

[7] https://tools.ietf.org/id/draft-henry-tsvwg-diffserv-to-qci-03.html, February 2020, Diffserv to QCI Mapping, draft-henry-tsvwg-diffserv-to-qci-03

Therefore, for every 5G vertical represented by the requested UE SST value, a CN function would need to be instantiated at the edge of the network, see Figure 26.

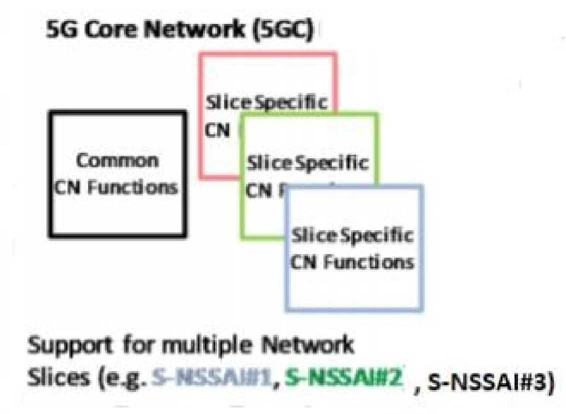

Figure 26. Common and slice-specific NFs

In addition, a NSSF (Network Slice Selection Function) is needed to provide the response of allowed or denied service, see Figure 27.

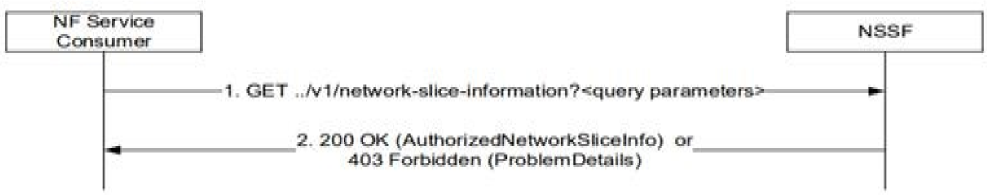

Figure 27. Interaction with NSSF

Technical approach

Slicing over satcom is enabled by Layer 2 over satellite solution from Avanti. This solution supports pure L2oS, point-to-multipoint 802.11 QnQ tags, MAC learning and broadcast domain across the space segment, including support of higher layer protocols.

The slice types will be mapped to a specific UE PDU/QoS Flow/VLAN 802.1q C-Tag and delivered to the 5GC relevant network function. "Common CN functions" and also "Specific CN Functions" will be available so that markings can be unique for the specific but the same for the common ones, with support for the N3 (UP) traffic and also transporting the N1 and N2 (CP) data between UE/RAN and the AMF.

An example of the mapped parameters can be seen in Figure 28.

Common Functions = VLAN100, DSCP CS7
eMBB Slice = VLAN 1 DSCP CS6, EF VLAN Tag 1 802.1q SLA 100/20
URLLC Slice = VLAN 2 DSCP CS2, CS5 VLAN Tag 2 802.1q SLA 50/50
mMTC Slice = VLAN 3 DSCP CS3, CS4 VLAN Tag 3 802.1q SLA 10/10

Figure 28. Example of parameters mapping

The Service Based Architecture (SBA) will support Control Plane User Plane Separation (CUPS) and Network Functions (NF) instantiation. The functions may reside locally at the edge or across the satellite. A dedicated UPF function for each slice would be provided. A common function VLAN would be used for the Control Plane (CP) functions (AMF-SMF). Then the exclusively provided slice capabilities would be transported by the dedicated VLAN as shown in the previous example.

The satellite service setup in the Limassol 5G platform is based on a Layer 3 solution. To showcase full slicing of the satellite network, an L2 service would need to be setup and cannot be implemented in the course of this project. A verified L2oS solution for pre-5G connectivity is available on a different VSAT network hub vendor system so the addition of static 5G slice support is expected to be relatively easy.

4.2.5. Docker/Kubernetes support at the edge

In phase 3, Kubernetes was installed at the Edge site, as a lighter VIM alternative, resource effective solution for the compute node. Components of the monitoring stack and IoT applications are running as Docker containers organized in PODs, managed by Kubernetes. Since we have a single node Kubernetes installation and to avoid redundancy, we decided to proceed with standalone mode, which includes only the kubelet service acting as the node agent and omits the Kubernetes control plane services (etcd, scheduler, kube-manager, cloud-manager). Kubelet agent ensures that defined containers are always running and healthy.

Current set up allows to leverage Kubernetes built in functionalities like managing containers as PODs, use of CNI network plugins and the supported Kubernetes volumes for storage. CNI network plugins provide container connectivity internally and internet access though NAT. Required services are described in POD.yml files and Docker CLI is used for interacting with containers.

```
NAMES                                                                    COMMAND                  STATUS
k8s_gotify_weed-detection-dell-edge_default_e98ce34588f06833acc20c16e5dbaf15_12   "./gotify-app"           Up 30 minutes
k8s_nginx_weed-detection-dell-edge_default_e98ce34588f06833acc20c16e5dbaf15_12    "/docker-entrypoint.…"   Up 30 minutes
k8s_grafana_prom-dell-edge_default_6a417e769d32414b3f22fa6daa44d10a_8             "/run.sh"                Up 30 minutes
k8s_tensorflow_weed-det-dell-edge_default_1b31dc0fb849076aaacab096d896015f_12     "python -u api.py"       Up 30 minutes
k8s_prometheus_prom-dell-edge_default_6a417e769d32414b3f22fa6daa44d10a_8          "/bin/prometheus --c…"   Up 30 minutes
k8s_POD_prom-dell-edge_default_6a417e769d32414b3f22fa6daa44d10a_8                 "/pause"                 Up 30 minutes
k8s_POD_weed-det-dell-edge_default_1b31dc0fb849076aaacab096d896015f_12            "/pause"                 Up 30 minutes
k8s_POD_weed-detection-dell-edge_default_e98ce34588f06833acc20c16e5dbaf15_12      "/pause"                 Up 30 minutes
localadmin@dell-edge:~$
```

Figure 29. Apps running as containers at Kubernetes edge node

```
apiVersion: v1
kind: Pod
metadata:
  name: weed-detection
spec:
  containers:
  - name: nginx
    image: nginx:latest
    imagePullPolicy: IfNotPresent
    ports:
    - containerPort: 80
      hostPort: 80
      protocol: TCP
    - containerPort: 443
      hostPort: 443
      protocol: TCP
    volumeMounts:
    - name: nginx-conf
      mountPath: /etc/nginx/nginx.conf
  - name: gotify
    image: gotify/server
    imagePullPolicy: IfNotPresent
    ports:
    - containerPort: 80
      hostPort: 5001
    volumeMounts:
    - name: gotify-data
      mountPath: /app/data
    env:
    - name: GOTIFY_DEFAULTUSER_PASS
      value: "custom"
    - name: GOTIFY_SERVER_PORT
      value: "80"
    - name: GOTIFY_SERVER_LISTENADDR
      value:
    - name: GOTIFY_SERVER_SSL_ENABLED
      value: "false"
    - name: GOTIFY_SERVER_SSL_REDIRECTTOHTTPS
      value: "true"
    - name: GOTIFY_SERVER_SSL_LISTENADDR
```

Figure 30. POD yaml including services running as containers

4.2.6. Integration of Monitoring framework

The Monitoring Framework is based on a set of underlying components deployed at edge and core cloud. Metrics are collected using Prometheus exporters at the edge site and streamed by Prometheus server to Influx DB located at the core DC. Data are then extracted from Influx DB and processed by the deep learning model with results visualized under Grafana dashboard.

The figure below depicts the integration of the monitoring framework which monitors Amarisoft Callbox 5G RAN, Edge site managed by Kubernetes and Core DC operated by Openstack.

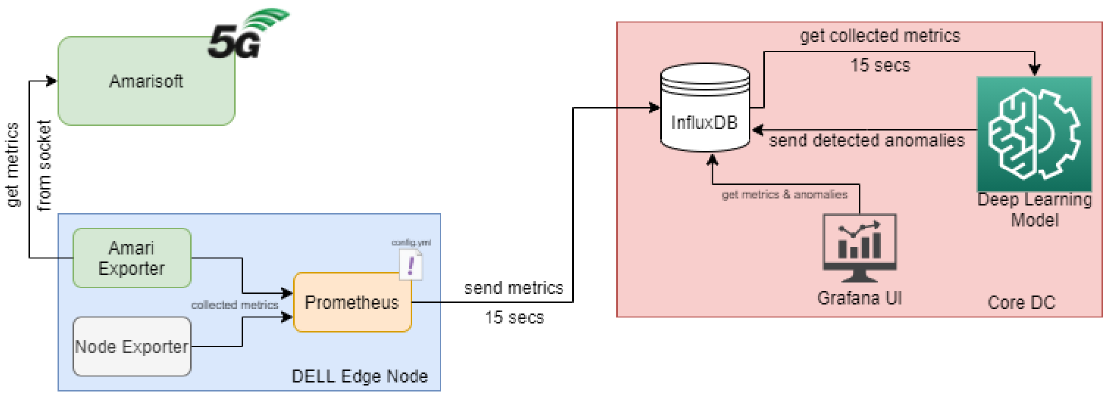

Figure 31. RAN and Edge node metrics flow

The Prometheus server located at the edge node is responsible for metrics collection by scraping registered targets and publishing metric data to Influx HTTP API using remote write functionality. All required configurations including targets, data sources, scraping interval are included in Prometheus.yml file.

```
# Remote write configuration for Influx
remote_write:
  - url: "http://10.10.x.x:8086/api/v1/prom/write?db=prometheus_db&u=user&p=passwd"
scrape_configs:
  - job_name: 'amari_exporter'
    scrape_interval: 15s
    static_configs:
      - targets: ["localhost:3333"]
  - job_name: 'node_exporter_dellEdge'
    scrape_interval: 15s
    static_configs:
      - targets: ["localhost:9100"]
    metric_relabel_configs:
      - source_labels: [__name__]
        regex: 'node_cpu_seconds_total|node_memory_Buffers_bytes|node_memory_Cached_bytes|node_memory_Mem.+|node
        action: keep
```

Figure 32. Prometheus yaml config

At the edge node, data collection is implemented using a Node exporter. Once installed in a Linux machine, the Node exporter collects system metrics grouped by CPU, memory, network, filesystem and exposes them through an API. An exporter tailored to the Amarisoft gNB was developed in the frame of the project and is also installed, collecting RAN metrics exposed by Amarisoft API. These include downlink/uplink bitrate, RX/TX CPU usage and RX-TX delay.

tx_cpu_time	
time-series	time (*)
tag	__name__
tag	instance
tag	job
field	value (*)

rx_cpu_time	
time-series	time (*)
tag	__name__
tag	instance
tag	job
field	value (*)

dl_bitrate	
time-series	time (*)
tag	__name__
tag	cellId (*)
tag	instance
tag	job
field	value (*)

ul_bitrate	
time-series	time (*)
tag	__name__
tag	cellId (*)
tag	instance
tag	job
field	value (*)

node_cpu_seconds_total	
time-series	time (*)
tag	__name__
tag	cpu (*)
tag	instance
tag	job
tag	mode (*)
field	value (*)

node_memory_MemFree_bytes	
time-series	time (*)
tag	__name__
tag	instance
tag	job
field	value (*)

node_network_receive_bytes_total	
time-series	time (*)
tag	__name__
tag	device (*)
tag	instance
tag	job
field	value (*)

node_network_transmit_bytes_total	
time-series	time (*)
tag	__name__
tag	device (*)
tag	instance
tag	job
field	value (*)

Figure 33. Influx DB tables for RAN metrics

4.2.7. 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 NFVO (OSM), Influx DB, Grafana and testing probes were not affected.

Release B components include:

- 5Genesis Portal
- 5Genesis Experiment Lifecycle Manager (ELCM)
- Slice Manager
- Security Framework (see Sec. 4.2.7)
- Dispatcher
- MONROE VN[7]

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 in the Core Data Center, operated by Openstack VIM. Testing probes (ping/ iperf agent and MONROE) are also running inside VMs bundled with an agent responsible for communication with OpenTap[8].

The Dispatcher is now added to the experiment execution flow, by adding a layer of authentication between the Portal requests and the ELCM. The Security Framework (see Sec. 4.2.7) is responsible for monitoring collected metrics identifying possible anomalies. The Monroe VN can be called from OpenTap to execute ping or other tests. Another upgrade of the platform is the migration of OpenTap in Linux. This allows Portal, ELCM, OpenTap services to be bundled inside a VM operated by Openstack.

The updated version of the Portal is enhanced with VNF onboarding option on selected cloud location (edge or core). An overview of the components interfaces is depicted below:

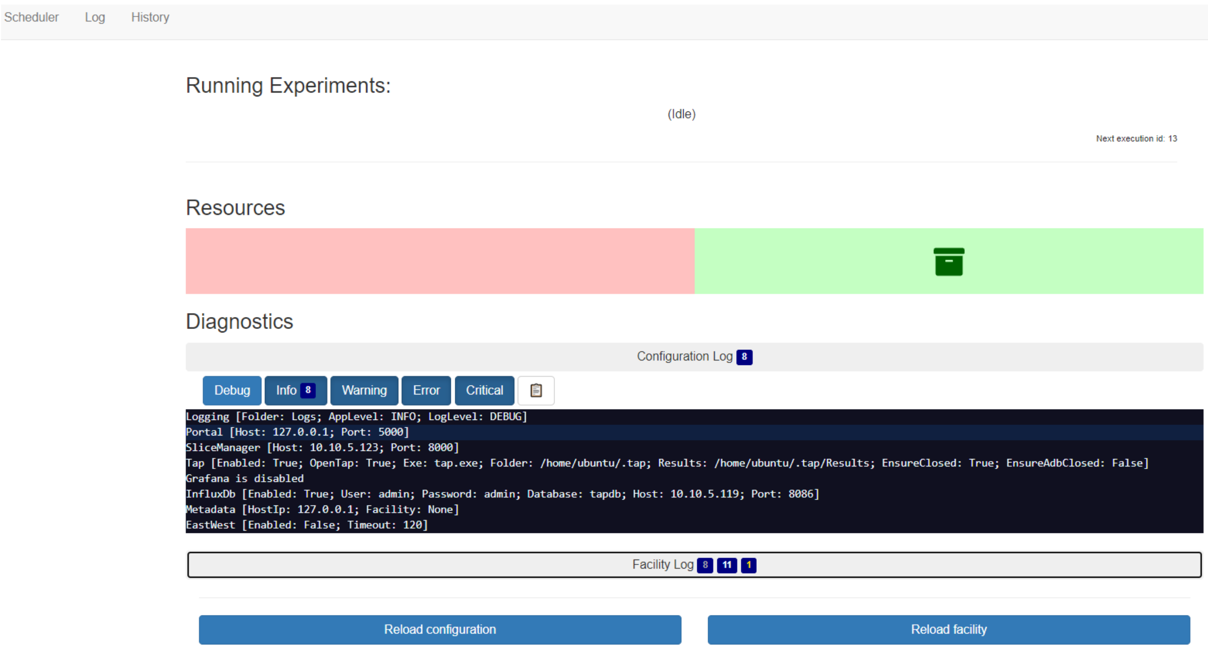

Figure 34. ELCM Dashboard

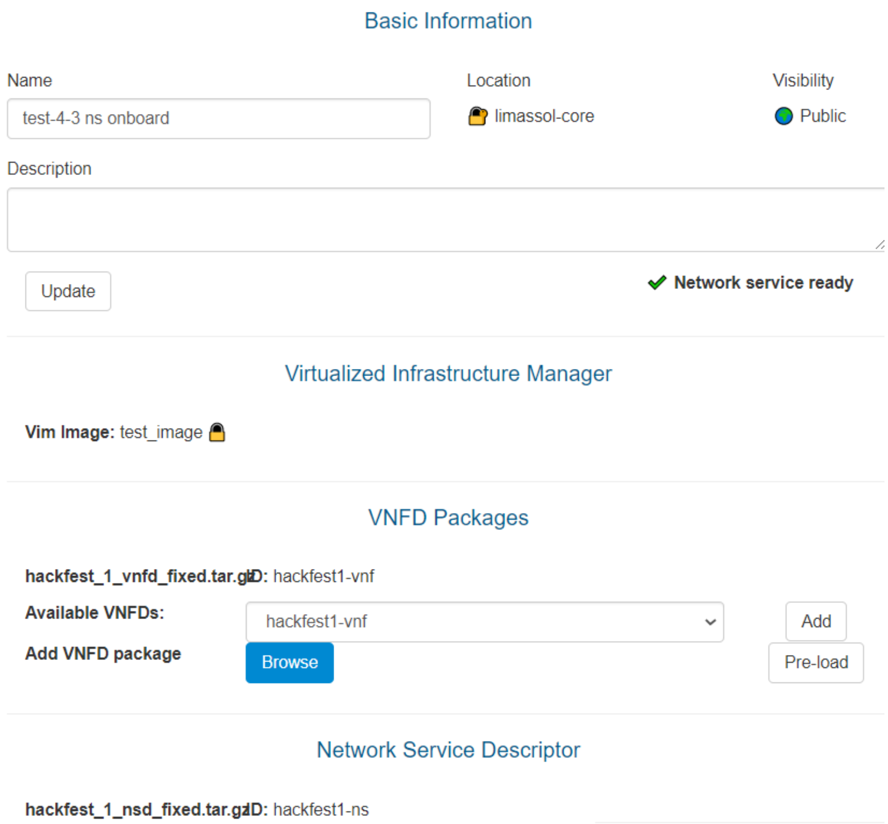

Figure 35. VNF onboarding through Portal UI

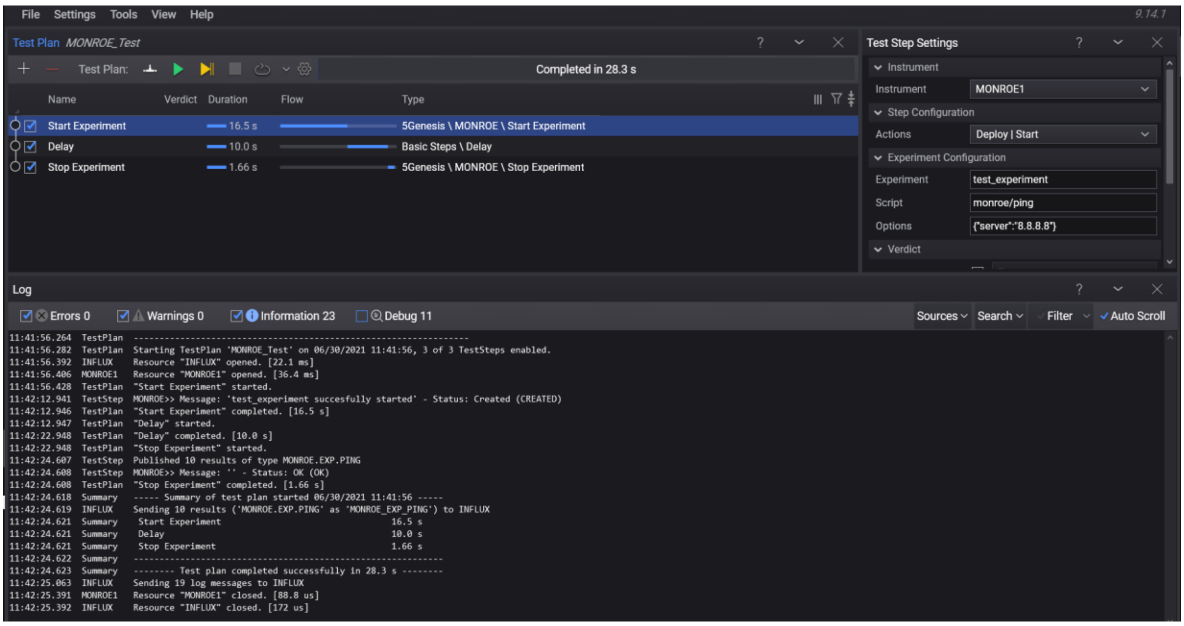

Figure 36. Monroe test plan from TAP GUI

4.2.8. Integration of 5G Security Analytics Release B

During Phase 3, the 5G Security Analytics framework, deployed in the Limassol platform, was further enhanced and upgraded to include all the features of the Release B of the framework.

This upgrade focused on two aspects. First, the flow processing pipeline was extended to include anomaly detection based on an Autoencoder algorithm. Second, the newly developed metrics processing pipeline was integrated. This was connected to the monitoring framework (based on the Prometheus monitoring system, see Sec. 4.2.6). Bespoke exporters (collectors) were deployed to collect metrics from the 5G RAN and the 5G edge computing infrastructure. The ML processing engine, based on Autoencoder/LSTM (Long Short-Term Memory) model, was trained using data from "normal" traffic and emulated security incidents, collected in the Limassol platform.

The results of the algorithm were integrated in the Grafana dashboard, which now combines the monitoring metrics with the detected anomalies, so that the platform operator can have a holistic view of the status of the infrastructure (see Figure 37)

Finally, extensive tests were carried out to evaluate the performance of both pipelines under emulated security incident scenarios, with quite promising results.

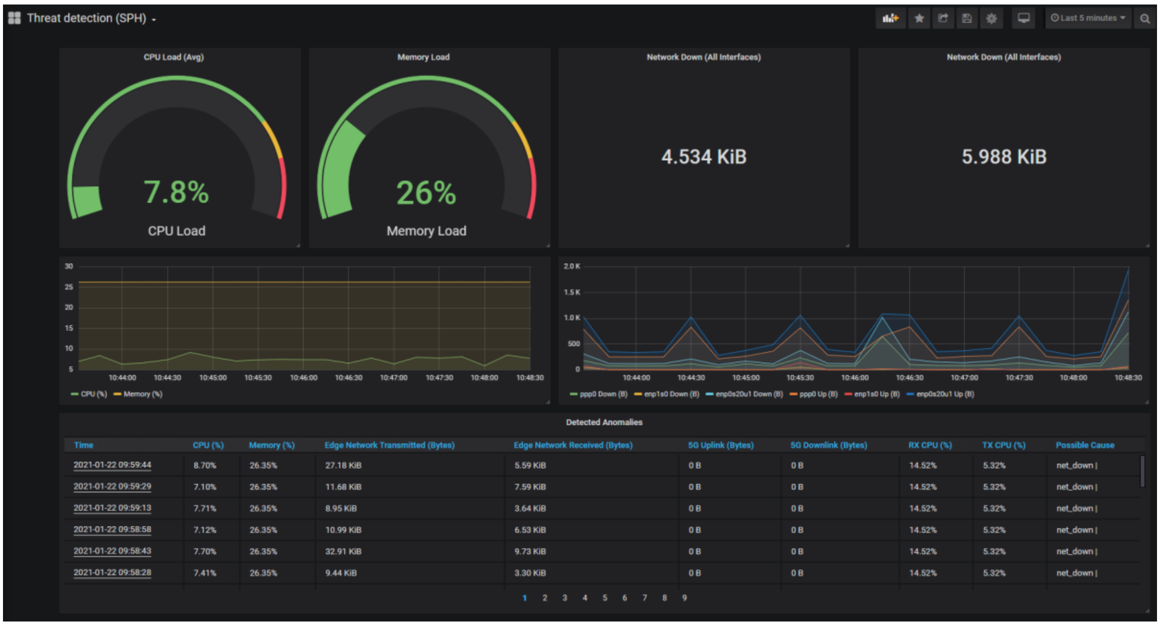

Figure 37. List of detected outliers as part of the monitoring UI

The deployment and testing of the security analytics framework of 5GENESIS is presented in detail in Deliverable D3.14 [9].

4.2.9. Spectrum allocation evolution

This section describes a simulator built on purpose to study the spectrum management scenario assigned to the 5GENESIS Limassol testbed. This scenario is presented in section 2.3.2.5. We decided to use a simulator instead of experimental demonstration using the testbed because the limited number of deployed base stations and terrestrial backhaul links makes it difficult to demonstrate the reconfiguration of the backhaul topology for spectrum management purposes. Additionally, this approach also avoided problems related with spectrum licensing.

4.2.9.1. Assumptions on the backhaul network infrastructure

For the backhaul architecture, we consider that the base stations of a mobile network are organized in clusters, with one SDN switch co-located at each base station. All the SDN switches belonging to the same cluster are controlled by a single SDN controller. As depicted in Figure 38, we further assume that each SDN switch supports one link providing access to the core network through a wired backhaul, one link providing access to the core network through a satellite backhaul and up to six links providing wireless backhaul connectivity to neighboring base stations.

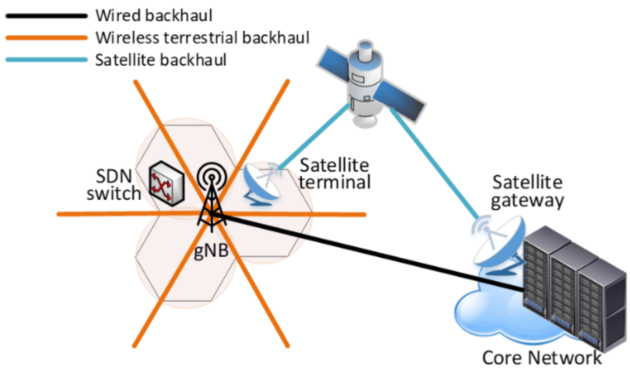

Figure 38. Networking equipment collocated with each base station

To command the switches in a given cluster, there is also an application running 1) on the Network Slice Management Function (NSMF) within the Slice Manager when non-real time adaptation of the backhaul network is required, or 2) on top of the SDN controller when real time adaption is needed. The main responsibilities of that application include configuring the backhaul links, assigning the traffic of each network slice to the adequate backhaul link, monitoring the traffic flows in the switches, and measuring the actual throughput of each network slice.

4.2.9.2. Simulator description

5GENESIS aims to determine optimum configuration of the integrated terrestrial-satellite backhaul network, which requires the less amount of spectrum to deliver the required extra capacity to the base stations requiring it in a given moment in time.

It is challenging to determine the optimum backhaul topology by conventional optimization techniques in 5G scenarios that consider i) several end-to-end network slices with different delay requirements, and ii) the activation/deactivation of some satellite and terrestrial backhaul links. Thus, 5GENESIS proposed to use machine learning (ML), more specifically reinforcement learning (RL) algorithms, to continuously optimize the wireless and satellite backhaul networks so as they can provide additional capacity to specific base stations where the wired backhaul network is not able to provide all the required capacity.

In other words, the ML algorithms should automatically adapt the topology, bandwidth and routing tables of the wireless backhaul network. More specifically, the RL algorithms have to decide which base station(s) will retransmit backhaul traffic to nearby base stations and which bandwidth is necessary to use in each retransmission, taking into account the limitations of the wired backhaul and the availability of the satellite backhaul.

Figure 39 gives a high level description of the simulator built to determine the optimum configuration of the wired-terrestrial-satellite backhaul network from the point of view of spectrum utilization.

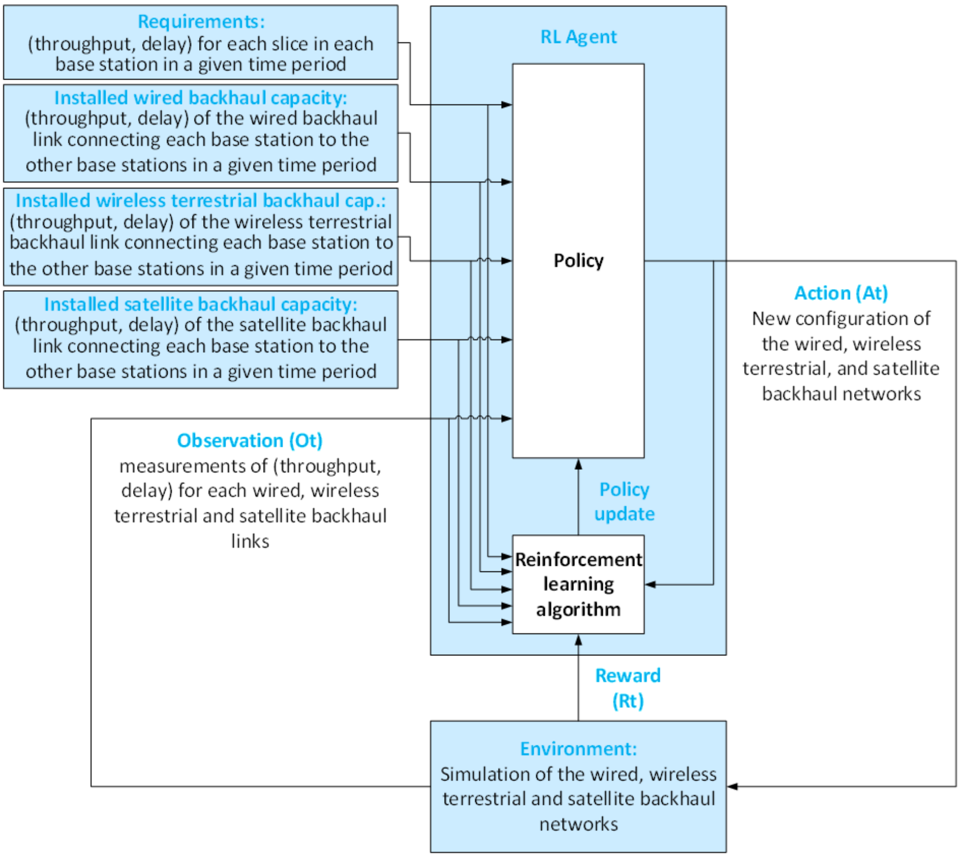

Figure 39. Simulator intended to determine the optimum configuration for the integrated wired-terrestrial-satellite backhaul network.

4.2.9.3. Input dataset

To determine the requirements of each network slice in each base station in a given time period we used the Big Data Challenge dataset [13] that is freely available in the Internet. Among other information, this dataset contains the Internet traffic measured every 10 minutes during 2 months (November, December) across the Milan area. The dataset considered that this service area was divided in 100-by-100 square-shaped pixels, with dimension 235-by-235m each.

9901	9902	...	9999	10000
9801	...	...	9899	9900
...	...	...	...	...
101	102	...	...	200
1	2	3	...	100

Figure 40. Milan grid [13]

Although this dataset describes the spatial and temporal traffic patterns in a real network, its direct use as input data to our simulator is not possible. This is due to fact that the dataset hides several commercial sensitive information such as:

- The number and position of the base stations is not known. Thus, we had to assume the cell size and the base station positions, using as a guide the coverage map depicted in Figure 41.
- The services that are responsible for generating Internet traffic in each base station are not known. The dataset contains the total number of bits that were exchanged in each pixel in each 10 minutes interval. However, for network slicing purposes, we need to know how this traffic was distributed in DL and UL among the several types of network slices. This information is not contained in the dataset, so consider creating a synthesised dataset based on some assumption. For example, our assumption considers that the type of network slices and the distribution of traffic among them varies according to 1) the area where each pixel is located (i.e. rural area, residential area, nightlife area, touristic/commercial area, public services area, sports/cultural events area), and 2) the time of the day and the day of the week.

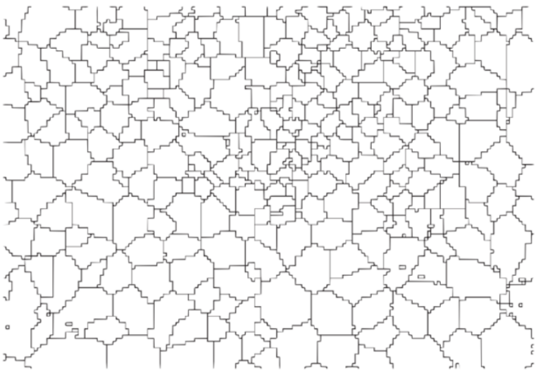

Figure 41.-- Example of Milan coverage map [13]

4.2.9.4. Installed backhaul capacity

For the installed capacity, we consider the values defined in previous sections for each type of backhaul links deployed in the Limassol testbed.

The installed capacity of each wired backhaul link depends on the capacity of the fibers that are used. Some of these values are **10Gbps** (DL) and **10Gbps** (UL), while others are forced to be **0**

Gbps to express wired links that cannot be used, because they are, for example, not deployed or are under maintenance. The delay of the wired backhaul links depends on the processing time at the sending gNB, the type of and length of the fiber, and the number and type of regeneration points in the fiber path.

The installed capacity of each wireless terrestrial backhaul link depends on the used bandwidth, the selected radio technology, the number of transmitting and receiving antennas and the SINR of the link. In each base station, these values are defined as **(150Mbps – DL capacity used by the access network)** for DL and **(50Mbps - UL capacity used by the access network)** for UL, although some of these values may be forced to be **0 Mbps** to express wireless links that cannot be used because they are, for example, not deployed, are under maintenance, or will interfere with any incumbent wireless network. The delay of the wireless backhaul links depends on the processing time at the sending gNB, the range of the wireless links and the number of retransmissions required by HARQ.

The installed capacity of each satellite backhaul links depends on the used bandwidth, the type of satellite used (conventional or high-throughput satellite), the selected radio technology, the size of the parabolic dishes, and the SINR of the link. In each base station, these values are defined as **15Mbps** (downstream) and **5Mbps** (upstream), although some of these values can be forced to be **0 Mbps** to express satellite links that cannot be used, because, for example, the gNB has not satellite equipment, the satellite or gNB equipment are under maintenance, the satellite is not in line of sight, or the satellite links will interfere with any incumbent wireless network. The delay of the satellite backhaul links depends on the processing time at the satellite gateway, the ranges of the upstream and downstream wireless links and the processing time at the satellite.

4.2.9.5. RL Agent

The RL agent uses a reward function that intends to minimize the amount of spectrum allocated to the wireless terrestrial backhaul network. In other words, it tries to avoid any wireless terrestrial backhaul link to use a higher bandwidth than necessary to provide the required capacity to each base station. The rationale behind this strategy is that we do not want that any mobile network uses more spectrum than necessary, in either access or backhaul domains, so that the spectrum can be used by other networks.

The selected RL algorithms employed to update the policy were Asynchronous Advantage Actor Critic (A3C) [14], Soft-Actor-Critic (SAC) [15], RAINBOW [16], Trust Region Policy Optimization (TRPO) [17], Proximal Policy Optimization (PPO) [18] , and Twin Delayed Deep Deterministic Policy Gradient (Twin Delayed DDPG) [19].

4.2.10. Developments for UC1: 5G Maritime Communications

The main application to be demonstrated in a maritime environment in order to show the added-value of 5G onboard is an AR-enabled corrosion detection application based on edge computing. In this use case, an engineer with AR glasses and a 5G mobile phone, can walk around the ship and identify places with rust in near-real time.

5G networks can provide very low latency and high speeds, so they are suitable for sending a big amount of data and getting a response back very fast, leveraging edge computing.

In our case, an engineer wears AR glasses and carries a 5G terminal (smartphone). The glasses are connected to the phone using WiFi, so the 5G mobile phone essentially operates as a router. A custom Android application has been developed for the AR glasses, in order to send the acquired images through the 5G network to the Edge compute node and to receive the results. There are two main operations in the Android application. On the one hand, one service runs in background and takes feed from the glasses' camera as JPEG image frames. On the other hand, a second service sends requests in the Edge node, in order to retrieve the processed images and show them in the glasses' screen. In the Edge node there is a server, which provides an API for sending images and consuming the same images after detection. When new images are received, the server feeds them into an object detection model, which search for places in the image with rust. When the object detection operation is finished, the image is sent to a queue, where the Android application query. When the Android application receives the processed images, it displays them on the screen. If there is rust in the image and the model has detected it, there will be a rectangle and a label around the area with the rust.

Our Edge node, integrated in the mobile hotspot (see Sec. 4.2.2) is a Dell Edge Gateway 5000. For accelerating the object detection operation, we have used Intel Neural Compute Stick 2 (Intel NSC2). Our object detection model has been trained using transfer learning from Mobilenet SSD v2. We have trained using images containing labelled areas with rust. The input size of the model is a 300x300 pixel image, and its output is the coordinates of the detected areas that contain rust. The server that receives and processes the images is developed in Python, using Flask framework.

The Android application sends video frames as JPEG images with resolution 340x280 pixels. The framerate of the video is 10 frames per second (fps), and the receiver service asks for processed images every 0.2s. The final result is displayed on Vuzix M300XL AR glasses.

Figure 42. Corrosion detection application running on Vuzix M300XL AR glasses served over 5G

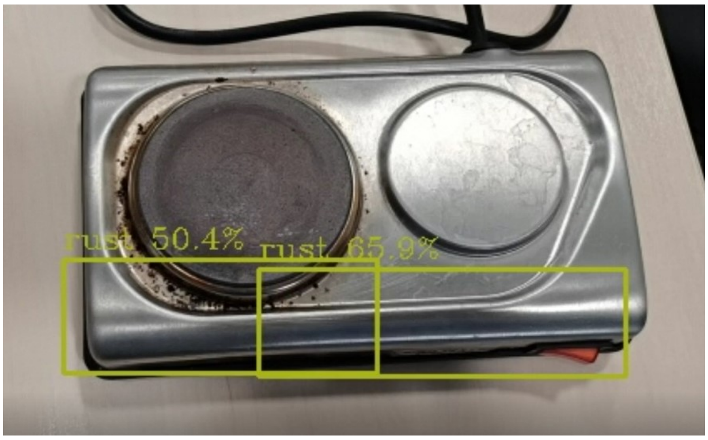

Figure 43. Output of corrosion detection application (lab tests)

4.2.11. Developments for UC2: 5G Rural applications

After the testing period in Phase 2, we focused on the implementation of devices and services needed for the rural applications. In particular, the following accomplishments were achieved for the smart irrigation application:

- Enhancement of the device with environmental sensors, including a soil moisture and a raindrop sensor.
- Development of a battery-powered LoRaWAN actuator device, consisting of an electrovalve and a flow meter sensor.
- Deployment of a IoT platform based on FIWARE for managing the data from the INTER-IoT gateways. Orion Context Broker, Perseo Complex Event Processor, Comet Short Term Historic and a JSON agent have been implemented.
- Implementation of the irrigation logic based on custom rules (in a market-ready deployment, data should be gathered from knowledge databases for agriculture).

For the application related to the autonomous weed detection and elimination, the following achievements were accomplished:

- Configuration and integration of SIMCOM SIM8200EA 5G HAT as 5G UE.
- Integration of Intel® Movidius™ Neural Compute Stick in the edge infrastructure (no GPU was available).
- Compilation and annotation of daisy flower database (around 250 images with more than 1000 daisy flowers labelled) to act as weed. Complemented with contextual images and other types of plants.
- AI model trained. SSD has been used instead of Fast R-CNN or other alternatives since fast inference time is needed for real-time video
- Integration and deployment of an object detection service. Tested with different video servers (RTMP, RTSP), clients (custom for raspberry and available from third parties for mobile phones) and files (video streams and standalone images).
- Development of API based on Flask for facilitating its integration with openTAP.
- Integration of notification server (open-source from Gotify project).

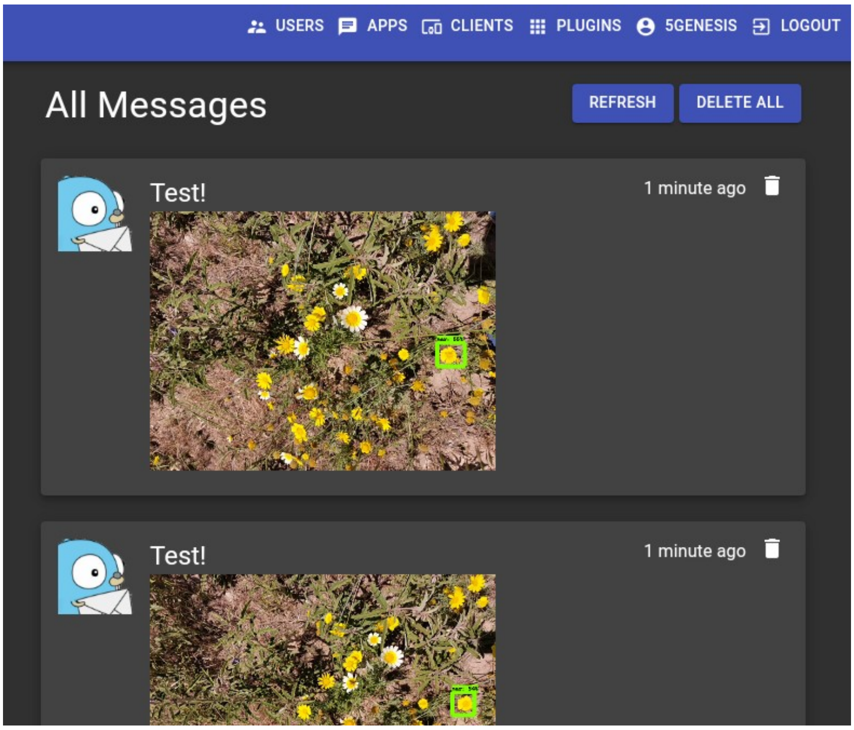

Figure 44. Preliminary field trials of the integrated rural UC app

5. Conclusions

The present document focused on the Release C (final) of the platform, as it was developed during the third implementation phase. The Phase 3 activities achieved the realisation of the 5GENESIS architecture on its whole, and eventually delivered a full-stack, end-to-end 5G experimental testbed with all the added-value features associated with the Limassol platform specificities. To that end, Phase 3 further evolved the 5G configuration, by employing fully functional 5G NR with commercial terminals and 5G core functions and upgraded the upper layer (Open5GENESIS) components with their latest, feature-rich versions.

During the next months, extensive tests will be performed to ensure that all the newly integrated services and components work as expected and, in parallel, the platform partners will continue their efforts towards fine-tuning and optimising the operation of the platform.

The Release C of the platform will be used for the third round of experiments during Q3/Q4 2021, and the report on the KPIs will be available in deliverable D6.3 in December 2021.

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