5Genesis

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

[H2020 - Grant Agreement No. 815178]

Deliverable D4.8

The Limassol Platform (Release B)

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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
C-RAN	Cloud-RAN
CSP	Content Service Provider
CUPS	Control and User Plane Separation
eICIC	Enhanced Inter-Cell Interference Coordination
eMBB	Enhanced Mobile Broadband-5G Generic Service
eMBMS	Evolved Multimedia Broadcast Multicast Services
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

Acronym	Meaning
RU	Radio Unit
SCPC	Single Carrier Per Channel
SDN	Software Defined Network
SDR	Software Defined Radio
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, in order to achieve the following innovative features: i) ubiquitous coverage with reduced latency, ii) support for multi-radio slicing, iii) 5G throughput enhancement via air interface aggregation, where necessary and iv) dynamic spectrum allocation between satellite and terrestrial.

The aim of Phase 2 has been to complete the dual-backhaul configuration, integrate the Release A of coordination layer components as well as deploy a first version of the 5G NR.

In specific, at the end of Phase 2, the following tasks have been achieved:

- Integration of the terrestrial backhaul and finalisation of the dual-backhaul architecture;
- Deployment of an early version of 5G NR in "noS1" mode (no control plane);
- Enhancement of inter-site connectivity by installing bespoke routing equipment at the satellite earth station;
- Integration of core and edge clouds, extending MANO capabilities to include the satellite edge assets;
- Integration of SDN capabilities, via a centralised SDN controller and SDN switches at the core and edge;
- Finalisation of the link aggregation functions;
- Deployment of Security Analytics;
- Early deployment of Spectrum Management functions;
- Integration of Release A of Coordination layer functionalities, i.e.
    - The 5GENESIS Portal
    - The 5GENESIS Experiment Lifecycle Manager (ELCM) and its executive back-end, i.e. OpenTAP
    - The 5GENESIS Slice Manager
    - The storage (InfluxDB) and visualization (Grafana) components of the monitoring subsystem

During the last three months of this cycle, 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 toward integrating elements and technologies.

The platform will be used for the second round of experiments until March 2020, and the report on the KPIs will be available in deliverable D6.2 in March 2019. This document will be followed by the Deliverable describing the Release C of the platform in December 2020.

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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 follows with a description of the intended evolution of the platform, listing the current accomplishments during Phase 1 and Phase 2, as well as the milestones to reach in the deployment of Phase 3.

Section 4 is devoted to the two use cases that will be tested in the final version of the platform, describing their components, the scenarios of utilization and the expected outcome.

Section 5 discusses the objectives of the Operation and Management procedures that will govern the day to day use of the platform.

Finally, Section 6 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 Overview

2.1.1. Overall 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.

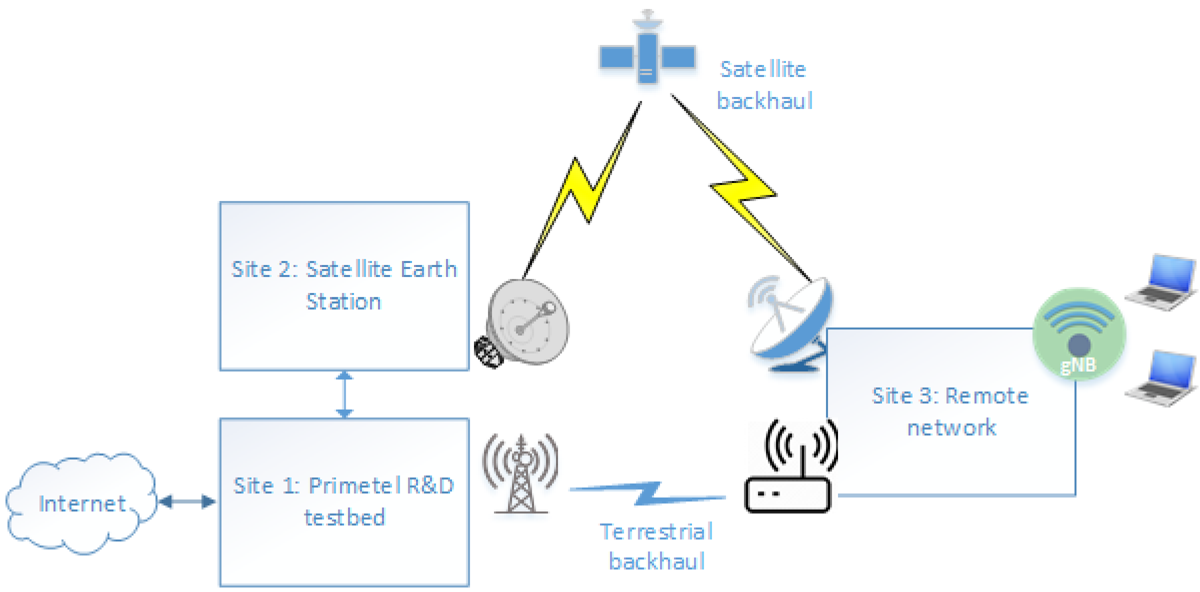

Figure 1. High-level topology of the Limassol testbed

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]

2.1.2. 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 center, 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 fiber 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. The necessary spectrum to operate a commercial 4G network has already been secured, of which a small part will be allocated to 5GENESIS. At least 5 MHz bandwidth from LTE Band 1 (2100 MHz) is used to transmit the 5GENESIS 4G test signal during the first testing phase of the project. The frequencies of operation are between 1950 – 1965 MHz for the uplink and between 2140 –2155 MHz for the downlink. PLC has also acquired a test license for the 3.5 GHz spectrum for 5G trials.

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 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 (see Figure 3).

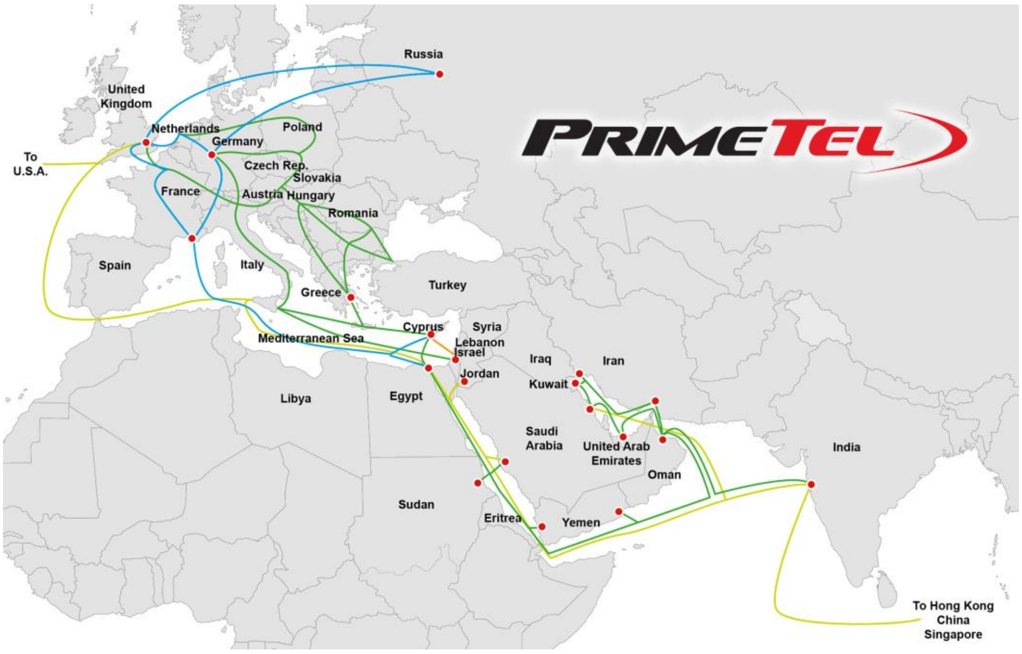

Figure 3. PLC's international network, securing connectivity for the 5GENESIS Limassol platform

2.1.3. 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 (Cyprus) 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-fiber 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 to 21.20 GHz.

Figure 4. 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 center 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 HTS satellite. 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.

Figure 5 below depicts Avanti's ground network. The Limassol platform is backhauled through HYLAS 2 satellite and Makarios (Cyprus) GES. The Cyprus GES is connected via Ethernet (L2) over fiber 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.

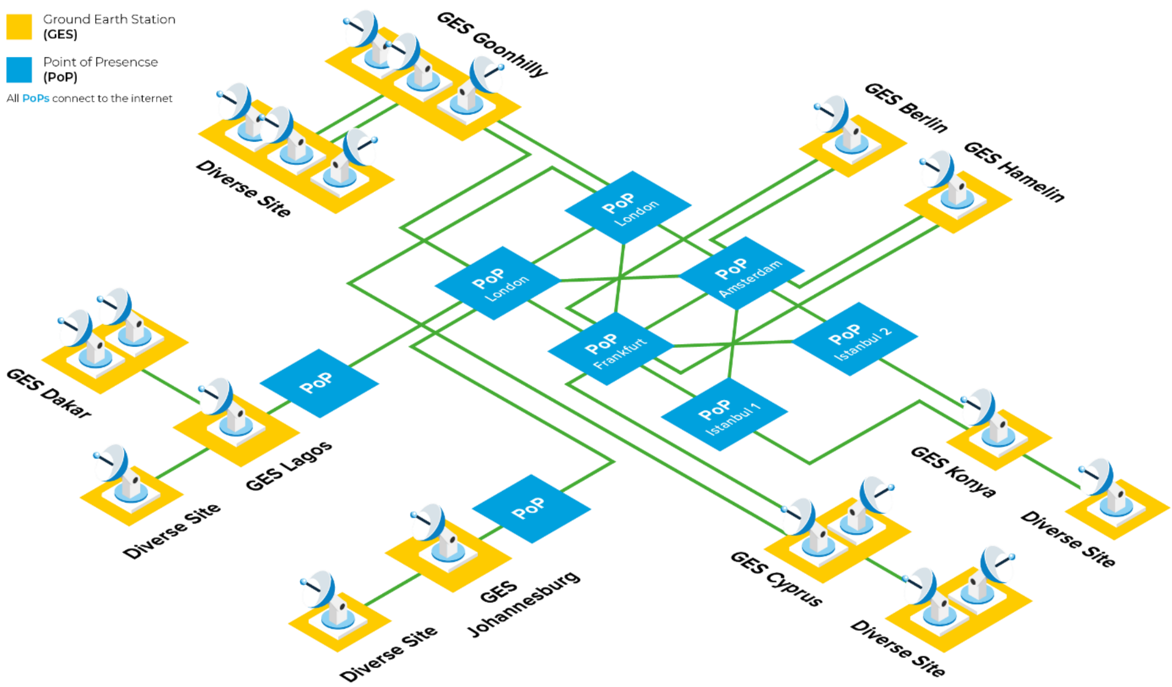

Figure 5. Avanti's ground network infrastructure[1]

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 6, 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.

[1] Note: Istanbul PoPs are currently disconnected.

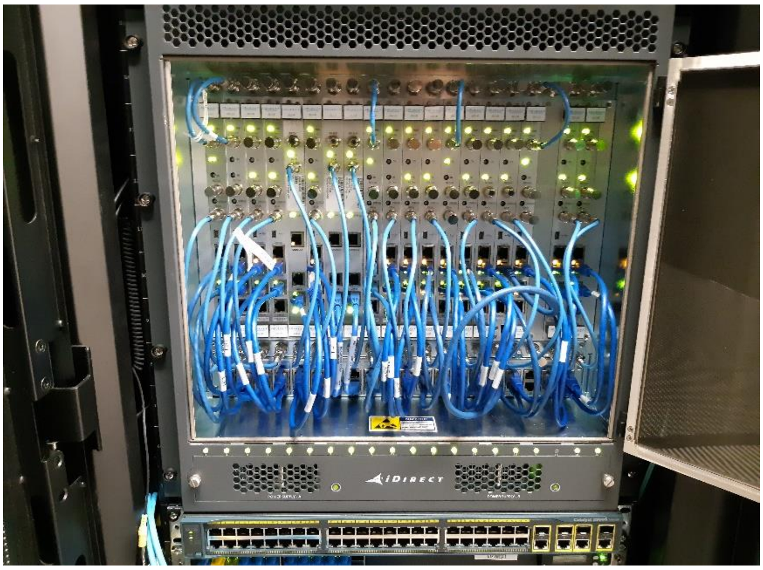

Figure 6. iDirect Evolution Hub

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.

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

Figure 7 below depicts the 5G mobile hotspot, comprising the aforementioned components.

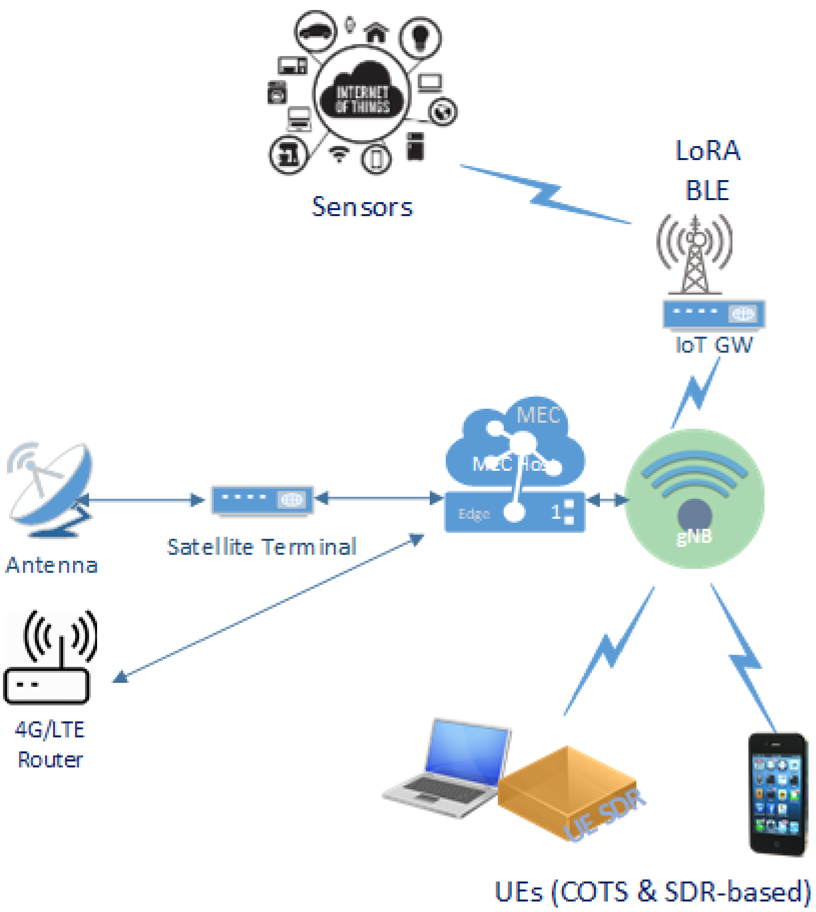

Figure 7. Key elements of the remote 5G hotspot

The 5G hotspot features computing assets (one or two compute nodes) in order to host the edge computing services. These rely on i) standard desktop PCs and ii) dedicated platforms for edge computing.

Most assets of the mobile hot-spot will be housed, during Phase 3 of the project, in a small-factor portable rack, so that it can easily transported and installed on ad-hoc basis.

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 8. iDirect X7 satellite terminal installed at 5GENESIS platform

The access network comprises of:

- A gNB, based on the OpenAirInterface suite and the setup provided by. The gNB is implemented using an ETTUS N310 SDR platform, driven by a laptop computer running the OAI software.
- Non3GPP radio access points, including WiFi and LoRa.

The outdoor components of the 5G hotspot are mostly the antennas for establishing the backhaul link as well as the access networks.

For the latter, outdoor omnidirectional and/or sector antennas are used, depending on the usage scenario, along with an RF front-end (amplifier) in order to establish the proper signal level, always in line with the local regulation and the spectrum license.

For the satellite backhaul link, there are two antenna usage scenarios, depending on whether the scenario involves fixed or mobile use.

For the fixed use, a standard fixed vSAT antenna is used, equipped with a 120 cm dish (Figure 9).

Figure 9. Fixed satellite antenna installed to backhaul the 5G hotspot

For the mobile use (and especially the maritime communications scenario), an active antenna element is required, in order to achieve continuous tracking of the geostationary satellite, even during movement. For this purpose, a 3-axis stabilized satellite antenna will be employed during the field trials to take place in Phase 3 of the project.

2.2. Target Deployment

Figure 10 depicts the target physical topology for the Limassol platform, where the main components of the system are illustrated.

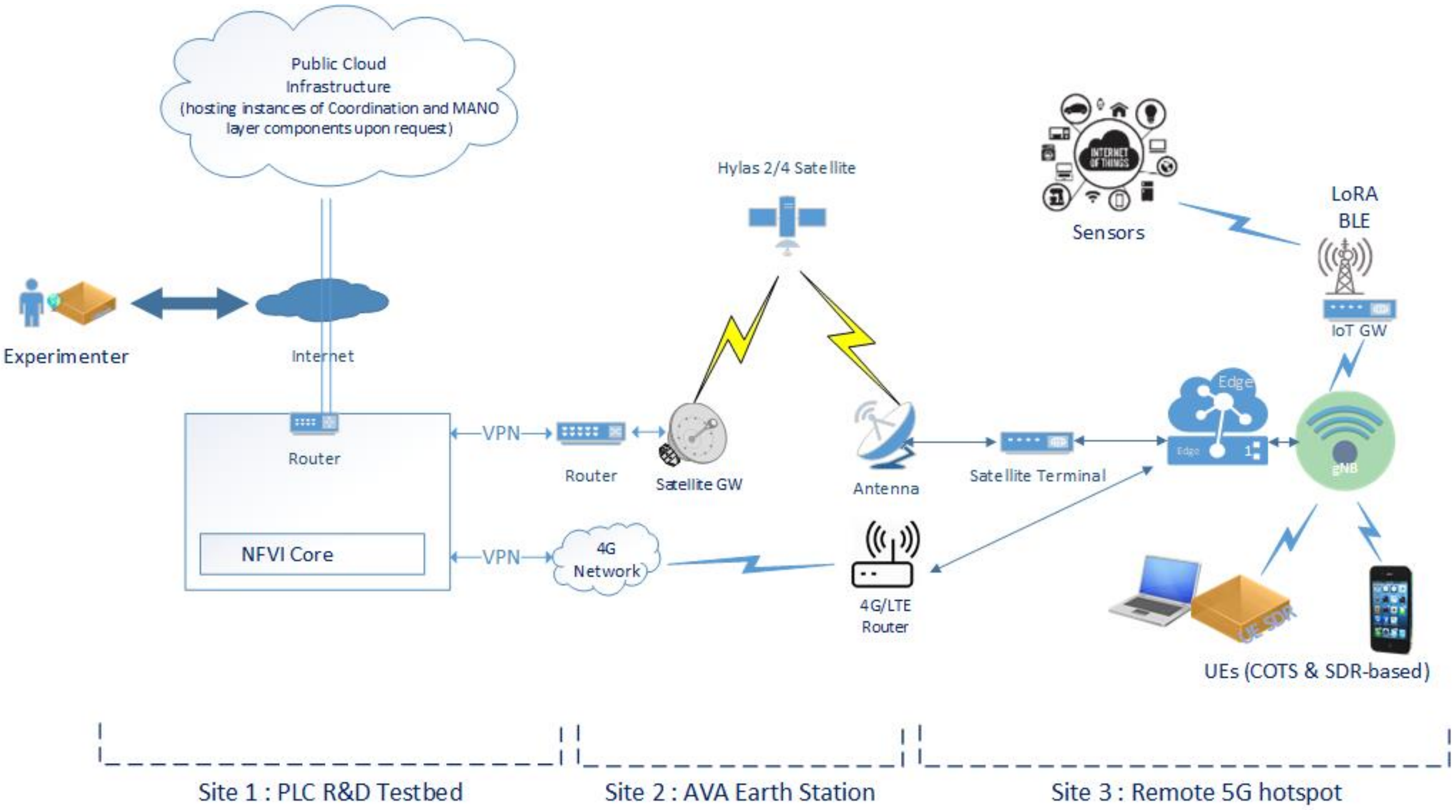

Figure 10. Limassol platform target physical topology

The aim of the Limassol platform is to constitute an open network infrastructure, available to the 5GENESIS consortium partners and third parties not only for experimentation, but also for adaptation and further extension.

The core of the platform is supported by an OpenStack cluster with SDN switches, acting as core NFV Infrastructure (NFVI), but also hosting virtualized management functions.

The Coordination and MANO (Management and Orchestration) functions manage and orchestrate the platform infrastructure, resources and services. These functions are deployed as VMs and VNFs in the OpenStack cluster. In case of resource shortage, the Limassol platform provides the option to deploy/offload them in a public cloud (Microsoft Azure).

In addition, the OpenStack-based core NFVI includes the necessary VNFs and service functions. The CN functions (EPC and 5GC) are deployed both in stand-alone servers and as VMs in the cluster (vEPC, v5GC).

In addition to the Coordination/MANO components and the CN functions, the OpenStack cluster hosts IoT interoperability, spectrum management and link aggregation functions, also installed as separate VMs to complete the portfolio of platform services.

The Limassol platform offers a satellite backhaul towards providing wide-area coverage for M2M communications and voice services. The satellite gateway is the entry point for the satellite backhaul, a key element of the Limassol platform. Connectivity of the core NFVI to the satellite gateway is implemented over an L3VPN.

For use cases related to service and context continuity, as well as service agility, a hybrid backhaul approach is adopted. A secondary terrestrial backhaul, based on the 4G technology, is implemented, consisting of a 4G network and a remote 4G router.

At the satellite edge, computing equipment is deployed to allow the deployment of local traffic handling functions (such as e.g. Local Break-Out or data adaptation functions). The edge equipment enables content and applications to be processed as close as possible to the edge of the network, close to the end user, thus improving the user experience and reducing the traffic that has to be sent through the backhaul.

The radio access component is implemented in the frequency band of 3.5 GHz. It is SDR-based, consisting of a software-driven baseband unit (BBU), an RF digital front-end (DFE), and the antenna modules. The UEs are both COTS devices (4G smartphones and also 5G ones, when they become available), as well as SDR-driven.

Finally, IoT-oriented radio access networks are included, such as BLE and LoRaWAN.

The sections to follow present in detail the components of the platform.

2.2.1. Platform Infrastructure Layer

Table 1 below provides an overview of the infrastructure layer components and associated technologies 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	Athonet EPC and 5G Core, NextEPC	Single instance
5GNR	Eurecom OpenAirInterface	Single instance & SDR HW
LTE EUTRAN	Eurecom OpenAirInterface	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 (FIWARE Orion for first iteration).	Bespoke devices
Probes	MONROE	Multiple instances deployed across the network
Edge VNFs	EPC/5GC UPF, IoT interoperability function	Multiple instances deployed at the edge of the network

UEs	Commercial 4G mobile phones compatible with OAI (Nexus 5, Galaxy S6) and commercial 5G mobile phones (in Phase 3)	COTS devices
Traffic Generator	Open-source traffic generator (e.g. Ostinato, Seagull, WARP17, TRex)	COTS devices and SW

2.2.1.1. Mobile Network Technology

Radio Access

In the Limassol platform, the implementation of the radio front-end (NR and EUTRAN) is fully 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 Limassol platform will integrate the OAI eNB and 5g-NR gNBs and UE components to perform end-to-end experimentation and KPI measurement collection. In this context, the protocol stack extensions for 5g-NR UE is being made gradually available throughout the different phases of 5GENESIS, starting from the physical layer and continuing with the rest of the RAN protocol stack (MAC, RRC, PDCP). The OAI gNB and UE can be launched and configured easily through a Command Line Interface (CLI). Based on this CLI the gNB and UE can also be controlled remotely through external software.

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.

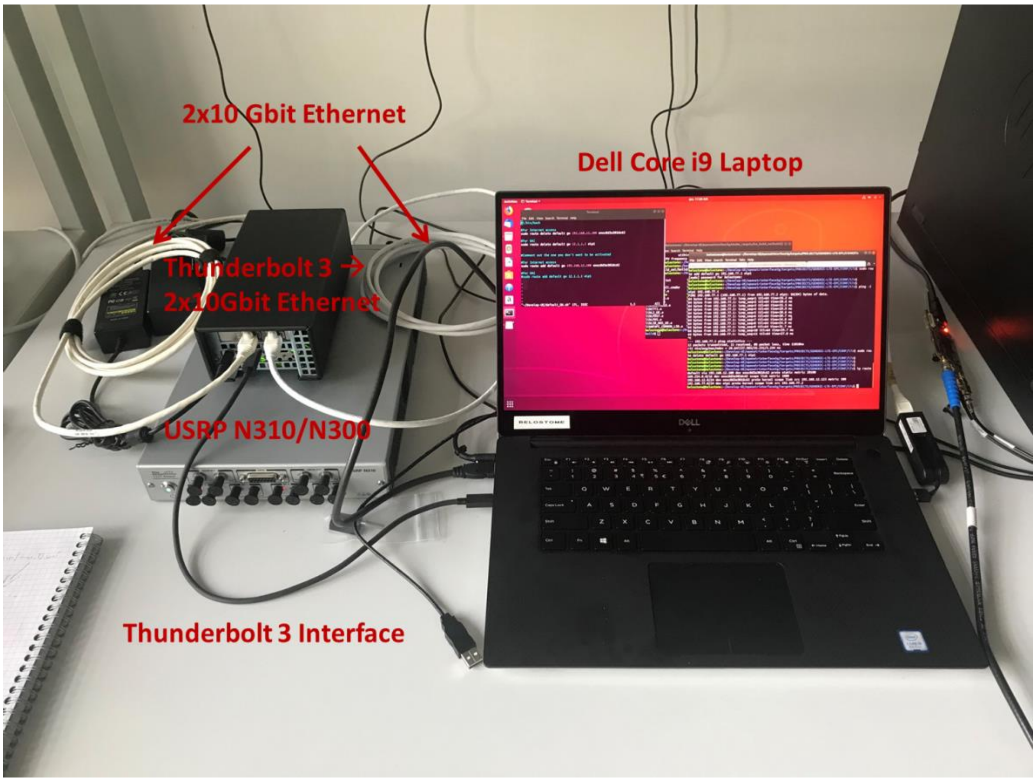

Figure 11. 5G-NR radio platform running OpenAirInterface.

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 and Frimata, 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 and 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

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.

2.2.1.2. 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, as soon as they have been implemented.

In any case, the focus is on hosting the VNFs, the EPC 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 currently on one Dell R430 server (Figure 12), with the plan to add more if necessary, in the future, in case more resources are needed for data plane components.

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

The Core Cloud server(s) are running on Ubuntu Linux 18.04LTS.

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

2.2.1.3. 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 currently based on a commodity Dell small-form-factor workstation, which is being replaced by more tailored equipment which has been specifically procured for the needs of 5GENESIS, such as the Dell Edge Gateway 5100 (Figure 13).

Figure 13. Dell Edge Gateway 5100, used at the satcom edge

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.

2.2.1.4. 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. n 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 14 (b).

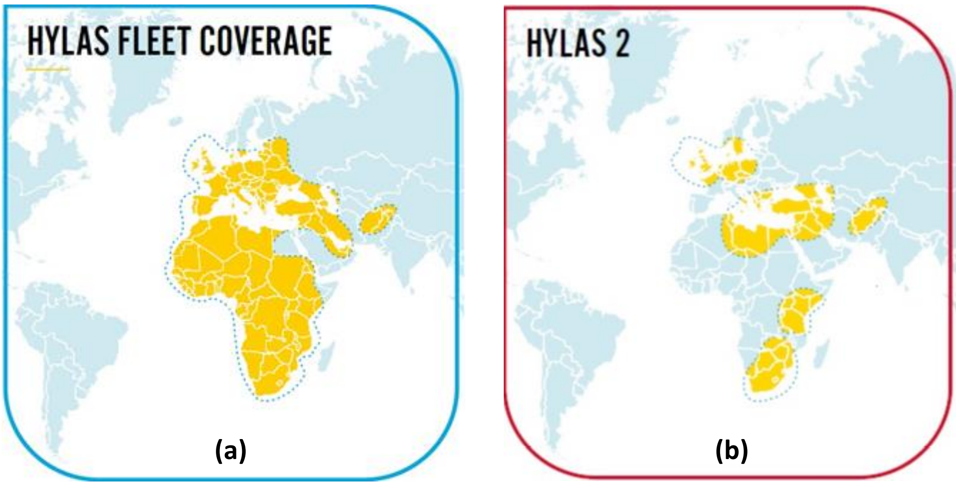

Figure 14. Avanti's (a) HYLAS Fleet coverage (b) HYLAS 2 coverage

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 endeavor 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 will require 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 can't deliver the performance expected by the 5G service. This is typically the case when a vessel equipped with a gNodeB leaves the harbor: 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 aims therefore at designing and setting up 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 harbor 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 it is expected 5G will show the same result, 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 behavior 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, demonstrated positive results.

2.2.2. 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

Slice Manager	Katana (developed in 5GENESIS)	Single instance
VIM	OpenStack	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	Open Air Interface Management	Single instance
EPC/5GC NMS	Athonet EMS	Single instance

2.2.2.1. 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 A of Katana is described in detail in Deliverable D3.3 [9]. In the Limassol platform, the slice manager is expected to manage the lifecycle of slices consisting of:

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

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.

2.2.2.2. 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.

2.2.2.3. 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; view remote status; view network statistics; monitor performance of networks (e.g.

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

latency, signal-to-noise-ratio), sub-networks and individual network elements; and manage alarms, warnings and network events.

2.2.2.4. Element Management Systems

NR 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.

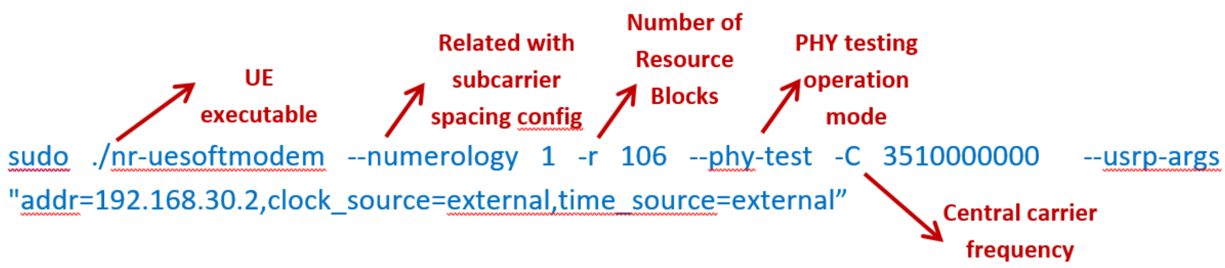

Figure 15. NR configuration from the CLI

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

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

EPC/5GC 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.

2.2.2.5. Spectrum Management

The principal objective of 5GENESIS is the deployment of 5G testbeds open to externals for experimentation. In some testbeds, as is the case of the Limassol testbed, there is also the objective to prepare the testbed to use some dynamic spectrum management techniques that would allow that one mobile network from one telecom operator may use the spectrum that other telecom operators, or other radio services, are not using in a given time or in a given geography.

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 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.

We identified two alternatives as the bands that could be used to draw the terrestrial backhaul network:

- Solution 1: use part of the 2GHz band (1920-1980MHz; 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 solution 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 unused spectrum to build a network of backhaul links that will enhance the capacity of other base stations that require additional capacity.

- Solution 2: 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 terrestrial backhaul links to other base stations. It should be stressed, that backhaul links will only be considered when these links do not interfere with the other services using the same band.

Figure 16 illustrates the scenario under study for ‘solution 2’. There, the goal is to activate / deactivate / configure the terrestrial (depicted in orange) and satellite (depicted in blue) backhaul links, so they deliver the required capacity to specific base stations, while they do not interfere with the other services also using the band (links shown in green).

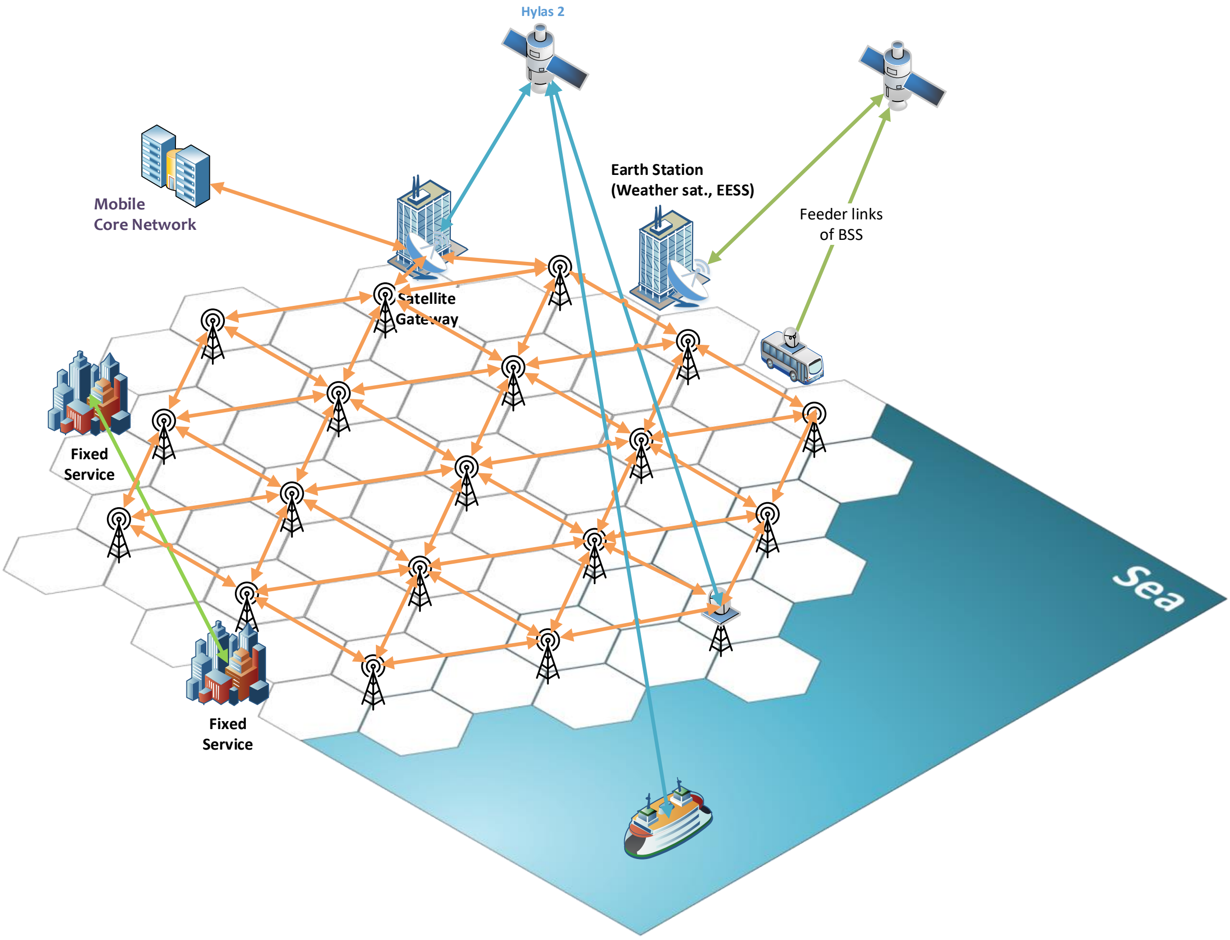

Figure 16. Sharing of satellite band to build a network of terrestrial backhaul links (orange) that complements the satellite backhaul network (blue) while not interfering with other services (green) using the same band.

As the bands under consideration are licensed bands, the solution being proposed has similarities with Spectrum Trading in case of “Solution 1”, and with Licensed Shared Access (LSA) in case of “Solution 2”.

We propose to extend these approaches by considering dynamic sharing of spectrum both in time and in geography. Currently, none of them considers such levels of dynamicity.

Given limited reconfiguration capabilities of 4G networks, after the mobile network knows that the spectrum is not in use by the other operators/incumbent, it will use that spectrum based on the same pre-defined static channel plan across the entire network. This fact limits sharing gains, as the amount of spectrum that might be available varies in time and in geography.

In Limassol, when using “Solution 1”, 5GENESIS intends to extend “spectrum trading” by considering i) reuse of spectrum by mobile operators according to channel plans that vary in time and 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 backhaul links using the shared spectrum.

When using “Solution 2”, 5GENESIS intends to extend “Licensed shared Access” by considering i) 5G and a different LSA band, ii) reuse of spectrum by mobile operators according to channel plans that vary in time and geography, iii) use the shared spectrum for backhaul purposes, iv) coordinate satellite and terrestrial backhaul, v) develop a method to automatically activate/deactivate/configure the terrestrial backhaul links using the shared spectrum.

As far as the proponents of these solutions know, there are no commercial products available in the market, which actually implements them. Their implementation, among others, requires the use of a spectrum database to provide input data. Therefore, if open-source databases containing spectrum information for Cyprus are not available, we may have to use commercial databases (e.g. Fairspectrum) as input to the spectrum sharing techniques being developed.

As the testbed being developed has limited geographical scope, the gains obtained from using shared spectrum in a wide backhaul network will be assessed through simulation. IT is currently adapting their simulator in order to be aligned with the use cases being demonstrated in Limassol by the end of the project.

After integrating the spectrum management algorithms in the 5GENESIS Management layer functions, we intend to deploy these functionalities in the Limassol platform in order to prepare it to be able to automatically coordinate the satellite and terrestrial backhauls.

A relevant metric to be measured will be the time required for the reconfiguration of terrestrial backhaul link(s) when using SDN and NFV technologies. It should be stressed that no wide-scale experimentation of spectrum management techniques will be demonstrated in Limassol.

If the experimenter desires to use the Limassol testbed to test spectrum management techniques, it will be under their responsibility to provide any extra hardware required, as well as the acquisition of the adequate spectrum licenses.

2.2.3. 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. Evolution of the Limassol Platform

3.1. Phase 2 Instantiation of the 5GENESIS Architecture

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

Figure 17 below visualizes the per-phase instantiation of the 5GENESIS architectural blueprint in the Limassol platform. It shows the functional blocks implemented and integrated in Phases 1 & 2, as well as the functionalities planned for integration in Phase 3.

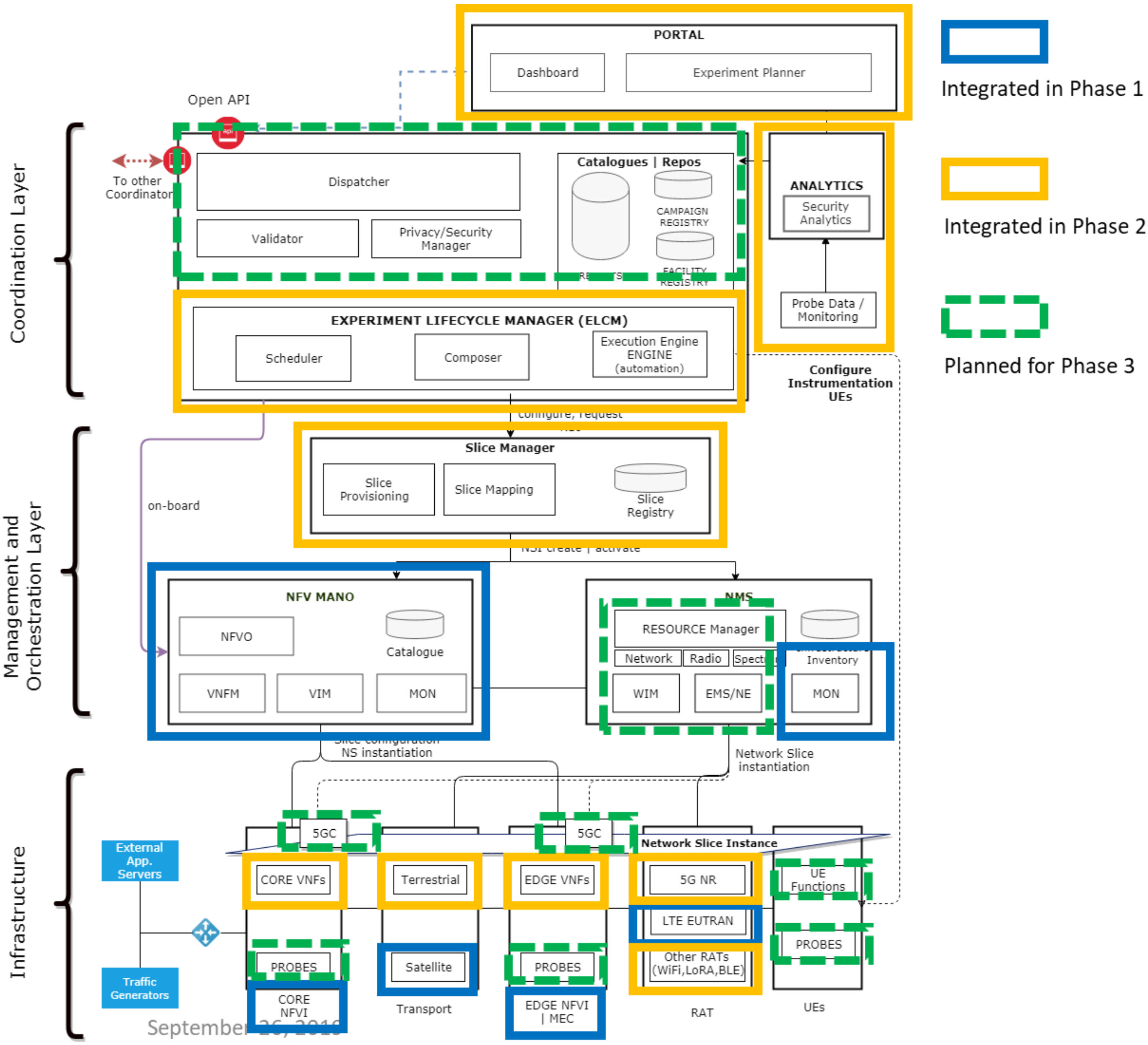

Figure 17. Per-phase instantiation of the 5GENESIS architectural blueprint in the Limassol platform

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. 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 is: 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 are also integrated. Last, the integration of the monitoring and analytics components, as well as the Security Analytics framework are done in this phase.

Finally, the aim of Phase 3 will be to further evolve the 5G configuration, by employing fully functional 5G NR with commercial terminals and 5G core functions. In Phase 3, moreover, the integration of the Coordination layer will be completed, in order to demonstrate end-to-end experiment orchestration and lifecycle management over multiple network slices, using a mobile remote 5G hotspot. The maritime communications scenario will be fully deployed in this phase.

Overall, at the end of Phase 2, two alternative deployment configurations have been implemented, as summarized in Table 3 below. The first one (Lim_Ph2_1) integrates the vast majority of the testbed capabilities, representing a complete end-to-end network with dual backhaul and NFV/SDN at the core and edge, with vEPC and 4G RAN. The second one (Lim_Ph2_2) focuses on the 5G NR capabilities, with a “No-S1” setup, currently isolated from the rest of the testbed.

Table 3 Phase 2 Deployment Configurations in the Limassol platform

Deployment Parameters	Technologies Deployed	
ID	Lim_Ph2_1	Lim_Ph2_2
Description	End-to-end testbed	5G NR – NoS1
Core Cloud	OpenStack Rocky	N/A
Edge Cloud	OpenStack Rocky	N/A
# Edge Locations	1	N/A
WAN/Network	Dual backhaul (satellite & terrestrial),	N/A

	OpenDaylight SDN controller, EKINOPS link aggregation functions	
Slice Manager	Katana	N/A
MANO	OSM v6	N/A
NMS	LibreNMS	N/A
Monitoring	Prometheus	N/A
3GPP Technology	4G LTE+	5G NR
Non-3GPP Technology	LoRA	N/A
Core Network	Athonet vEPC	N/A
RAN	Eurecom OAI	Eurecom OAI
UE	COTS Cat.12 (600/300)	Eurecom OAI
Relevant Use Cases	UC1/UC2	UC1/UC2

3.2. Phase 1 Accomplishments

At the end of Phase 1, the following tasks have been achieved, as reported in detail in D4.7 [4]:

- Establishment of a VPN infrastructure in order to enable the interconnection of the sites over the Internet, as well as allow remote management and configuration.
- Deployment of EUTRAN (OpenAirInterface platform, over SDR infrastructure) at 2.1 GHz band
- Integration of EPC and testing with COTS 4G terminals
- Installation and integration of the satellite backhaul, i.e. installation of the satellite terminal and configuration of the SatCom service
- Deployment of the NFV Infrastructure, based on OpenStack
- Deployment of the NFV Management and Orchestration (MANO) stack, based on OpenStack and OSM

- Deployment of the edge computing infrastructure
- Integration of a first version of the IoT use case

3.3. Phase 2 Accomplishments

3.3.1. Integration of terrestrial backhaul

In the Limassol platform, PrimeTel's own LTE mobile network is used for backhauling edge IP traffic to the core. PrimeTel started its commercial mobile network offering as MVNO (Mobile Virtual Network Operator) and has evolved into a full MNO (Mobile Network Operator) in the last few years by deploying its own state-of-the-art RAN (Radio Access Network) and core network functions. Mobile network coverage in general is island-wide, with high-speed LTE access continuously expanding. PrimeTel has established roaming agreements with more than 190 countries and territories, thereby ensuring ubiquitous access for the Limassol platform mobile edge network.

More specifically, PrimeTel has provided the equipment and connectivity required, in order for its commercial LTE network to be integrated into the Limassol platform. At the edge network side, a commercial CPE (Customer-Premises Equipment) has been installed (ZTE MF283V Cat 4 LTE modem for up to 150M/50Mbps LTE FDD DL/UL) which uses a specially provisioned SIM card for 5GENESIS, for unlimited LTE network access (speed and data usage.) A rack-mount router (Mikrotik RB2011) has also been installed, connected to the CPE via 1Gbps Ethernet and used to establish a L2TP/IPSec VPN link back to the core through the mobile network. The rack-mount router is used to provide 1Gbps Ethernet connectivity to the MEC host and route all IP traffic securely over the VPN link (see Figure 18.) In the event that the VPN link to the core is dropped, the router is configured to blackhole edge traffic in order to stop it from leaking to the internet. Both the CPE and the rack-mount router are configured to be remotely accessible through the Limassol platform management network.

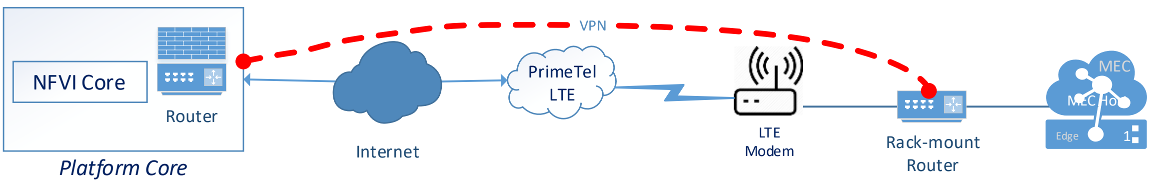

Figure 18: LTE backhaul network segment

3.3.2. Integration of 5G NR

Since a full-stack implementation of the 5G protocol stack is not yet available for use at the Limassol platform, 5G NR for Phase 2 is restricted to the primary scenario, where only the data plane functionality is evaluated. This corresponds to the "NoS1" setup, where IP traffic is transmitted from the gNB to the UE and back, without any signaling to the core functions for network attachment/mobility management etc.

The test configuration for 5G NR (See Table 3, configuration "Lim_Ph2_2") includes:

- A laptop running the OpenAirInterface gNB software, connected via 10GbE connection to a Software Defined Radio (SDR) unit capable of handling 5G radio, namely the NI USRP N310
- A second laptop running the OpenAirInterface UE software, connected via 10GbE connection to a NI USRP N310

In Phase 3, the NR set will be upgraded with full 5G NSA functionality as the OpenAirInterface software evolves to include the relevant features.

3.3.3. Enhancement of inter-site connectivity

The main enhancement of inter-site connectivity in the Limassol platform is encapsulated in the implementation of a bespoke private end-to-end network connection via satellite.

The inherent high latency of satellite links (round trip time > 600 ms) renders the TCP/IP protocol unusable since it was originally designed for low latency terrestrial network communications. As thoroughly explained in ReleaseA document of Limassol Platform (D4.7 section 4.3.2.1), satellite network hub vendors overcome this limitation with TCP/IP acceleration. However, TCP acceleration has its own limitations.

While private network connectivity in terrestrially backhauled networks (e.g. fiber based) works very well using VPN (such as IPsec), this solution is not an option for satellite backhauled networks due to the use of TCP acceleration. TCP acceleration requires TCP headers to remain unencrypted in order to work and IPsec VPN encrypts them. Other UDP-based VPN solutions such as WireGuard-VPN and Open-VPN also bypass TCP acceleration and don't work well.

Since a private connection between the 5G UE and the platform 5G core was necessary, a different solution was provided not resorting to an end-to-end VPN connection. Instead, the satellite modem was re-configured to connect privately to the satellite Gateway terminating its connection to a colocation router which in turn communicated with the platform core via IPsec VPN through the internet. This architecture works very well maintaining TCP acceleration and private network connectivity.

Figure 19. Colocation router installed for 5GENESIS at Makarios Earth Station

3.3.4. Integration of core and edge cloud

In Phase 2, the compute node at the satellite edge was upgraded in order to be fully managed by OpenStack and thus integrated in the platform MANO stack.

Initial efforts focused on deploying only the OpenStack compute services at the node, with the intention of transforming it to a compute node which would be managed by the central OpenStack controller at the platform data centre. However, such a configuration was proven not feasible due to several reasons (absence of L2 connectivity between the core and the edge, complexity of network configuration due to the dual backhaul and the multiple interfaces needed for the accommodation of the link aggregation functions).

Thus, it was decided to go for a full OpenStack (Rocky) deployment at the edge node, which was successfully completed. Only the installation of the Dashboard (Horizon) was omitted, considered as not necessary, in order to save some resources at the node. Currently, the core and edge cloud infrastructures are visible to the NFVO (OSM), as two separate VIMs, corresponding to different VIM accounts.

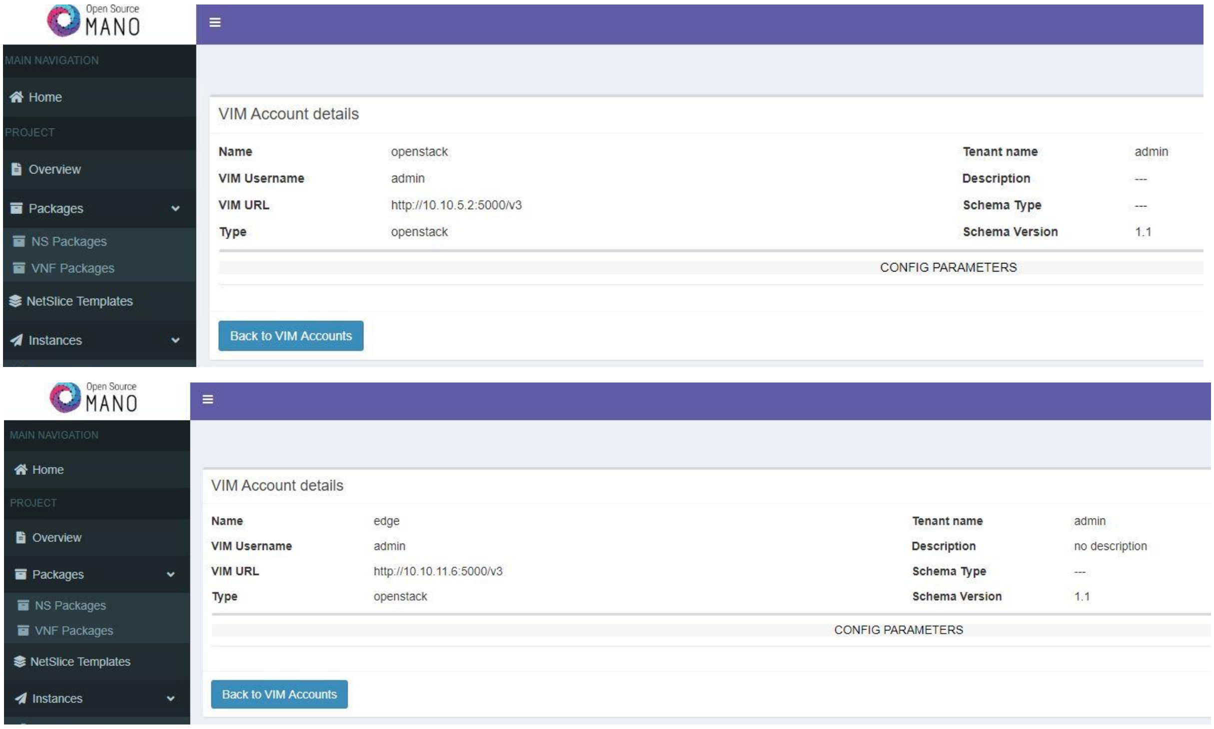

Figure 20. NFVO managing core and edge VIM (OpenStack) infrastructures

As a side activity relevant to the cloud infrastructure, the storage of the core NFVI was upgraded by adding an extra TB of capacity.

3.3.5. Deployment of link aggregation functions

Ekinops link aggregation functions, namely IUG (Intelligent User Gateway) and ING (Intelligent Network Gateway) are deployed as separate VNFs respectively on the edge and the core openstack instances, the diagram depicted in Figure 21 below illustrates the deployment architecture.

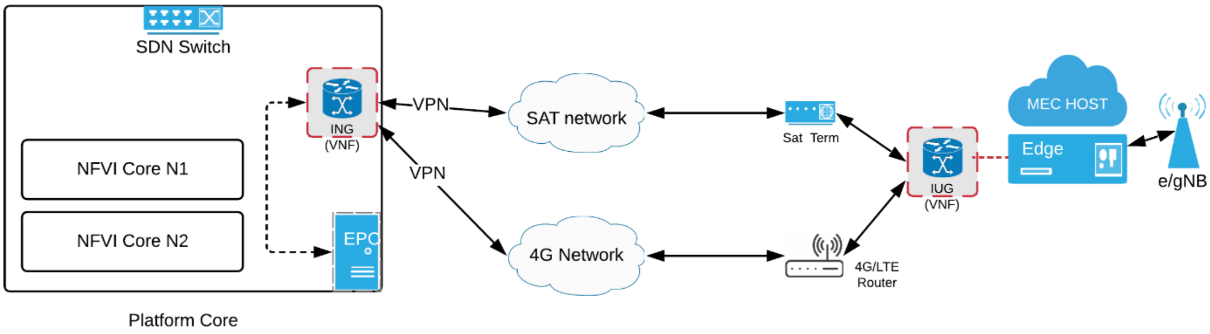

Figure 21. Integration of link aggregation functions in the overall architecture

As shown in the deployment architecture, each multilink VNF forwards data plane traffic across three different networks (i-e, the satellite network, the 4G network and the local network). Besides using three interfaces for data plane traffic it is worth noting that the VNFs also require an additional management interface for configuration and monitoring purpose.

Regarding the multilink operation, the link aggregation functions work as follows:

- On the gNodeB side, the IUG VNF intercepts TCP traffic inside GTP-u encapsulated packets, establishes MPTCP subflows over the satellite and 4G networks and then send TCP segments using PSBOL algorithm (Path Selection Based on Object Length)
- On the EPC side (platform core), the ING VNF reconstructs the original TCP session and forward the resulting GTP-u packets to the EPC.

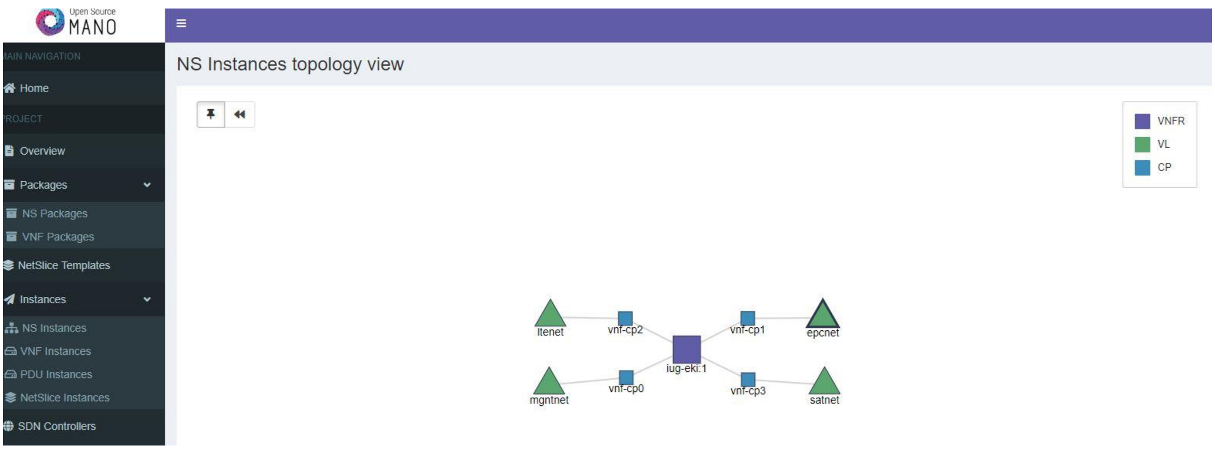

Figure 22. Ekinops link aggregation VNF deployed at the satellite edge

3.3.6. Deployment of Security Analytics platform

Release A of the 5GENESIS Security Analytics platform (as described in detail in D3.13 [5]) has been deployed and fully integrated in the Limassol platform. In specific, two virtual machines have been deployed in the OpenStack-based infrastructure at the platform core:

- VM1 – Master node (8 vCPUs, 16 GB RAM, 50 GB storage)

- VM2 – Worker node (8 vCPUs, 20 GB RAM, 100 GB storage)

The Release A of the Security Analytics platform is able to process network flow information in NetFlow 9 format. For this purpose, the central router of the Limassol platform was configured to dispatch real-time NetFlow information to the Master node, where it is ingested, preprocessed and subject to analysis. Figure 23 below shows a graph (Ingest Summary) produced by the Security Analytics platform GUI and overviewing the information (no. of flows) ingested in the engine.

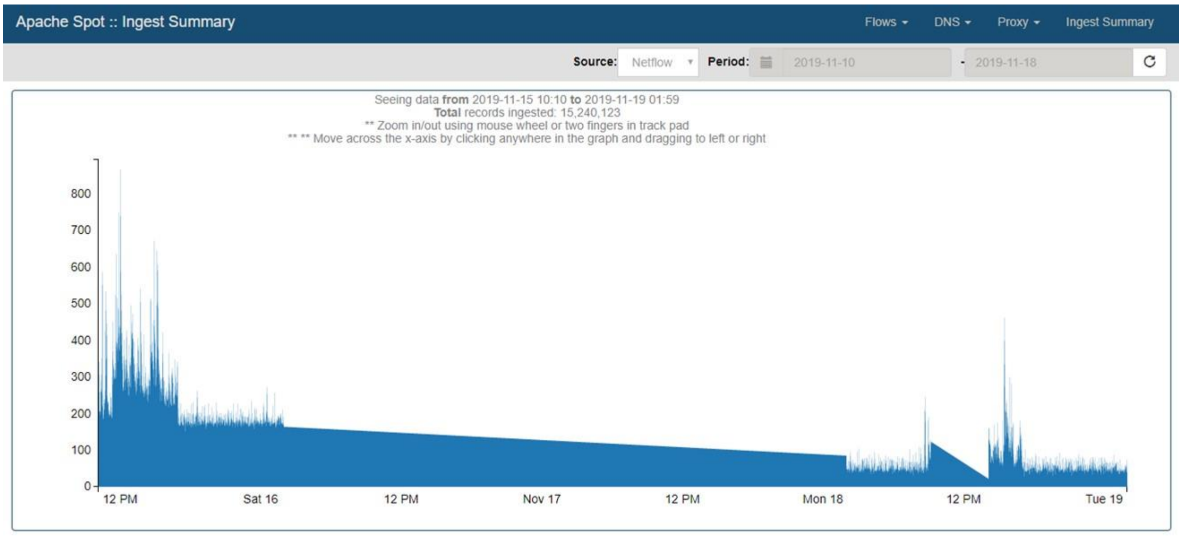

Figure 23. Graph of ingested information into the Security Analytics platform

Figure 24 below shows some screenshots from the GUI of the Security Analytics platform, operating in Limassol. In specific, the following are shown: List of suspicious flows; Network view (including discrimination between internal and external nodes); Connection details (distribution of connections for a single host).

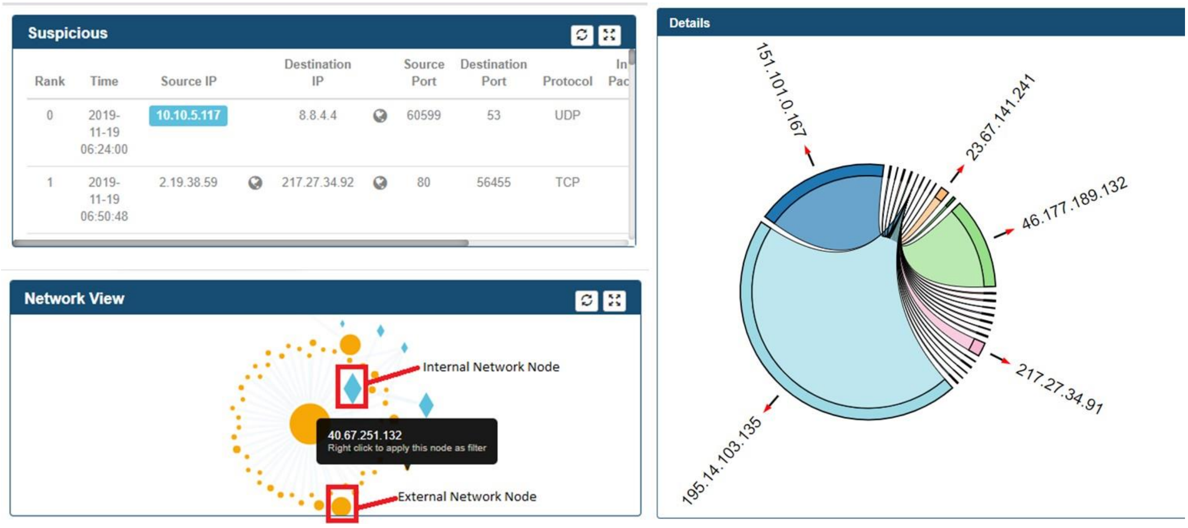

Figure 24. Views of the GUI of the Security Analytics platform GUI, operating in Limassol

Currently, the volume of traffic in the Limassol platform is very limited and does not include any actual user traffic, which does not allow the Machine Learning algorithms of the security analytics to perform correctly and capture events which might actually correspond to anomalies/security incidents. For this purpose, the work on security analytics integration currently involves the replaying of publicly available pre-captured traffic, in order to emulate realistic network conditions.

3.3.7. Deployment of Spectrum Management functions

Spectrum management in Limassol testbed is concentrated in the sharing of an IMT band (e.g. 2.1 GHz) among access domain and terrestrial backhaul network domain, and in the integration of terrestrial and satellite backhaul network domains. The terrestrial backhaul network uses 2.1 GHz IMT band, while the satellite backhaul uses Ka band (downlink 17.7-20.2 GHz, uplink: 27.5-30 GHz). As depicted in Figure 25, the spectrum management algorithm is implemented in a hierarchical structure, consisting of a centralized Network Slice Management Function (NSMF) that takes care of frequency allocation to different domains (i.e. access, terrestrial backhaul, and satellite backhaul) as it is at this level that cross-domain management operations are possible within a network slice.

The NSMF carries out the following operations. It receives, from the Slice Manager, the list of IMT bands that may be used by the mobile network, together with the indication of which base stations have satellite terminals. It processes this data and determines which base stations will use a satellite backhaul and which ones will use a terrestrial backhaul link, as well as their respective bandwidths. This permits the algorithm to update the topology of the *integrated backhaul network* in order to provide backhaul capacity when and where it is needed, freeing the unnecessary spectrum for other networks.

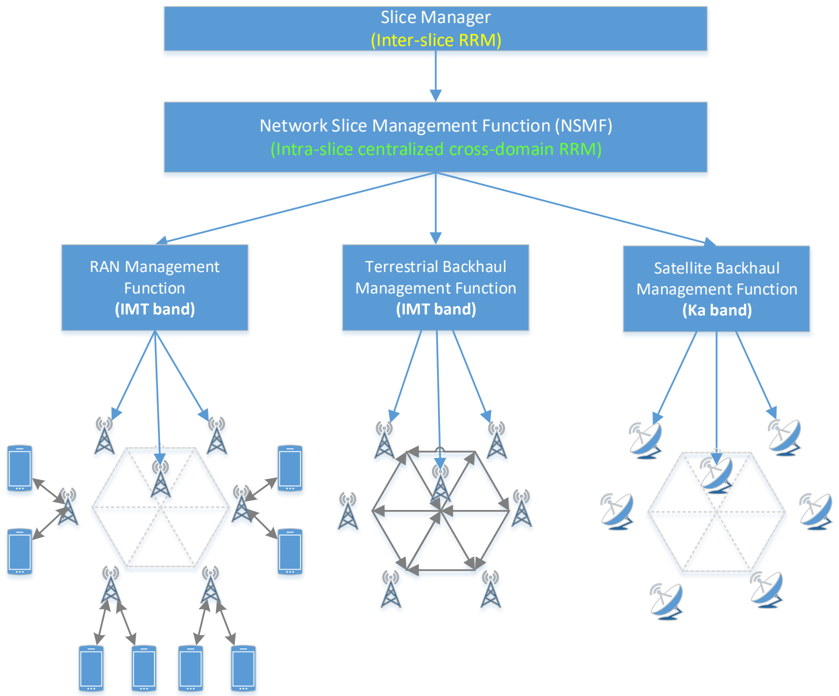

Figure 25 – Spectrum management for self-backhauling mobile networks using integrated terrestrial-satellite networks.

During phase 2, the spectrum management algorithms have been developed and their performance is currently being evaluated through simulations. During phase 3, they will be integrated in the testbed, although the demonstration activities will be reduced due to the fact that the conditions in the testbed are expected to stay quite constant, thus not benefiting from the proposed dynamic spectrum management technique.

3.3.8. Integration of Coordination layer components

During Phase 2, the deployment integration of the Release A of most coordination layer components was completed. These include:

- The 5GENESIS Portal
- The 5GENESIS Experiment Lifecycle Manager (ELCM) and its executive back-end, i.e. OpenTAP
- The 5GENESIS Slice Manager
- The storage (InfluxDB) and visualization (Grafana) components of the monitoring subsystem

The above mentioned elements have been interconnected using the integration and testing procedures detailed in D5.1. It is now possible to configure and execute an experiment via the Portal, have it automated by the ELCM, collect the measurements in the monitoring backend and visualize them.

Also, the Release A of the Slice Manager was deployed and integrated with the NFVO (OSM). The deployment and lifecycle management of a simple slice containing a set of VNFs was verified.

All coordination layer components have been deployed as VMs in the core OpenStack infrastructure in the platform Data Centre, with the exception of ELCM/OpenTAP, which currently runs only under Windows. Due to inherent difficulties with launching Windows VMs in the OpenStack infrastructure, these components were installed in a separate physical machine. However, the plan is to eventually migrate to Linux and have also these components hosted in OpenStack.

In addition, testing probes were deployed in Openstack. An iPerf Agent is running in each probe VM, responsible for communication with OpenTap through agent’s REST Api.

The test case illustrated in the screenshots below, includes an iPerf measurement between two probes started from the Portal UI and executed as an OpenTap test plan. Results from OpenTAP are saved in InfluxDB with new “ExecutionId” for every test executed from portal UI.

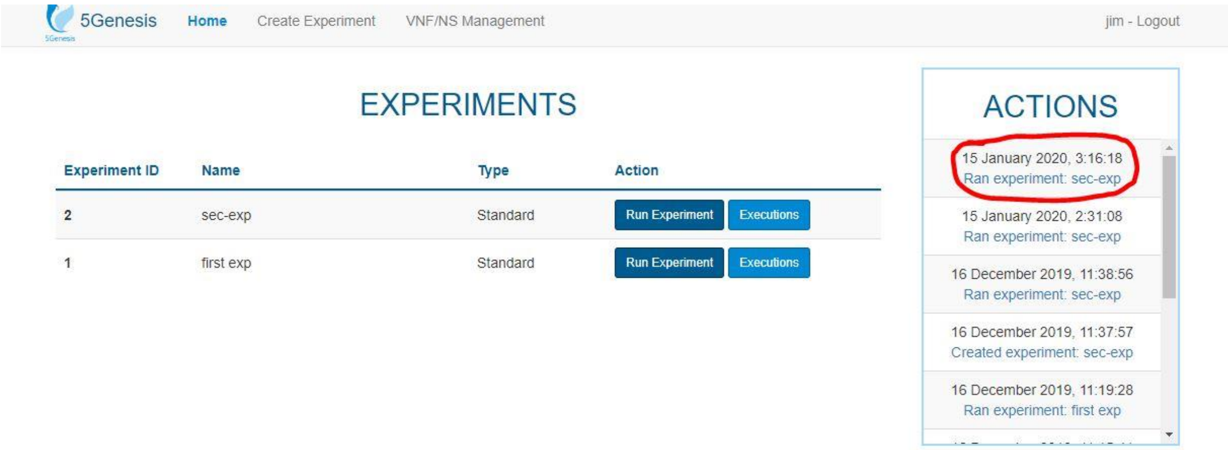

Figure 26. Experiment configured via the Portal

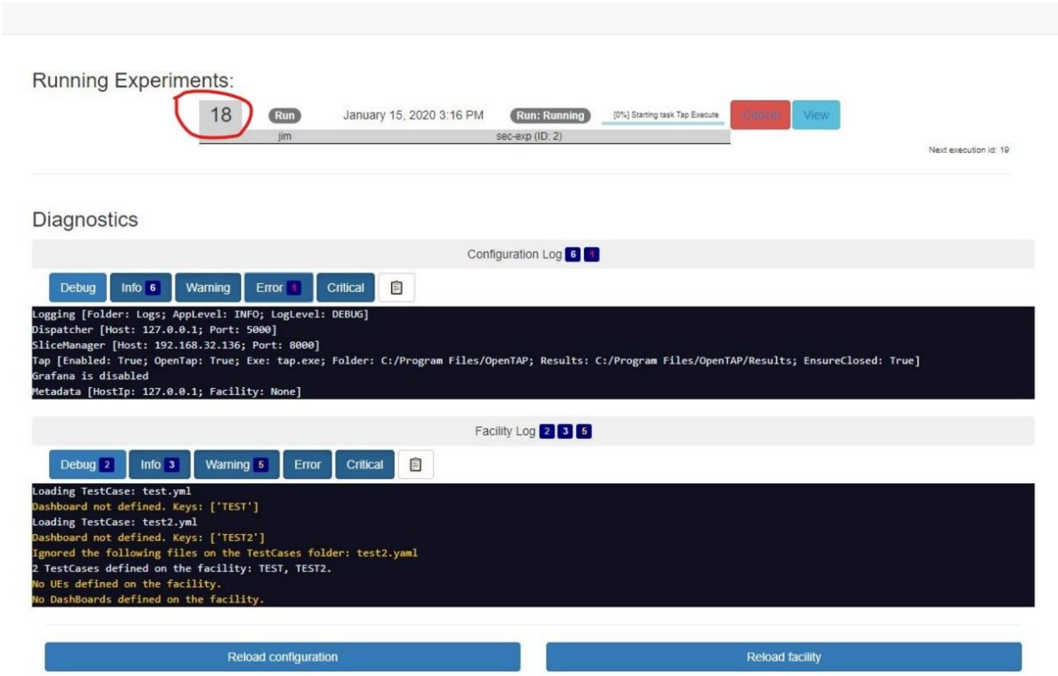

Figure 27. Experiment monitored via the Portal

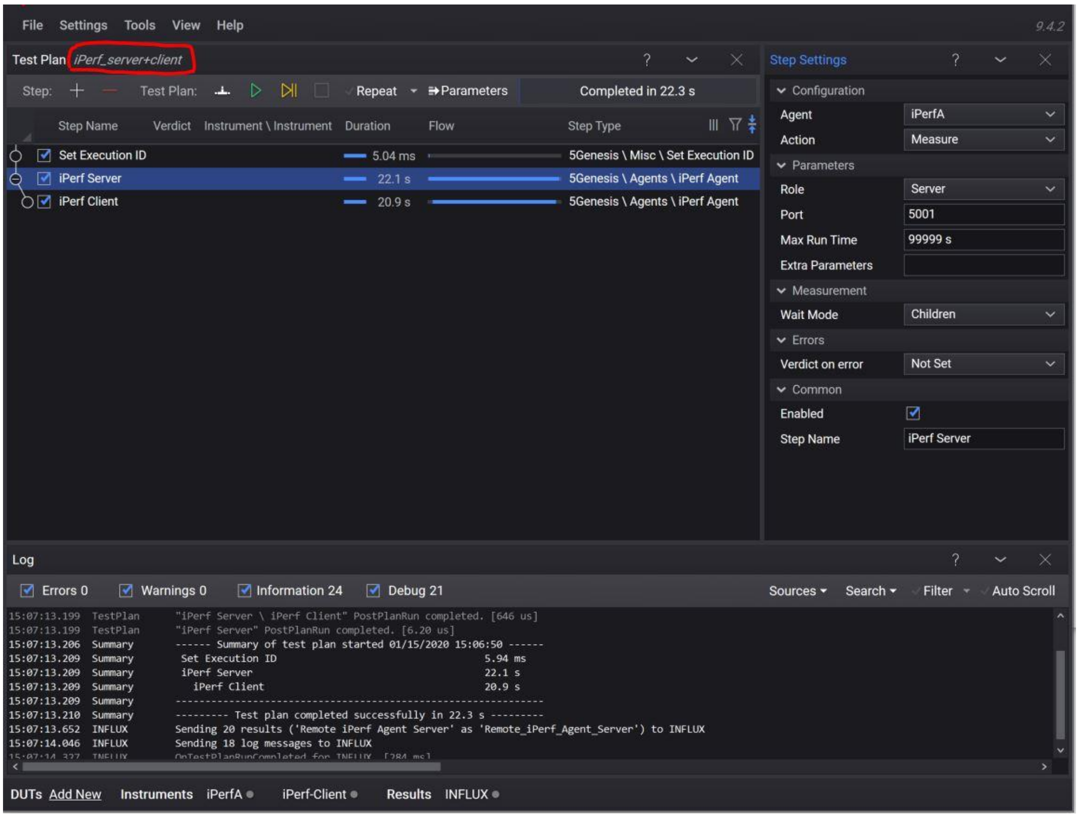

Figure 28. Experiment execution automated in OpenTAP

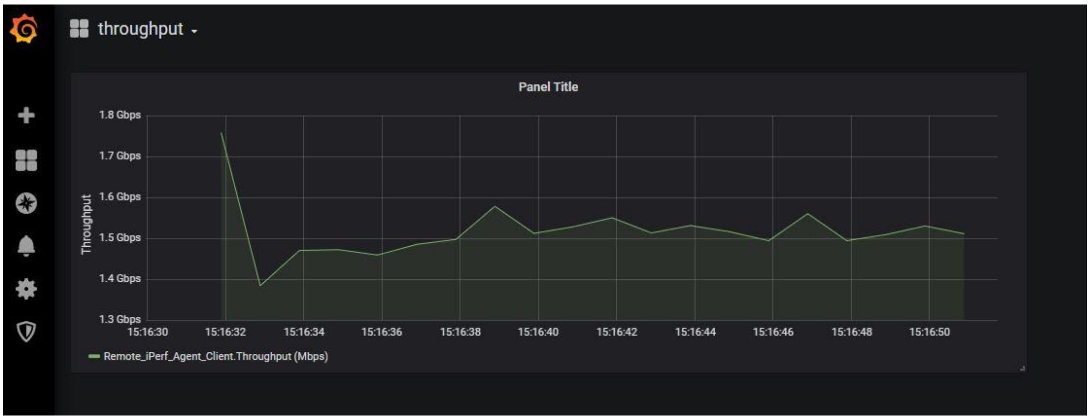

Figure 29. Experiment results visualized in Grafana front-end

3.4. Next Milestones

The activities planned for the third and final phase of the Limassol platform development include the following:

- Upgrade to 5G NR and integration in the platform, so that NR is fully supported in the access segment. Non-stand-alone configuration will be initially supported, with the aim to reach SA configuration by the end of the project, always depending on the development progress of the corresponding modules.
- Upgrade to 5G Core, depending on the progress of Stand-alone configuration as well as the availability of the corresponding functionalities.

- End-to-end slicing, i.e. provisioning of complex slices across the platform, including VNFs at the core and edge, dedicated resources at the backhaul and also at the access network. Integration of Release B of the Slice Manager, interconnection with all relevant Infrastructure layer functions of the platform.
- Integration of the MONROE probes and interconnection with the MONROE monitoring framework.
- Development of a portable 5G Hotspot, for the implementation of use cases in the field.
- Integration of Release B (upgrade) of all coordination layer components.
- Implementation and execution of UC1 and UC2 in the field.

4. Use Case Specific Extensions

4.1. Use Cases Target Deployment

4.1.1. 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. Two scenarios will be included, which are quite relevant to the needs of modern cargo fleets:

i) *Crew welfare and on-board communications:* the crew will be able to seamlessly use their personal 5G smartphones on board, as they were on shore. Crew-to-crew and crew-to-vessel communication will be locally served using 5G local breakout (LBO) mechanisms, deployed as edge services, to avoid unnecessary overload of the satellite backhaul.

ii) *Officer-to-office communications:* selected ship officers (Captain, First Engineer etc.) will be able to directly contact the offices of the shipping company using their personal 5G smartphones, from any location on the vessel (not only from the bridge). 5G slicing will be used to protect this service and prioritise it over the welfare service (i).

A third scenario will be elaborated in the course of the project, combining on-board and ashore content, in order to show the value of eMBB on-board without the constraints of the satellite link.

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 Phase 3, 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.

The full implementation of UC1 is planned for Phase 3.

As for the user equipment, it is expected that, by Phase 3, when this demo is planned, commercial 5G smartphones will already be on the market.

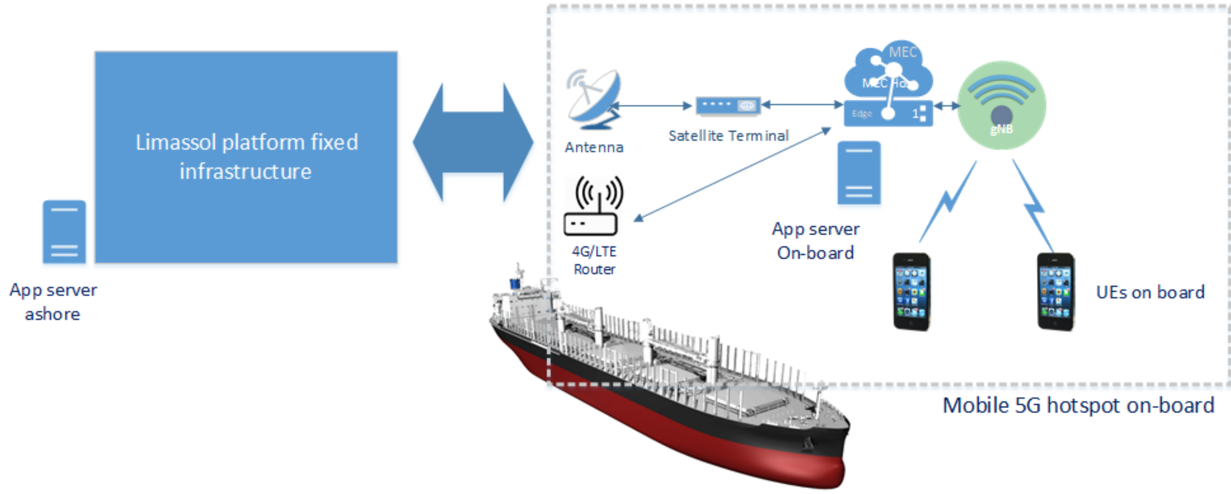

Figure 30. Configuration for the maritime communications scenario

4.1.2. UC2: 5G Capacity-on-demand and IoT in Rural Areas

This use case is focused on providing connectivity in underserved areas, like rural areas. Moreover, IoT services are provided at the top of the infrastructure created by the composition of the Satcom link and the terrestrial backhaul.

For this Use Case, the main objective is the integration of Non-3GPP Access network within the 5G infrastructure. The main approach taken for the implementation is that physical and virtual gateways will be directly connected over 5G-NSA infrastructure. To integrate the physical gateway connection onto the 5G infrastructure the selected method was 'Via 3GPP access network, using S1 interface, thus the gateway must support: LTE connectivity and have an IP stack'

For the first iteration of the UC1 we integrated one of the solutions provided by the EU funded project INTER-IoT[5]. This solution includes the connection to heterogeneous devices through a gateway (divided in physical and virtual parts) that translates the information provided by the sensors to common data formats and protocols. Specifically, during Phase 1 we aimed at the demonstration of a simple IoT scenario where a sensor and an actuator where connected to different physical gateways and communicated over the Limassol Infrastructure.

In particular, the solution was composed by several physical components (LoRaWAN compatible device, Arduino compatible device and physical gateways) and virtual ones (virtual gateway and IoT services)

Regarding components and technologies used for UC2 Phase two, there have not been significant modifications to the hardware/software used for this second phase of the UC implementation, but rather to the configuration and lifecycle management of the components.

Examples of the components used for the UC2 can be observed in the Figure 31, from left to right an Arduino compatible device equipped with actuator LEDs in different colors used to display the changes in temperature, humidity, battery life, etc. A Physical gateway with the

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

LoRa module and antenna and a customized LoRa device with temperature, pressure and humidity sensors.

Figure 31: Arduino device with Colour LEDs, Physical Gateway LoRa compatible and LoRa device with sensors for UC2.

For the first phase of integration, we were able to deploy the IoT service with two Physical Gateways and two Virtual Gateways, respectively connected, together with a LoRa device and an Arduino device. In Phase two, we increased the number of devices, testing in the lab different types of commercial Lora devices. Moreover, for Phase 2 we are testing the integration of the MONROE node in order to collect better and more accurate information from the IoT devices.

During Phase 1, the deployment of the physical gateway was performed correctly, and the virtual gateway was deployed in two locations (edge and core). However, as there were no VIM installed in the edge (yet), the deployment of the VMs was done manually. However, for the second Phase, with end-to-end MANO support, this logical deployment has been modified and improved using VNFs to implement the services provided by the Virtual-GW, thus allowing its deployment in real-time through the creation of a Network Service with its different VNFs, being managed by the orchestrator on the fly.

4.2. Use Cases Phase 2 Accomplishments

4.2.1. UC1: 5G Maritime Communications

As mentioned above, the implementation of UC1 is planned for Phase 3. So far, the following relevant preparatory tasks have been achieved:

- Integration of core and edge cloud for the deployment of edge services (see Sec. 3.3.4)
- Integration of link aggregation functions, so that the 5G hotspot at the vessel can benefit from either terrestrial and satellite backhauling (see Sec. 3.3.5)
- First deployment of slice manager (see Sec. 0)
- A series of discussions/focused workshops between SHC, AVA and MARAN to discuss and clarify the logistics for the pilot as well as the exact applications to be demonstrated.

4.2.2. UC2: 5G Capacity-on-demand and IoT in Rural Areas

After the testing period in Phase one, we focus on the improvement of the KPIs measurement gathering within the UC2 for the second phase of testing.

One of the main KPIs to be measured in the Phase two testing period will be the service creation time, that is the time until service is requested and this is provided, including the slice deployment, the Network Service creation and the VNF deployment, configuration and running. Hereby, in order to provide IoT services on demand, the IoT Virtual-GW has been containerized in a VNF to facilitate handling by the management and orchestrator components (WP3) in the Limassol platform. 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 are the main accomplishments for this period.

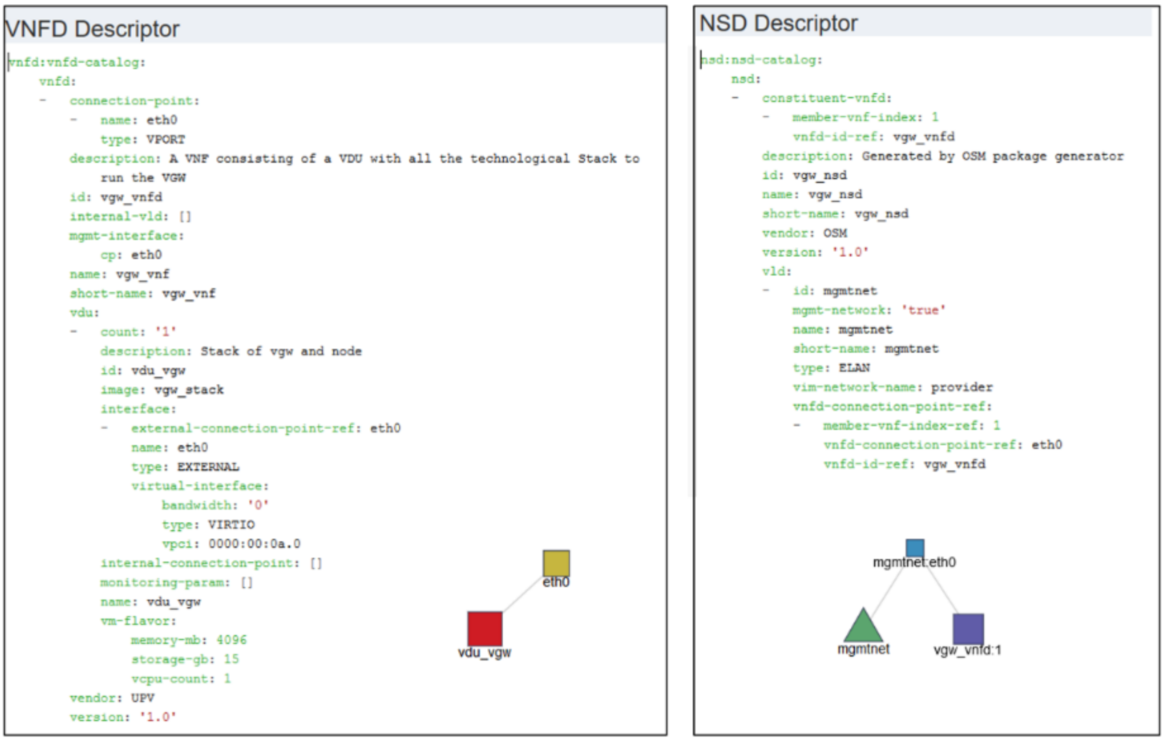

Figure 32. VNF and NS descriptors for the IoT use case components

4.3. Next Milestones

5G Maritime Communications use case: In the months to come, MARAN, AVA and SHC will fix the details of the logistics and proceed with the leasing of the use case-specific equipment (with particular focus on the 3-axis stabilized antenna needed for this purpose). Appropriate equipment and applications will be deployed for the use case.

IoT Use Case implementation: During the next phase, an IoT scenario will be prepared for field trials (rural case). The MONROE node will also be integrated for monitoring.

For the implementation of both UCs in a field environment under Phase 3, the essential components of the mobile hotspot will be integrated in a portable container (rack or similar).

5. CONCLUSIONS

This document presented the second release of the Limassol platform, as well as the design and technological choices (to date) towards its final implementation. During this second iteration, the focus has been on the tighter integration of Release A components (such as end-to-end management and orchestration extending to the satellite edge), the deployment of Coordination layer components (Portal, ELCM, Slice Manager, Monitoring) as well as the upgrade to early implementations of 5G NR.

During the last three months of this cycle, 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 toward integrating elements and technologies.

The platform will be used for the second round of experiments until March 2020, and the report on the KPIs will be available in deliverable D6.2 in March 2019. This document will be followed by the Deliverable describing the Release C of the platform in December 2020.

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