5Genesis

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

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Deliverable D4.3

The Athens Platform (Release C)

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LIST OF ACRONYMS

Acronym	Meaning
5G PPP	5G Infrastructure Public Private Partnership
5GC	5G Core
5G-IA	The 5G Infrastructure Association
AMF	Access and Mobility Function
AP	Access Point
AR	Augmented Reality
AUSF	Authentication Server Function
AWS	Amazon Web Services
BYOD	Bring Your Own Device
CA	Carrier Aggregation
CESC	Cloud-Enabled Small Cell
CO	Central Office
CoMP	Coordinated Multi-Point transmission/reception
COTS	Components off the self
CPRI	Common Public Radio Interface
C-RAN	Cloud-RAN
CSP	Content Service Provider
CUPS	Control and User Plane Separation
DoS	Denial of Service
DDoS	Distributed Denial of Service
DU	Digital Unit
E2E	E2E
ECM	Eurecom
eICIC	Enhanced Inter-Cell Interference Coordination
eMBB	Enhanced Mobile Broadband-5G Generic Service
eMBMS	Evolved Multimedia Broadcast Multicast Services
EMS	Element Management System
eNB	eNodeB, evolved NodeB, LTE eq. of base station
EU	European Union
EPC	Evolved Packet Core
EUTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplexing
gNB	gNodeB, 5G NR, next generation NR eq. of base station
GPP	General Purpose Processor
HetNet	Heterogeneous Network
H-RAN	Heterogeneous RAN
ICIC	Inter-Cell Interference Coordination
ICMP	Internet Control Message protocol
IDS	Intrusion Detection System
IoT	Internet of Things
KPI	Key Performance Indicator

Acronym	Meaning
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution - Advanced
MANO	Management and Orchestration
MCS	Mission Critical Services
MEC	Mobile Edge Computing
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications-5G Generic Service
MOCN	Multi-Operator Core Network
MONROE	Measuring Mobile Broadband Networks in Europe.
MORAN	Multi Operator Radio Access Network
MPTCP	MultiPath TCP
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NS	Network Service
NSMF	Network Slice Management Function
NR	New Radio
OAI	OpenAirInterface
OAM	Operations, Administration & Management
ODL	OpenDayLight SDN Controller
OF	OpenFlow
OFDM	Orthogonal Frequency Division Multiplexing
ONAP	Open Networking Automation Platform
ORI	Open Radio Interface
OSM	Open Source MANO
OTT	Over-The-Top
PCell	Primary Cell
PCI	Physical Cell ID
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol (PDCP)
PoP	Point of Presence
P-GW	Packet data node GateWay
PNF	Physical Network Functions
PPDR	Public Protection and Disaster Relief systems
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RRH	Remote Radio Head
RRM	Radio Resource management
RU	Radio Unit
SDN	Software Defined Network
SDR	Software Defined Radio
SGi	Serving Gateway interface

Acronym	Meaning
SGW	Serving Gateway (3GPP)
SMF	Session Management Function
STA	Station
TCP	Transmission Control Protocol
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
UE	User Equipment
UPF	User Plane Function
uRLLC	Ultra-Reliable, Low-Latency Communications
VIM	Virtualised Infrastructure Manager
VR	Virtual Reality
WIM	WAN Infrastructure Manager
WSMP	WiFi Service Management Platform

List of Figures

List of Tables

Executive Summary

This document describes the final implementation design of the 5GENESIS Athens Platform. During the project, the Athens Platform has evolved to a facility with complete 5G mobile network technologies, cloud, and edge computing infrastructure, as well as automated experimentation capabilities, leading to an open experimentation testbed that will hopefully serve as a testing environment for vertical industries in the near future. The Athens platform is one of the 5GENESIS six experimental platforms located in Europe, aiming to validate several Key Performance Indicators (KPIs) defined by 5G-PPP, i.e., latency, throughput, speed, capacity, service creation time, etc. These platforms, located 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" [1], in response to the project requirements identified in deliverable D2.1 "Requirements of the facility" [2].

The Athens Platform is comprised of the NCSRD Campus, the OTE Academy facilities and the "Stavros Mavrothalassitis" Municipal Stadium of Egaleo. The evolution of the Athens platform has been achieved through a series of optimizations as new specifications and components are being made available either commercially or within the consortium. All 5GENESIS facilities follow a 3-phase integration and testing regime, where new features, functionalities and HW components are integrated in the infrastructure. Each integration cycle is followed by testing and validation.

This document highlights the changes and advances from Phase 1 (Release A), Phase 2 (Release B) and the final achievements during Phase 3 (Release C). In addition, each platform has demonstrated or will demonstrate a number of vertical use cases allowing specific KPI testing based on their relevance to the use case, the timeline of which was updated during the course of the project due to COVID-19 restrictions. For the Athens platform, three use cases are anticipated to be completed by the end of the Project, namely: i) Big Event in an actual soccer field; ii) Unmanned Aerial Vehicle (UAV)-aided surveillance and iii) Security-as-a-service. The experimentation activities over these use cases will be reported on the upcoming D6.3 Deliverable, due in December 2021.

The evolution of the Athens Platform from Phase 1 to Phase 3 in the course of WP4, has provided a set of technological achievements, summarized as follows:

- The deployment of Open5GENESIS Suite (Release B), an open experimentation framework that serves as the interface between the platform and the experimenter and is responsible for the experiment's instantiation and lifecycle management. The framework includes Coordination Layer components developed and integrated within 5GENESIS and include the Experimenter Access Portal, the Experiment Lifecycle Manager, Results Repository, Statistical Analysis Tools, the 5G Security Analytics Framework, as well as the Slice Manager.

- The custom development and deployment of the Slice Manager that began on Phase 1 and was completed on Phase 3, providing a variety of capabilities, such as per-slice monitoring, concurrent slicing and management of commercial and open-source equipment installed on the 5GENESIS Platform Sites.
- The installation and integration of several MANO components, including OSM as the Network Function Virtualisation (NFV) orchestrator, Network Management Systems, Element Management Systems for controlling RAN and Core components, as well as SDN controllers.
- A significant transport network spanning the NCSRD site through a spine-leaf network topology with WAN emulation capabilities, interconnecting the three sites, NCSRD, COSMOTE and Egaleo Stadium via an optical fiber link and point-to-point radio technology, respectively.
- The deployment of several 5G mobile network configurations, addressing a handful of 3GPP Options (Options 2/3/3x/3a) in SA and NSA modes, as well as a Local-Break-Out Node option that runs over the interconnection of the previously independent mobile networks operated by NCSRD and COSMOTE. These network configurations are described in detail in subsequent sections and are based on both commercial and open-source products, purchased/developed and integrated within 5GENESIS. These deployment options include edge cloud, slice management and monitoring capabilities that interact with the Coordination Layer and Management and Orchestration Layer components, leading to an overall automated 5G experimentation framework.
- The successful interconnection between the Athens and Malaga Platforms through GÉANT to support cross-platform experimentation.
- The successful use case trials that took place as preparatory demonstrations towards the final experimentation campaigns in the context of WP6.

The Athens Platform will serve as the testing environment of KPIs validation in WP6 activities and will add significant value in the 5G experimentation landscape. We hope that the testing facility will also attract an important number of interested stakeholders in the near future that wish to deploy and test their applications in a controlled environment with heterogeneous technologies. The Athens Platform is the result of continuous integration and testing procedures all along the course of the deployment, reassuring the experimenter on the soundness of the testbed before the experimentation cycle.

Table of Contents

1. INTRODUCTION

1.1. Purpose of the document

This document presents the final infrastructure deployments across the sites comprising the 5GENESIS Athens Platform located in Greece, which was implemented during Phase 3 of the Project. More specifically, the purpose of this deliverable is to meet the following WP4 objectives:

- Accommodate WP2 requirements and specifications.
- Integrate the components that were implemented in WP3 within each platform in order to constitute the 5GENESIS facility.
- Support and facilitate the deployment of the described Use Cases (Section 3).
- Enable system level validations as per WP5 specifications.
- Provide the means for the WP6 KPI validation and verification campaigns.

Currently, the project has released the following documents that are used as inputs to this document (see Table 1).

Table 1 Document interdependencies

id	Document title	Relevance
D2.1 [2]	Requirements of the Facility	The document sets the ground for the first set of requirements related to supported features at the testbed for the facilitation of the Use Cases.
D2.2 [1]	5GENESIS Overall Facility Design and Specifications	The 5GENESIS facility architecture is defined in this document. The list of functional components to be deployed in each testbed is defined.
D2.3 [3]	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D2.4 [4]	Final report on facility design and experimentation planning	This deliverable provides a complete view of the final 5GENESIS architecture, covering all the components of the experimentation chain, from the experiment control tools to the infrastructure.
D3.1 [5]	Management and orchestration (Release A)	The document presents the MANO solutions that are integrated in the infrastructure. Interfaces and deployment options are also described.

D3.3 [6] / D3.4 [7]	Slice management WP3 (Release A/B)	The documents detail the Slice Manager solution, its interfaces towards the MANO and NMS components in Releases A & B.
D3.5 [8]	Monitoring and WP3 analytics (Release A)	The document details the Infrastructure Monitoring components and the interfaces with infrastructure elements.
D3.9 [9]	5G Core Network WP3 Functions (Release A)	The document details the 5G Core network functions and provides input on their integration with the infrastructure and management components.
D3.11 [10]	5G Access Components and User Equipment (Release A)	The document details the 5G Radio Access components and UE devices.
D4.2 [11]	The Athens Platform	This document serves as an overview of the implementation efforts for the transformation of the Athens platform to an E2E 5G facility in the framework of the 5GENESIS project.
D5.1 [12]	System level tests and verifications	This document provides guidelines, integration tests and software packages for the realization of the 5GENESIS facility coordination layer components.

1.2. Structure of the document

The document is structured as follows:

Section 2 provides an overview of the topology of the Athens Platform, the Platform's sites, as well as a distilled summary of the components found at the three logical layers comprising the 5GENESIS Architecture, namely the *i)* Coordination Layer, *ii)* MANO Layer and *iii)* Infrastructure Layer).

Section 3 is devoted to the three use cases that will be realized in the final version of the Athens Platform, describing their components, the scenarios of utilization and the expected outcome.

Section 4 follows with a description of the Platform evolution over the period 2018-2021, listing the accomplishments during Phase 1 (2018-2019) and Phase 2 (2019-2020), as well as the final deployment achieved in Phase 3 (2020-2021).

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 Athens platform deployment. In addition, it allows to:

- Understand the requirements and risks for each deployed module and component within the Athens platform.
- Facilitate technology selection and design decisions for their components.
- Understand the limitations and restrictions in technology deployment and usage.

Finally, this document helps to justify design decisions for the deployment of 5G components and evaluate the progress in adoption and deployment of the 5G infrastructure.

2. ATHENS PLATFORM OVERVIEW

This section presents an overview of the Athens Platform topology, the constituting sites and the related technology components. It is a distilled summary of the extensive platform deployment description presented in deliverable D4.2 [11].

The section is structured in three subsections and presents the platform implementation on the basis of the layered approach proposed by the 5GENESIS Reference Architecture as defined in D2.2 [1].

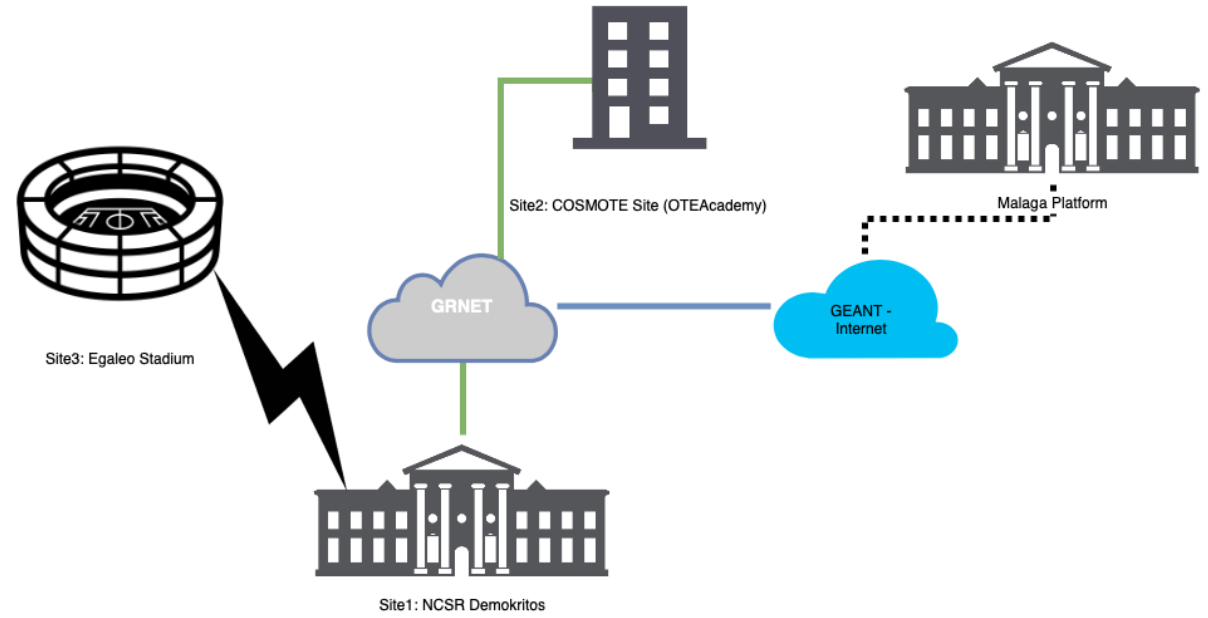
2.1. Platform Sites Topology

2.1.1. Overall topology

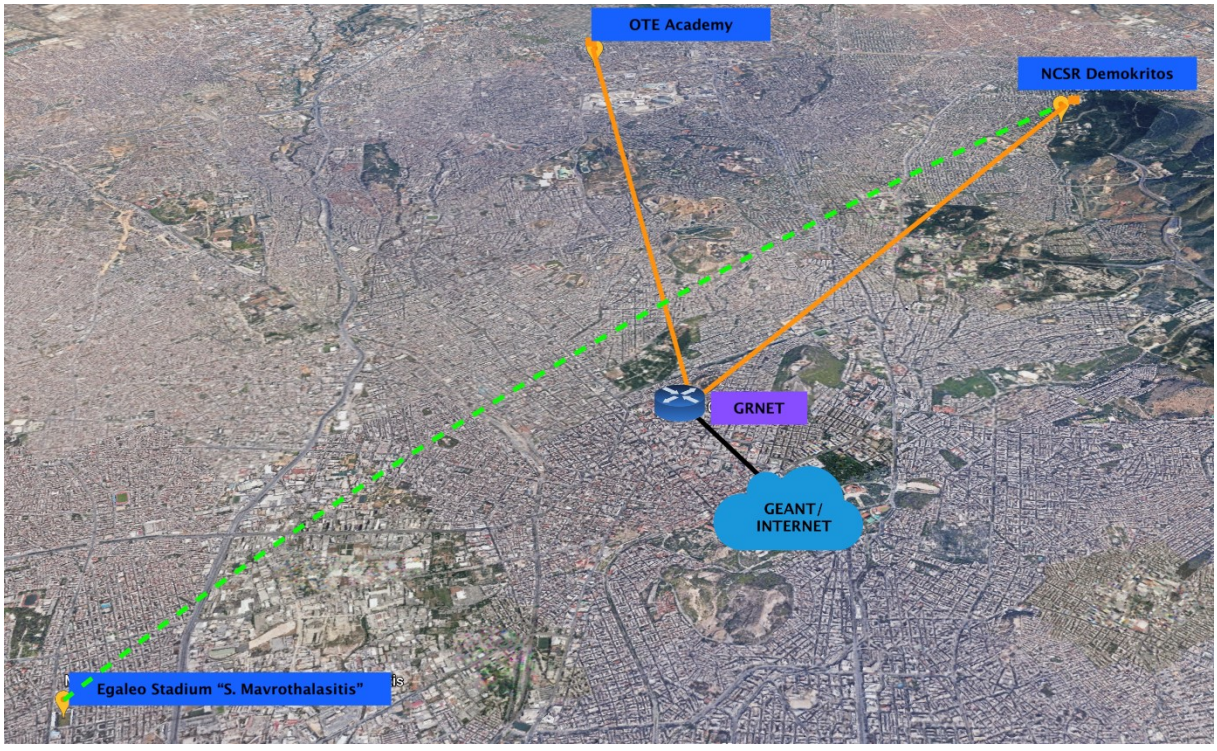
The Athens 5G platform comprises three dispersed sites in the Athens metropolitan area forming an end-to-end (E2E) experimental 5G testbed. It features 5G and 4G radio access technologies (RATs) deployed in both indoor and outdoor environments, combining software network technologies (*i.e.* NFV and SDN) and edge computing deployments. The sites that comprise the platform are illustrated in Figure 1 and they are described below:

- Site 1: The campus of NCSR "Demokritos", in north-east Athens, is a 150-acre area, combining indoor and outdoor environments, dispersed around the campus and interconnected by an optical fiber backbone; NCSRD is directly connected to Greek Educational, Academic and Research Network (GRNET)[1], which provides access to Internet and GÉANT (pan-European data network for the research and education community). This site is responsible for hosting most of the infrastructure required for the management, orchestration and coordination of the Athens Platform.
- Site 2: The COSMOTE building (OTEAcademy), in the north of Athens, is a multi-functional complex, combining various indoor and outdoor usage scenarios; It is also directly connected to GRNET which provides access to GÉANT. Internet access is provided by OTE network. This site is hosting infrastructure components, radio access components and NFV/Edge Computing infrastructure.
- Site 3: The stadium of Egaleo (Stavros Mavrothalasitis), in West Athens, that is used to host demonstrations in a more "realistic" environment and suitable to investigate terrestrial wireless backhaul related metrics (i.e., latency, throughput, etc.). Currently, the location's connectivity is based on a wireless point-to-point link to NCSRD, depicted in Figure 12. This site is hosting infrastructure components that allow the experimentation and support of use cases related with the edge computing, and Control Plane – User Plane separation in a realistic environment.

[1] GRNET http://grnet.gr



(a)



(b)

Figure 1 (a-b) Athens Platform Sites Overview

2.1.2. Site 1 - NCSRD Campus

NCSRD, one of the biggest research centers in Greece, has an extended campus area that is used to cover both indoor and outdoor testing scenarios (Figure 2). NCSRD provides a reliable operation of the network to the Athens Platform, computing and Radio Access Technology (RAT) deployments within its premises. In addition, NCSRD provides virtualized resources in its datacenter facilities as well as edge computing domains at specific locations. A variety of cloud and virtualization infrastructure is available to support core and edge deployments.

To cater for outdoor coverage, a MacroCell is installed at a high mast, providing coverage to the whole campus area (see Section 2.3.2). Indoor coverage is provided by four small cells that operate in selected locations. The Administration and Library deployments are based on eNBs that run the Amarisoft RAN software and connect to the Amarisoft Core Network component via the backhaul network.

The backhaul network is enabled by the campus's optical network. Both eNBs are using SDR hardware for the radio part (i.e USRP B210 and PCIe SDR board respectively). Finally, two Nokia Flexi Zone Multiband Indoor Pico BTS small cells are deployed at the Institute of Informatics and Telecommunications (IIT) building, which connect the backhaul network to the Athonet LTE EPC through 10Gbps Ethernet. In addition, the Media Networks Laboratory includes an open source mobile network implementation based on ECM's OpenAirInterface (OAI) elements that interoperate with COTS UEs. The OAI eNB has been deployed on an x86 physical host connected to a USRP B210, transmitting on FDD mode in band 7 (2600 MHz), while a second machine is running the virtualized OAI core network.

Regarding the evolution towards 5G, NCSRD was granted an experimental license for 5G trials for transmission in the 3.6 GHz frequency band. 5G RAN and Core elements have been deployed from Amarisoft (RAN and core), RunEL (RAN only), ECM (RAN only) and Athonet (core only), allowing several configurations of 3GPP Options in Standalone (SA) and Non-Standalone (NSA) Modes in both indoor and outdoor trials.

Wi-Fi access points (APs) are deployed to provide coverage to the gaps of the Mobile Network Cells. Wi-Fi APs are deployed in every building to help maximize the coverage and capacity of the access network. Typically, they operate at the 5 GHz ISM Band using the IEEE 802.11ac standard.

A physical deployment topology illustrating the radio coverage is provided in Figure 2.

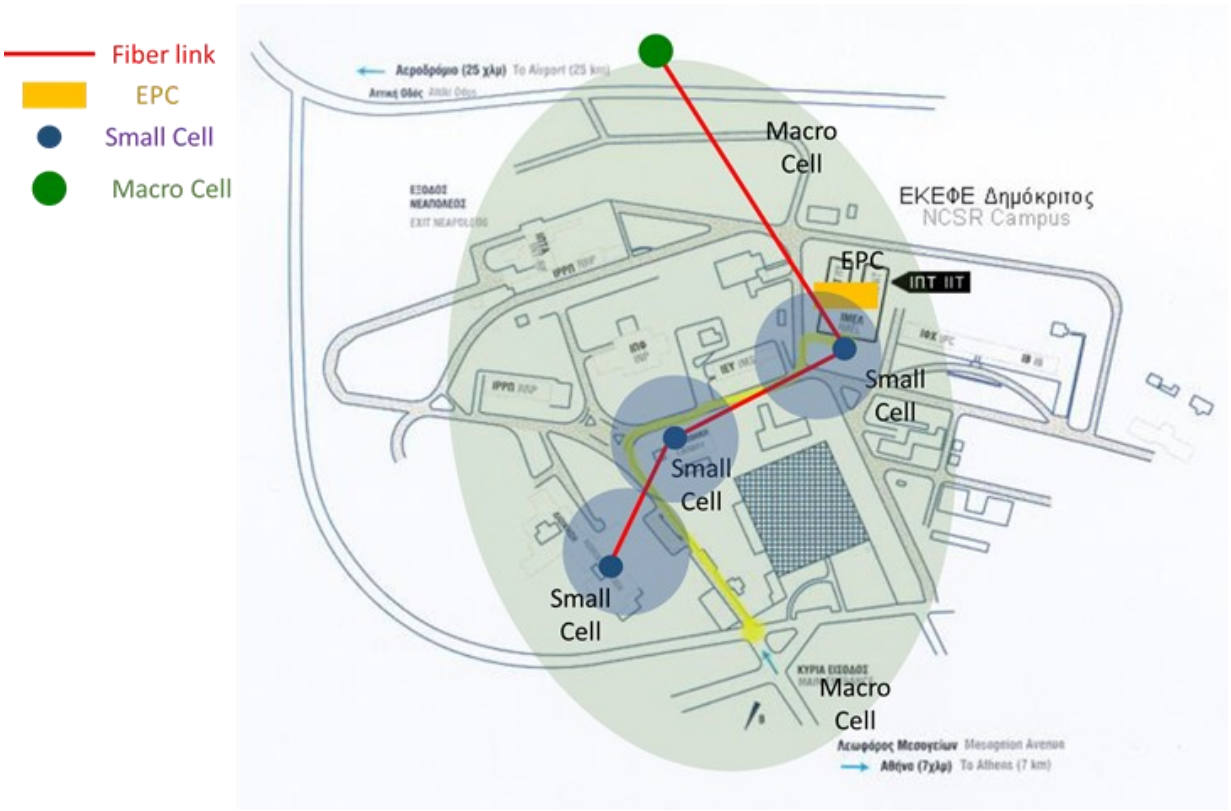


Figure 2 NCSRD Site

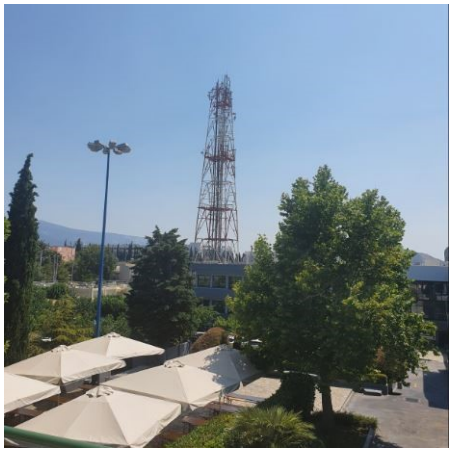
2.1.3. Site 2 - COSMOTE Site

COSMOTE's testbeds for research and development activities are located in OTE Academy's site at Marousi, Athens. The site can offer extensive data center infrastructure (more than 720 CPU cores, 1700GB RAM and 120TB storage space), and is interconnected (mostly) via 10Gbps fiber/copper links. More specifically, the setup can be split into one or more cloud slices (controllers/ compute nodes/ hypervisors) of various sizes, either in bare metal or virtualized form, and allows high degrees of freedom for customized configurations.

In the context of 5GENESIS Facility and the Athens Platform, COSMOTE is hosting edge network capabilities empowered by the lab's cloud infrastructure, as well as 5G outdoor and indoor deployments based on commercial equipment. COSMOTE's OpenStack implementation provides a private cloud service model, as Infrastructure as a Service (IaaS), where required use case VNFs are deployed. Furthermore, complementarily to the NCSRD core network deployment, an LTE/EPC/IMS edge network is used to support the use cases and exhibit edge computing capabilities. The setup is based on a lightweight 4G EPC/IMS – Evolved Packet Core/IP Multimedia Subsystem provided by Athonet. The deployment is complemented by a number of small cells connected to the EPC; namely a number of "Flexi Zone Multiband Indoor Pico BTS" (FZ MBI) provided by NOKIA. As of Phase 1, installation and configuration activities for the 5G Nokia AirScale indoor/outdoor NSA (option 3) system has been completed with the purpose of integrating it with the Athens Platform for the testing and validation of 5G KPIs.

Figure 3 illustrates the current deployment. It can be observed that the MANO and coordination components are installed in separate cloud infrastructure (IaaS cloud), and the actual mobile

network is operating over two edge clouds supporting local breakout (LBO) to enable MEC traffic redirection.



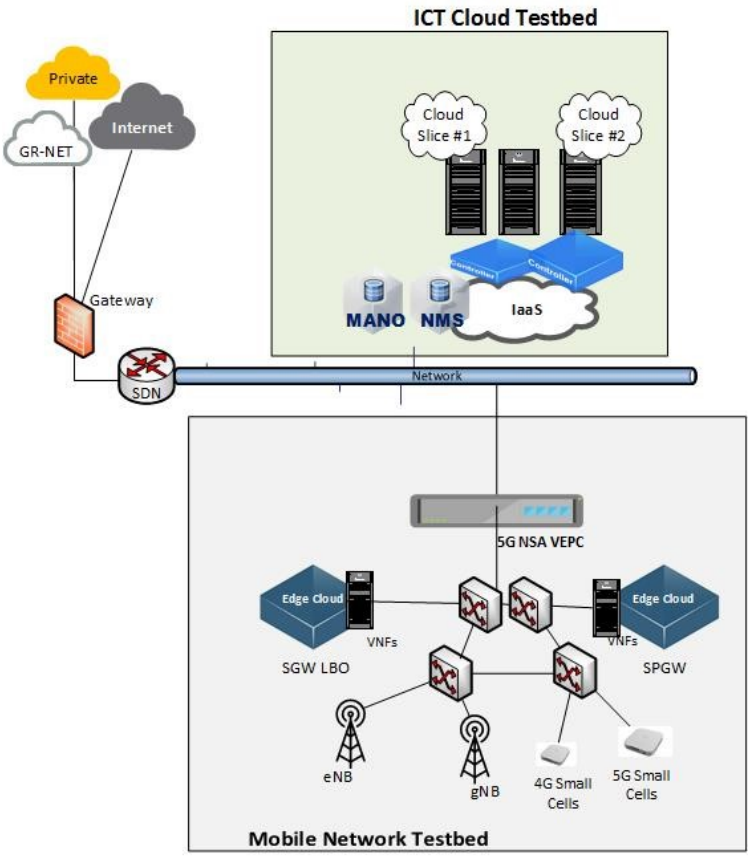


Figure 3 COSMOTE Site

2.1.4. Site 3 - Egaleo Stadium Site

Figure 4 presents the deployed architecture at the Egaleo Stadium. The RAN is composed of three small cells placed in cabinets providing coverage to the entire stadium. In addition, three cabinets that accommodate the 5G gNB components are already installed at the stadium. The stadium premises will also be equipped with small footprint edge computing infrastructure for the use case demonstration.

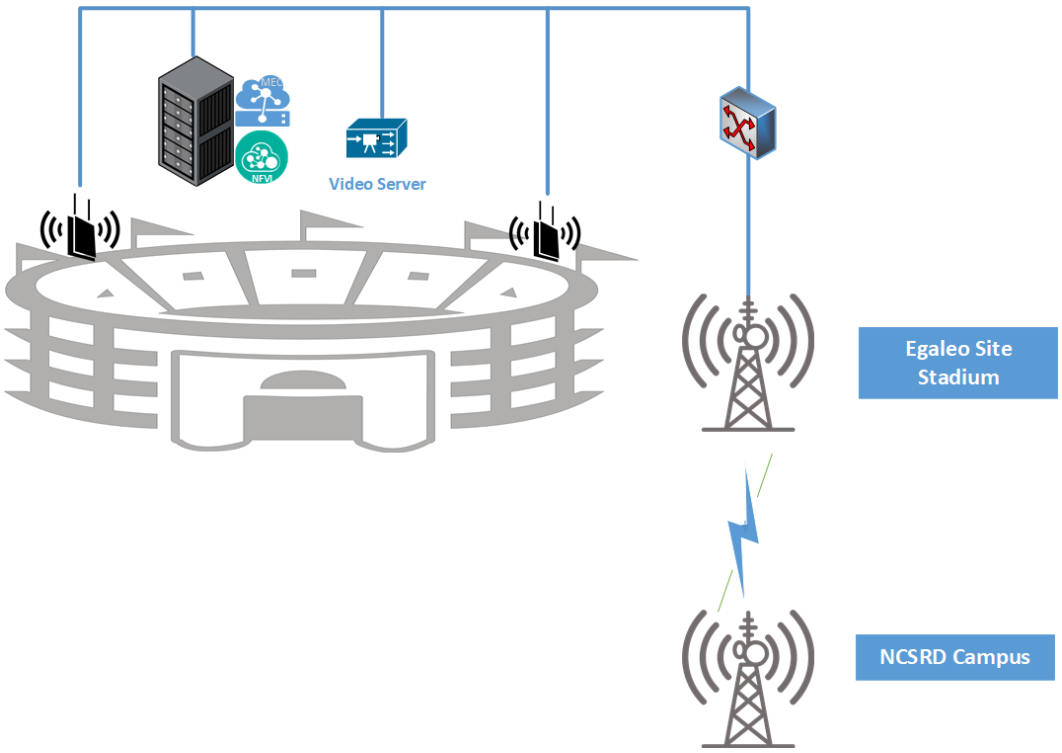


Figure 4 Egaleo Site

It should be highlighted that the equipment used in the stadium is available only during testing. This means that there is no fixed infrastructure deployed apart from the backhaul connecting to the NCSRD site and the cabinets that host the equipment during the test campaigns. This is due to precautionary reasons for equipment safety. During experiments, the required equipment is transferred to the site and configured specifically for the event.

2.2. Platform Deployment Setups

The Athens Platform provides a variety of 5G and 4G deployment setups, consisting of several vendor-specific and open-source products. This variety allows interested experimenters to select the most appropriate setups for testing and validating KPIs, while also comparing results on different scenarios.

Figure 5 provides an overall overview of the Athens Platform topology spanning over the three sites: NCSRD, COSMOTE and Egaleo Stadium, along with the deployed components and technologies as per the logical layers of the 5GENESIS Architecture. This Section provides an overall overview of the available setups in the Athens Platform, while Section 2.3 describes in detail the components and their implementations as they have been instantiated in the infrastructure of the Athens Platform, categorized in the logical layers of the 5GENESIS Architecture (namely the Infrastructure, MANO, and Coordination Layers).

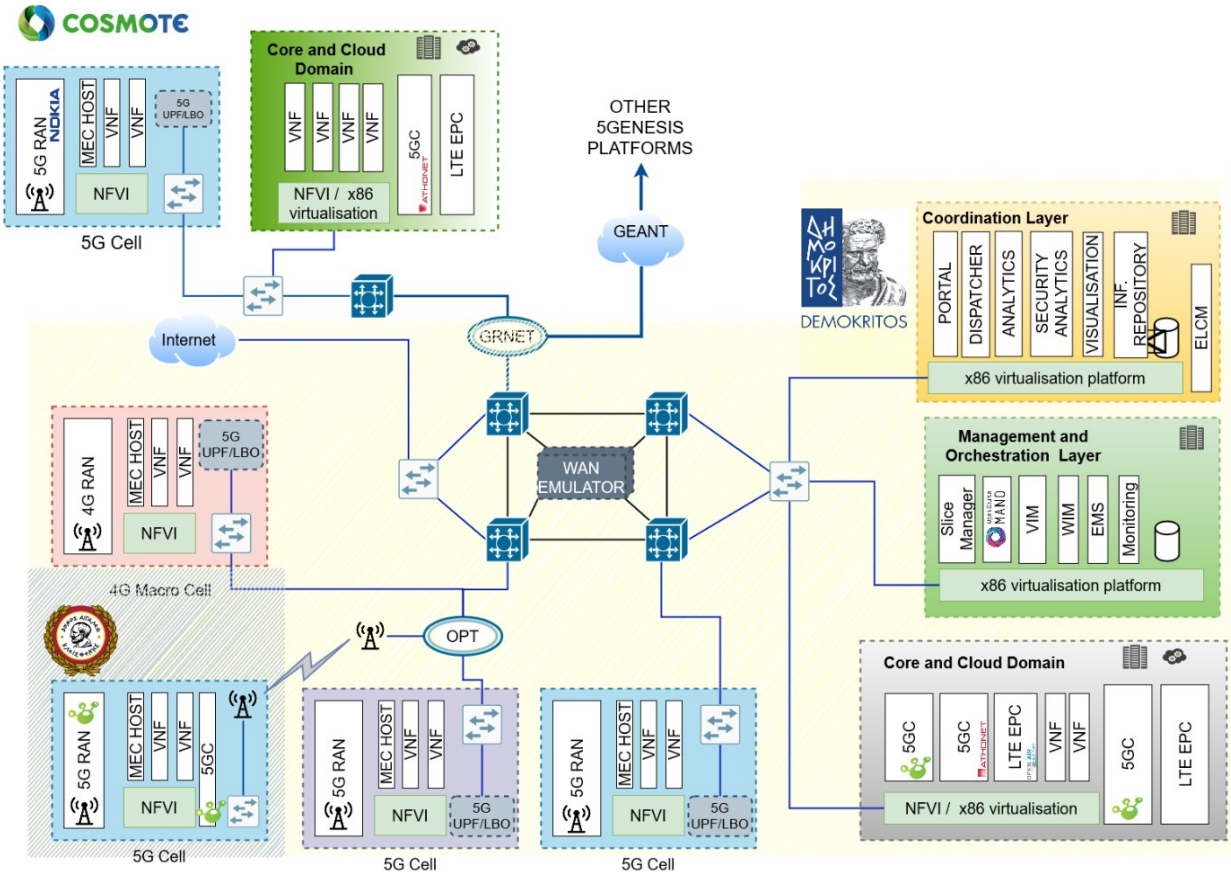


Figure 5 Athens Platform Topology

Table 2 and Table 3 include the available deployment setups located in the Athens Platform. Each setup is described by a unique identification number and includes information on the RAN, Core, Edge and Transport Network infrastructure, whether it integrates slice management capabilities, as well as the monitoring, management and orchestration components used in each case.

Each setup is used for different objectives. For example, setup *5G.1.noS1* include ECM's OAI gNB and nr-UE solutions and are used mainly for testing on the physical and MAC layers, since they do not include a connection to a 5GC (thus the name *"noS1"*). The integration of solutions brought from OAI and RuNEL were delayed due to COVID-19 and, thus, was removed from the plans for Athens Platform. The integration of this configuration will take place only on the Malaga Platform [13]. The remaining options in Table 2 consist of vendor specific equipment, provided by NOKIA, Amarisoft and Athonet, supporting a handful of 3GPP Options (Options 2/3/3x/3a) corresponding in SA and NSA modes. Table 3 provides an overview of the 4G configurations built from previous projects and extended during 5GENESIS to support the on-going verification and validation procedures of upper layer components until 5G equipment was made available. These commercial configurations are used with 5G and 4G UEs by several vendors.

Table 2 Athens Platform 5G Deployment Configurations

Deployment Parameters	5G Products/Technologies Options					
ID	5G.1.noS1	5G.3.Option3	5G.4.Option3	5G.5.Option3	5G.6.Option2	5G.7.Option2
Description	Open-source	Commercial NSA	Commercial NSA	Commercial NSA	Commercial SA	Commercial SA
Core Cloud	NA	NA	NA	OpenStack	OpenStack	OpenStack
Edge Cloud	NA	NA	NA	OpenStack	OpenStack	OpenStack
# Edge Locations	1	1	1	1	1	1
WAN/ Network	NA	SDN & Mininet	SDN & Mininet	SDN & Mininet	SDN & Mininet	SDN & Mininet
Slice Manager	NA	NA	NA	NA	Katana	Katana
MANO	NA	NA	NA	OSM	OSM	OSM
NMS	NA	NA	NA	OpenTAP	OpenTAP	OpenTAP
Monitoring	NA	Prometheus	Prometheus	NA	Prometheus	Prometheus
3GPP Technology	5G	5G NSA	5G NSA	5G NSA	5G SA	5G SA
3GPP Option	No-S1	Option 3x	Options 3x/3/3a	Option 3x	Option 2	Option 2
Non-3GPP Technology	NA	NA	NA	NA	NA	NA
EPC/5G Core Network	NA	Athonet Rel. 15	Amarisoft Rel. 15	Athonet Rel. 15	Amarisoft Rel. 16	Athonet Rel. 16 AWS
RAN	OAI gNB	Amarisoft eNB/gNB	Amarisoft eNB/gNB	NOKIA 5G Airscale	Amarisoft gNB	Amarisoft gNB
UE (Table 6)	OAI nr-UE	COTS UEs	COTS UEs	COTS UEs	COTS UEs	COTS UEs

Table 3 Athens Platform 4G Deployment Configurations

Deployment Parameters	LTE Products/Technologies Options			
ID	4G.1.SDR	4G.2.COM	4G.3.core	4G.4.edge
Description	OpenSource SDR with virtualized core	Vendor RAN with commercial vEPC	Commercial vEPC / SDR	Commercial EPC / SDR MEC
Core Cloud	NA	NA	YES - OpenStack	Yes- OpenStack
Edge Cloud	NA	NA	No	Yes - OpenStack
# Edge Locations	1	1	1	1
WAN/Network	SDN	SDN	SDN	SDN
Slice Manager	NA	NA	YES - Katana	Yes – Katana
MANO	NA	NA	OSM v6	OSM v6
NMS	NA	NA	eNB EMS	eNB EMS
Monitoring	NA	NA	Prometheus	Prometheus
3GPP Technology	4G LTE+	4G LTE+	4G LTE+	4G LTE+
3GPP Option	NA	NA	NA	NA
Non-3GPP Technology	NA	NA	NA	NA
Core Network	OAI vEPC	ATHONET vEPC	Amarisoft vEPC	Athonet EPC / MEC
RAN	OAI eNB	Nokia Flexizone picoBTS	Amarisoft eNB	Amarisoft eNB
UE	COTS Cat.12 (600/300)	COTS Cat.12 (600/300)	COTS Cat.12 (600/300)	COTS Cat.12 (600/300)

2.3. Platform Implementations

2.3.1. Platform Infrastructure Layer

Table 4 provides an overview of the 5GENESIS Infrastructure Layer components and associated technologies deployed in the Athens Platform. These components include the 5G, 4G RAN and Core equipment, as well as the core and edge clouds deployed in the Main and Edge Data Centres (DC). The infrastructure also provides Wi-Fi connectivity and probes for network monitoring.

Table 4 Infrastructure layer components and technologies in the 5GENESIS Athens Platform

Component	Product/Technology	Mode of Implementation
Main DC	COTS servers	OpenStack / VMware ESXi
Edge/Cloud Computing	COTS Servers / SFF x86 PCs	OpenStack / K8s
EPC/5GC	Athonet Rel.15 vEPC Athonet 5GC Amarisoft Rel. 16 5GC Amarisoft Rel. 15 5GC Amarisoft Rel. 14 4G LTE ECM OAI 4G Core	Multiple instances
5G NR	Amarisoft gNB Nokia Airscale System and 5G Small Cell (RRH) ECM OAI and REL Experimental 5G NR gNBs and UEs Commercial 5G smartphones	Multiple instances & SDR HW
LTE EUTRAN	ECM OAI / Amarisoft / Nokia AirScale / Nokia FlexiZone Commercial 4G mobile phones (Samsung A40, A90) Commercial 5G mobile phones (Samsung A90) plus USB dongles	Multiple instances & SDR HW
Non-3GPP Access Networks	Wi-Fi 802.11ac	Bespoke devices
Probes	MONROE, Iperf3, Ping, OWAMP	Multiple instances deployed across the network
Traffic Generator	IxChariot	COTS devices and SW

2.3.1.1. Main Data Center

The Main Data Center (DC) of the Athens Platform (see Figure 6) lifts the burden of hosting all the Coordination Layer components, the Slice Manager and all the MANO Layer components – i.e., Network Management System (NMS), Element Management System (EMS), NFVO, etc.). In addition, the Main DC also hosts the integration environment that is used during WP5 system-level and verification testing activities. Moreover, it is also hosting an NFV infrastructure (NFVI) that is orchestrated by the NFVO in order to instantiate network services and/or VNFs that relate to the use cases. For example, it can host a 5GC instance or a proxy VNF.

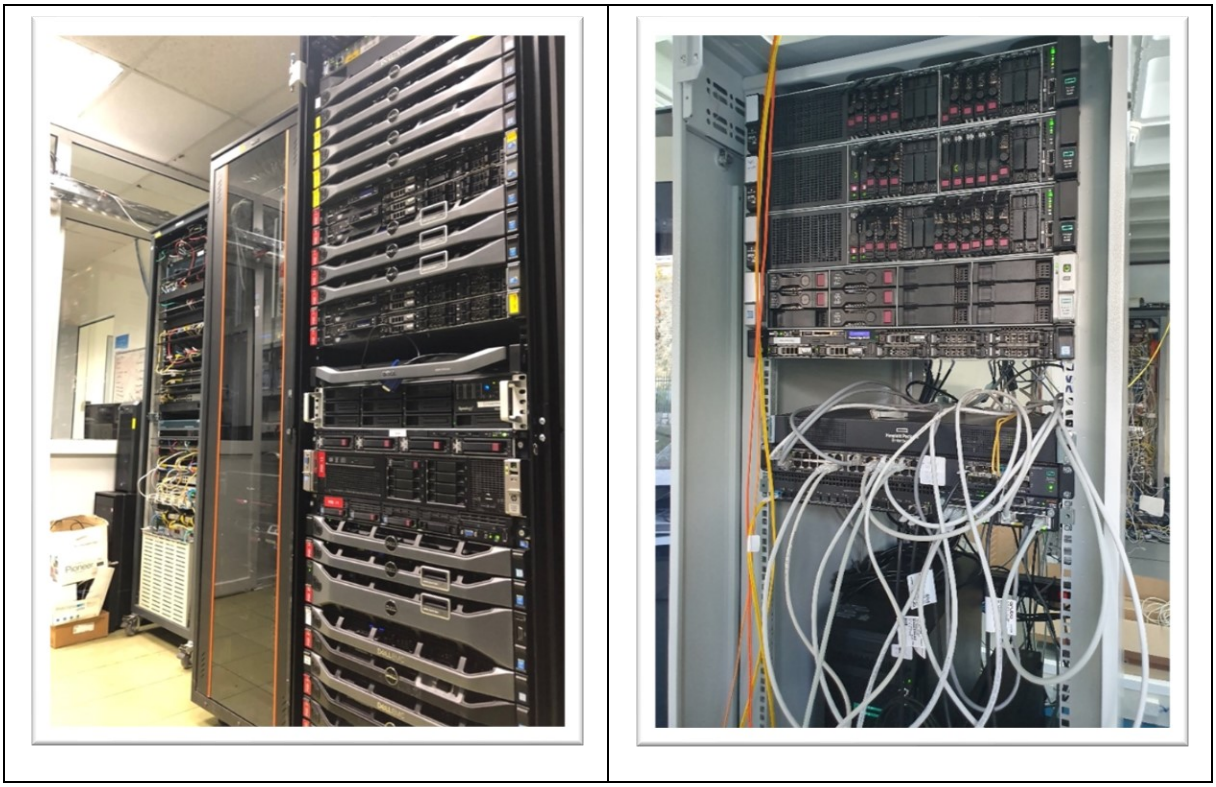


Figure 6 NCSRD Site (left) and COSMOTE Site (right) Main DC

Currently, the Main DC comprises 3 compute nodes, operating with OpenStack[2] release "Queens" providing multiple tenants (OpenStack Projects) to respond to both roles of Virtualised Infrastructure Manager (VIM) and for 5GENESIS software components deployment. Currently, it is deployed over three physical R630 DELL servers (2 x Intel Xeon CPU E5-2650 v4 @ 2.20GHz, 8C/16T, 96GB RAM, 2x1.2TB HDD), with the plan to add more nodes, if necessary, when resources are needed. The core OpenStack DC supports three provider flat layer-2 networks (*i.e.,* no VLANs), which are directly connected to the rest of the platform.

In addition to the above infrastructure and in order to facilitate the deployment of Virtual Machines with more stringent requirements (*i.e.*, Windows based), two VMware ESXi (2 x Intel Xeon CPU X5677 @ 3.47GHz, 4C/8T, 96GB RAM) nodes are also provided. These nodes are hosting Ixia's IxChariot traffic generator instances and Prometheus infrastructure monitoring instances.

Finally, to support redundancy and also allow for isolated execution a Main DC infrastructure is also deployed in COSMOTE for additional deployment of Coordination and MANO Layer components. The COSMOTE Main DC hosts on a DELL PowerEdge R630(Intel Xeon E5-2620 v4 @ 2.10GHz, 8vCPU, 32GB RAM) the Athonet r.15 vEPC of the COSMOTE testbed that is considered a separate nevertheless interconnected PLMN, as it is sharing with NCSRD through MOCN/MORAN (Multi-Operator Core Network/Multi Operator Radio Access Network) configurations, the radio access and edge facilities of the site. Also note that at the COSMOTE Main data center the Athonet's LBO node is hosted on an HPE DL360 Gen10 8SFF (Intel(R) Xeon(R) Silver 4110 CPU @ 2.10GHz, 16vCPUs, 16GB RAM) to implement the local break out functionality.

[2] Open source software for creating private and public clouds, https://www.OpenStack.org/

2.3.1.2. Edge Data Centers

The Athens Platform integrates edge computing infrastructure in various locations within its topology. The existing infrastructure can be later upgraded to a complete MEC infrastructure for deployment of edge applications and Network Service (NS) components. In order to achieve that, traffic that would normally reach the services sitting behind the 4G/5G core utilizing the backhaul connection can now be steered locally and either reach services instantiated at the edge or reach through the internet using local connections. In order to achieve that there is a need to deploy a 5GC function locally at the edge. This function is named User Plane Function (UPF) and provides this kind of functionality. For 4G and 5G NSA deployments there are solutions that can achieve similar functionality. The capability of allowing edge computing and traffic routing locally greatly benefits latency sensitive services. In addition, it allows for better scaling of backhaul connections and cost reductions.

The sites of NCSRD and COSMOTE stand primarily as permanent edge sites of the Athens Platform. In NCSRD two types of edge computing infrastructures are deployed. As shown in Figure 7, on one side there is an all-in-one installation of OpenStack small form factor (SFF) x86 PCs and, on the other side, a K8s-based docker orchestration infrastructure. In COSMOTE site the edge cloud is implemented using OpenStack Ussuri installation over an x86-based workstation, as illustrated in Figure 7.

For the purpose of the 5GENESIS trials, two compute nodes have been dedicated to the project, an HPE ML110 Gen10 8SFF (Intel(R) Xeon(R) Silver 4110 CPU @ 2.10GHz, 6x16 vCPU, 96Gb RAM,1,5T Disk, NVIDIA T4 GPU), located on COSMOTE and an HPE DL325 Gen10 8SFF (AMD EPYC 7281 16-Core Processor, 32 vCPUs, 128 GB RAM, 1,5T Disk), located in NCSRD.

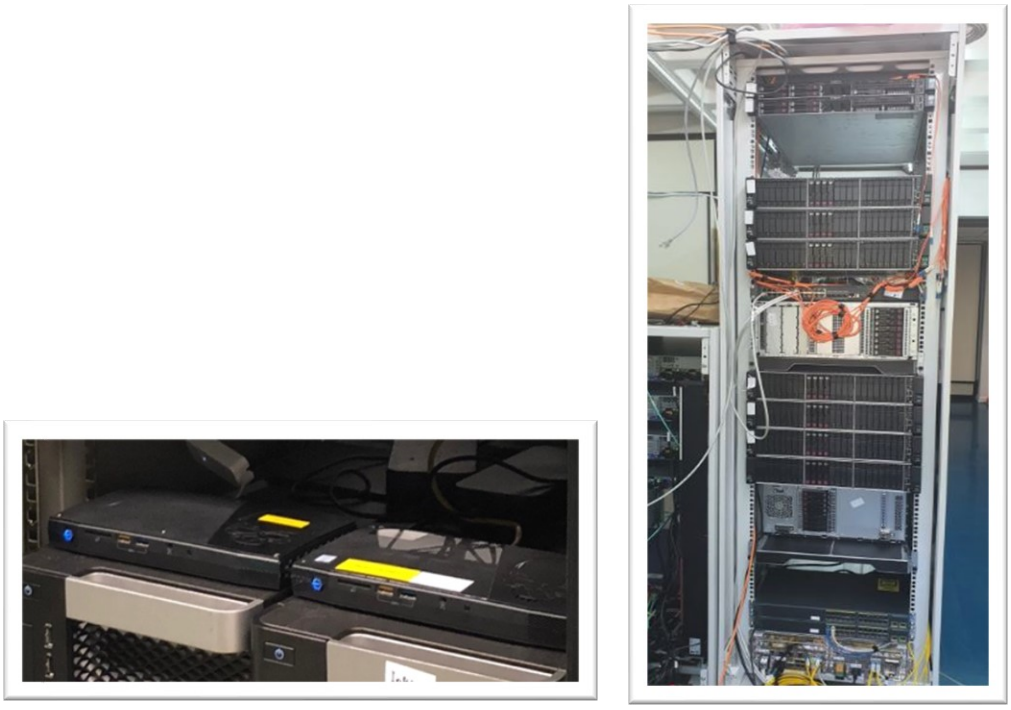


Figure 7 Edge Computing Infrastructure at NCSRD (left) and COSMOTE (right)

Figure 8: Egaleo Site Cabinets for edge equipment

An edge cloud domain is also activated at the Egaleo campus, supported by an all-in-one OpenStack NUC-based nodes. The edge nodes are deployed in the permanent cabinets that are installed at the Egaleo stadium for this purpose. As depicted in Figure 8, three cabinets are available to host the gNB components as well as the edge computing infrastructure to support the 5GENESIS activities.

2.3.1.3. Transport Network

The Athens Platform includes a transport network spanning the NCSRD site through a spine-leaf network topology with WAN emulation capabilities and that interconnects the three sites, NCSRD, COSMOTE and Egaleo Stadium via an optical fiber link and point-to-point radio technology, respectively. The following subsections describe in more detail the aforementioned technologies.

A. SDN Spine - Leaf Network

The WAN backbone network on the NCSRD site comprises several physical SDN Switches forming a spine – leaf architecture. All switches are OpenFlow enabled and support OpenFlow protocol version 1.3. They are controlled by a centralized OpenDayLight (ODL) SDN controller that is responsible for installing forwarding rules (flows) on each switch. Figure 9 presents the NCSRD spine-leaf network topology of Site 1 of Athens platform. Every lower-tier switch (leaf layer) is connected to each of the top-tier switches (spine layer) in a full-mesh topology. The leaf layer consists of access switches that connect to any physical or virtual device located on the NCSDR site, while the spine layer is the backbone of the network and is responsible for interconnecting all leaf switches and establish connectivity with the Internet and the other sites of the Athens Platform. The SDN backbone network can offer isolation and Quality of Service (QoS) policies for each network slice instantiated on the platform.

The physical topology of this transport network along with its interconnections is depicted in Figure 10.

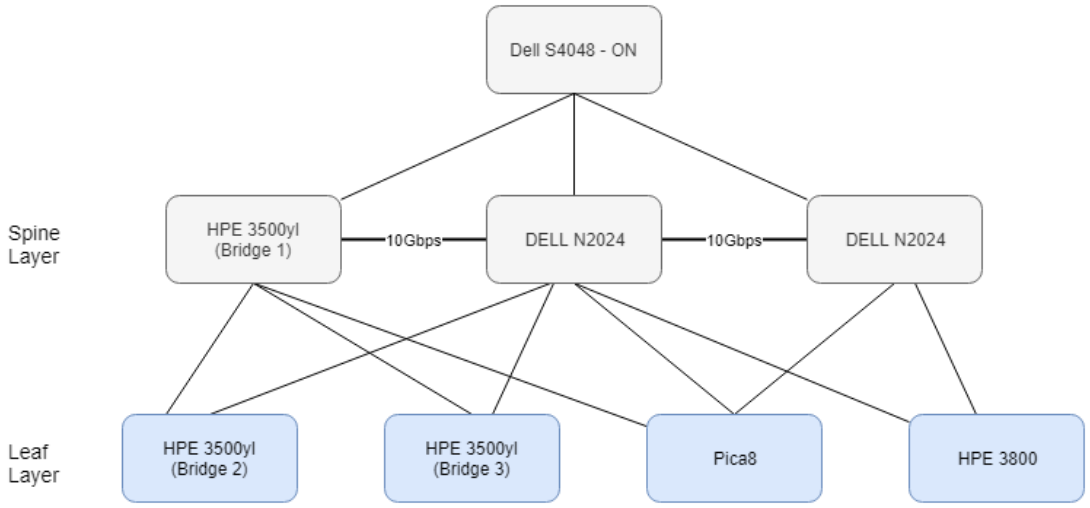


Figure 9 NCSRD spine – leaf network topology

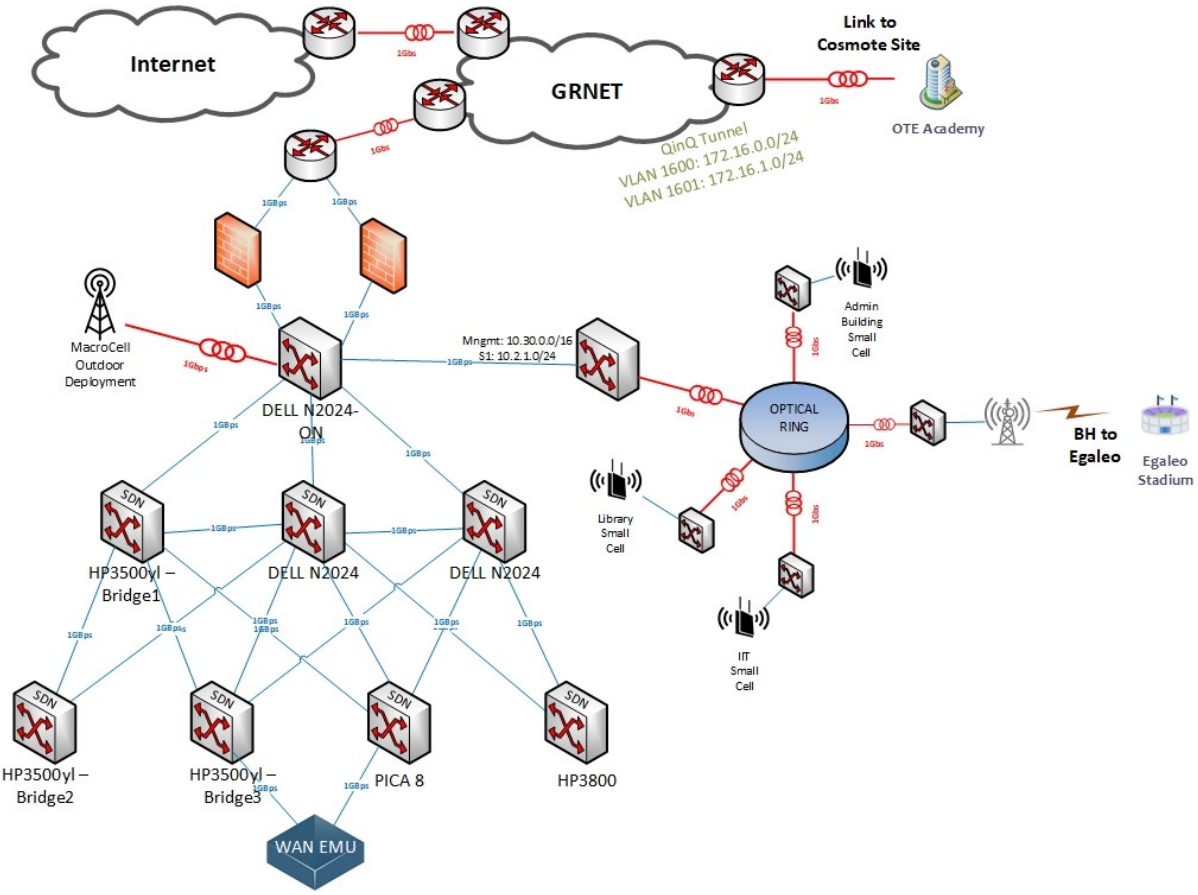


Figure 10: Transport Network at NCSRD Site

B. IP Core Network Gateway

An Integrated Services Router (ISR) by Cisco, alongside a Firewall (i.e. Cisco ASA 5510), are used for the realization of the core network gateway on the NCSRD site. Through these nodes the NCSRD core network is connected to the Internet, via the access provided by Greek Academic network provider (GRNET). Moreover, it is also used as the endpoint for the interconnection

between NCSRD and COSMOTE sites using the QinQ Ethernet transport (see section E). Finally, a VPN concentrator server allows remote users to connect to the NCSRD testbed via VPN offering all the standard tunnel types (i.e., OpenVPN, IPSec, Anyconnect).

C. WAN Emulator

The WAN emulator is implemented by the Mininet network emulator, running on a physical server on NCSRD site. It provides an easy way to get correct system behavior experiment with various realistic network topologies, while it runs real code including standard Unix/Linux network applications as well as the real Linux kernel and network stack.

Various realistic network topologies are implemented on the WAN emulator, creating an alternative routed connection between physical or virtual components of the platform. For example, Figure 11 presents a random network topology realized by Mininet. The emulator will allow larger transport network topologies to be realized in order to approach more realistic testing and validation during experimentation.

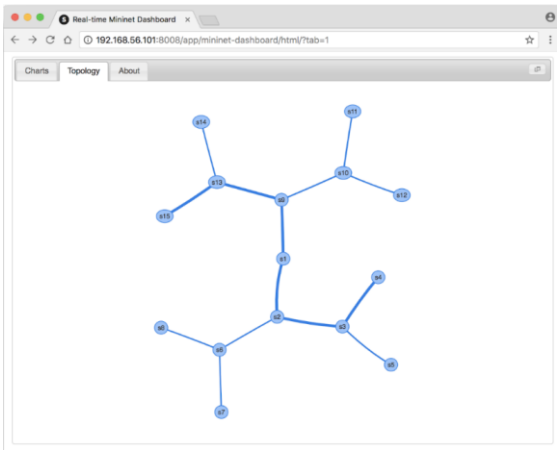


Figure 11 WAN Emulator example simulated network topology

D. Backhaul Connection NCSRD-Egaleo

Point-to-point radio technology operating at 5 GHz is used for the backhaul connection between the NCSRD site and the Egaleo stadium site. The devices used are the 5 GHz airMAX® AC Radio BaseStation with airPrism® Active RF Filtering Technology. One dish antenna has been installed on each site enabling the point-to-point connection. Thus, the Egaleo Stadium site can be used for demonstrations in a more "realistic" environment and suitable to investigate backhaul-related KPI metrics (i.e., latency, throughput, etc.).

A dish antenna was installed on a 60-meter-high mast at the NCSRD campus (see Figure 12a), while a similar dish antenna was installed at the stadium area (Figure 12b). Both antennas are powered by a Power over Ethernet (PoE) cable.

E. QinQ over GRNET for NCSRD-COSMOTE

A dedicated optical fiber link is used for the connection of NCSRD site and COSMOTE site on the Athens Platform, going through the GRNET backbone network. QinQ tunneling and VLAN translation, formally known as IEEE 802.1ad standard, is used over this link, in order to achieve L2 connectivity between the two remotely located sites, using a dedicated VLAN (vlan id 106)

as the service tag and any other VLAN as the customer tag on the Ethernet frame. This allows for support of VLAN-based slicing across the provisioned point-to-point Ethernet link.

Figure 12: a) High-Mast Antenna at NCSRD Campus and b) Egaleo Stadium antenna

2.3.2. Mobile Network Technology

The Athens platform mobile network technology is based on a multiplicity of RAN and Core solutions. The deployment already supports the 4G LTE Core open-source implementations (*i.e.,* NextEPC / OAI EPC) as well as commercial ones (i.e., Athonet/Amarisoft). As of Phase 3, the evolved 5G version of the platform uses Athonet vEPC, Amarisoft 5G Core and EPC Rel. 15, OAI 5G NR gNB/UE, Amarisoft 5G NR and Nokia AirScale. An integral part of the 5GENESIS Athens mobile network setup has been to interconnect the previously autonomous mobile networks operated by NCSRD and COSMOTE at their local sites.

2.3.2.1. Radio Access

5G New Radio (NR) is one of the most highlighted features of 5G. 5GNR encompasses a new OFDM-based air interface, designed to support the wide variation of 5G device-types, services, deployments and spectra. The Athens platform integrates two commercial solutions: Amarisoft 5G CallBox, which supports both NSA and SA deployments; and Nokia Airscale 5G Macro Cell. In addition, it has incorporated in its infrastructure ECM's OAI open-source solution. With respect to Release C of the Athens Platform, Table 5 summarizes the Radio Access components currently deployed.

Radio Access: 5G NR Deployments

At the COSMOTE site, commercial 5G equipment based on Nokia AirScale platform has been installed at OTE Academy premises. The current installation includes notably the following modules and supports indoor/outdoor operation with 5G NSA Core:

- 1 x AirScale BBU

- 1 x LTE BTS (ASIA) – Capacity Module (ABIA)
- 1 x 5G BTS (ASIK) – Capacity Module (ABIL)
- 2 x n78 NOKIA AirScale Micro RRH 4T/4R 20W (AWHQF)
- 2 x NOKIA AirScale Micro 4T4R B7 20W (AHHA)

Table 5 Athens Platform 5G Release C Radio Equipment Deployment

Site	Deployed Radio Access Equipment
NCSRD	• 1 Amarisoft Callbox Classic gNB/eNB (5G NSA & SA modes) - Laboratory / IIT Building • 2 NOKIA "Flexi Zone Multiband Indoor Pico BTS" (FZ MBI) small cells – IIT building / • 1 Amarisoft eNB on x86 server (SDR) – administration building • 1 Amarisoft eNB on x86 server (SDR) – library building • 1 Amarisoft eNB for the Macro Cell at outdoor location (high mast) providing coverage to a large part of NCSRD campus. • 1 OAI gNB (USRP N310) and 1 OAI nr-UE – Laboratory / IIT building
COSMOTE	• 8 NOKIA "Flexi Zone Multiband Indoor Pico BTS" (FZ MBI) small cells • NOKIA Airscale System and 5G Small Cell (RRH)
Egaleo Stadium	• Installation of three cabins that hosts small cells providing coverage to the stadium.

Note that at COSMOTE site the Nokia AirScale gNBs, supporting NSA deployment option 3.x, have been configured with MORAN to support their simultaneous operation with two PLMNs. Figure 13 presents the 5G NR equipment currently installed at COSMOTE premises.

(a) Baseband unit (b) Indoor Antennas (c) Outdoor Antennas

Figure 13 a. Nokia AirScale 5G BBU, b. AirScale Micro 4T4R, c. AirScale Outdoor Installation

During Phase 2, Amarisoft's 5G Callbox Solution (Figure 14) was integrated into Athens Platform at NCSRD, providing a stable mobile network system for testing and experimenting. Both the

Core and RAN functions are software defined and hosted on Linux-based systems. Currently, an all-in-one system is deployed and operating (RAN & Core in a compact server), running on an x86 node, using Fedora 30 operating system. The solution is Release 15/16 compliant. It provides support both for FDD and TDD transmission at FR1 and FR2 frequency bands. Bandwidth configuration varies between 5 to 50 MHz with MIMO options for up to 4x4[3]. Supported modulation schemes range up to 256QAM for Downlink transmission channel and 64 QAM for Uplink. Data subcarrier spacing can be modified between 15kHz to 120 kHz. The Amarisoft RAN solution has been successfully integrated with ATH EPC and tested with commercial COTS UEs.

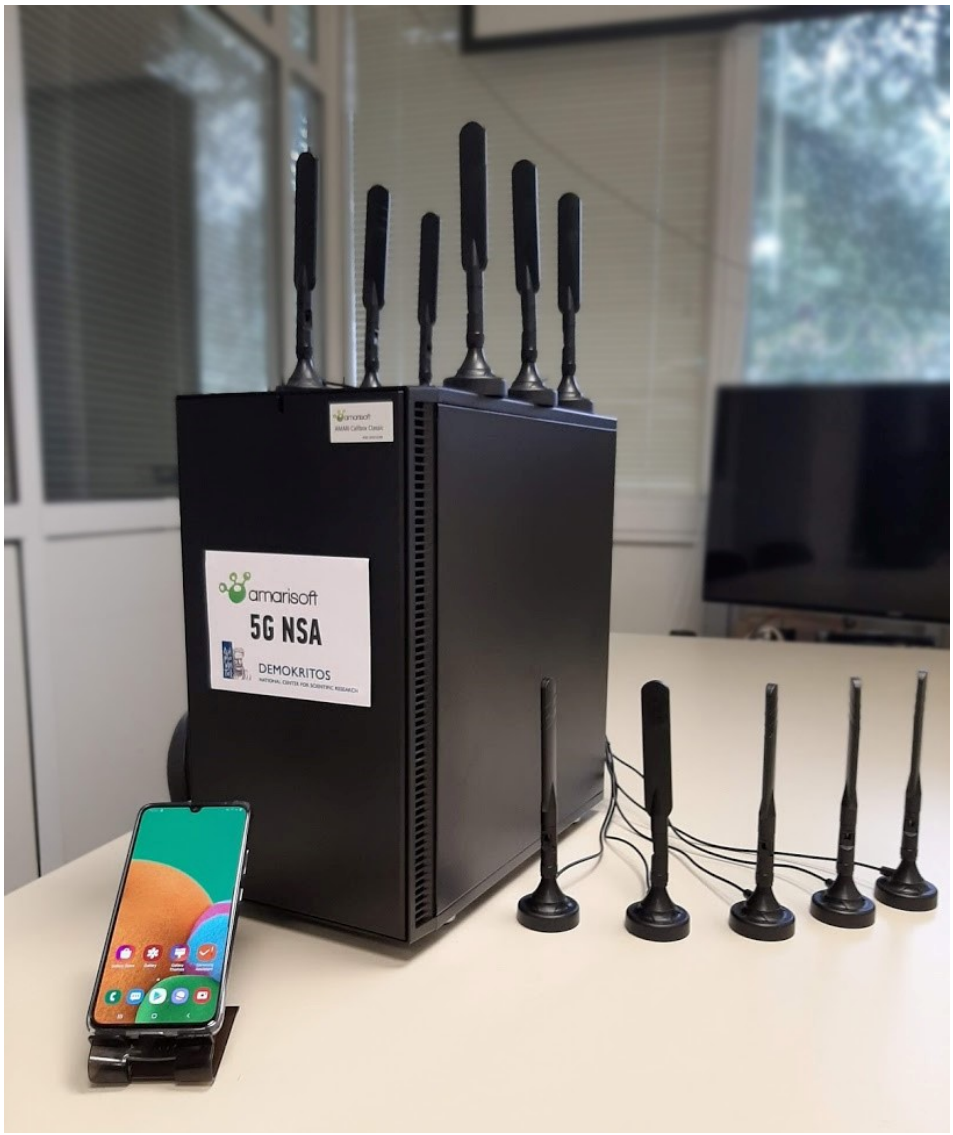


Figure 14 Amarisoft Callbox 5G NSA/SA Solution

NCSRD is also using two USRPs N310 for the OAI-based 5G NR implementation as depicted in Figure 15. The tests and integrations are performed with powerful (i9) laptop computers. It should be noted that currently, they are utilized in the context of the Portable Demonstrator, as described in D4.17 [14]. The Portable demonstrator is considered as a spin-off of the Athens

[3] Depending on the paid license

Platform and as such it integrates components that are tested and validated within the Athens platform environment.

Figure 15 OAI gNB and OAI nr-UE utilized in noS1 mode (without core network)

Radio Access: 4G LTE Deployments

The Athens platform includes an antenna array on a high mast in order to provide coverage in a large part of the NCSRD campus. A Kathrein 80010682 antenna is used with a carrier frequency of 2.6 GHz. The MacroCell implementation is based on an N210 USRP board connected to an eNB (x86 server) that runs Amarisoft RAN software. The installation is depicted in Figure 16. The Indoor LTE deployments of the Athens platform are based initially on OAI stable software implementation combined with Ettus SDR cards. As a legacy technology/infrastructure, this setup is not discussed in this document. In addition to the ECM

OAI, 4G eNB implementations are also available using Amarisoft Licensed Software. Finally, commercial solutions from Nokia are also available using the FlexiZone Indoor Pico BTS.

Figure 16 Macro Cell at NCSRD Site

2.3.2.2. Mobile Core Network

Mobile Core: 5GC

The main 5GC solution is based on Amarisoft's 5GC implementation that is Rel. 15 and Rel. 16 compliant supporting the SA deployment setups based on 3GPP Option 2 (Figure 14). It provides several 5G core network elements, such as the Access and Mobility Function (AMF), Authentication Server Function (AUSF), Session Management Function (SMF) and the User Plane Function (UPF) as an integrated software component. The product also supports configurable QoS flows and multi PDU sessions support. Another solution that was integrated during Phase 3 is ATH open 5GC deployed on AWS cloud[4], allowing its interface with any RAN globally over the AWS Cloud services.

Mobile Core: 4G+ EPC

The Athens Platform uses Athonet's mobile core (Figure 17) as a highly efficient and effective software-only implementation. There are two servers, one located on NCSRD and the other on COSMOTE. This is a software-only product that can run on either centralised or highly distributed on public cloud (e.g. AWS, Azure, Google, IBM, Oracle) or private cloud (e.g. telco cloud), enterprise data centres or on standard COTS servers running on Intel or ARM. Athonet's

[4] http://www.open5g.cloud/ http://www.open5g.cloud/

4G+ Core supports some additional functionalities to those provided by the 4G, such as the Serving Gateway Local Break Out (SGW - LBO), which is a software function/VNF that, deployed close to the RAN, provides a local secure network for placing locally offloaded content and services. It is also used to support 5G NSA configurations using Amarisoft 5G as RAN solution. Another alternative 4G mobile core solution is the open-source OAI implementation, provided by ECM and is used mainly in experimentation when high performance computing power is not required.

Figure 17 ATH vEPC server installed on NCSRD laboratory site

2.3.2.3. Local Breakout Node

An integral part of the implementation of the 5GENESIS mobile network has been the interconnection of the previously independent mobile networks operated by NCSRD and COSMOTE. For this purpose, at the main data center of COSMOTE an LBO SGW node has been installed, following the implementation details reported in [9] and [15] for Athonet's MEC Interconnection. The LBO-SGW has been connected to the NCSRD Athonet's vEPC for the purpose of serving 5GENESIS subscribers, with the capability to either break-out the traffic in the local COSMOTE edge cloud, or to route SGi traffic to the PGW at the NCSRD site, depending on the traffic characteristics (Figure 18). Typically, the rules of breaking out the traffic can be set with high granularity, spanning from the APN used, the target application server, as well as the UE IP pools. The LBO-SGW has been setup to support (MOCN) so that to simultaneously support traffic from the COSMOTE (experimental) PLMN.

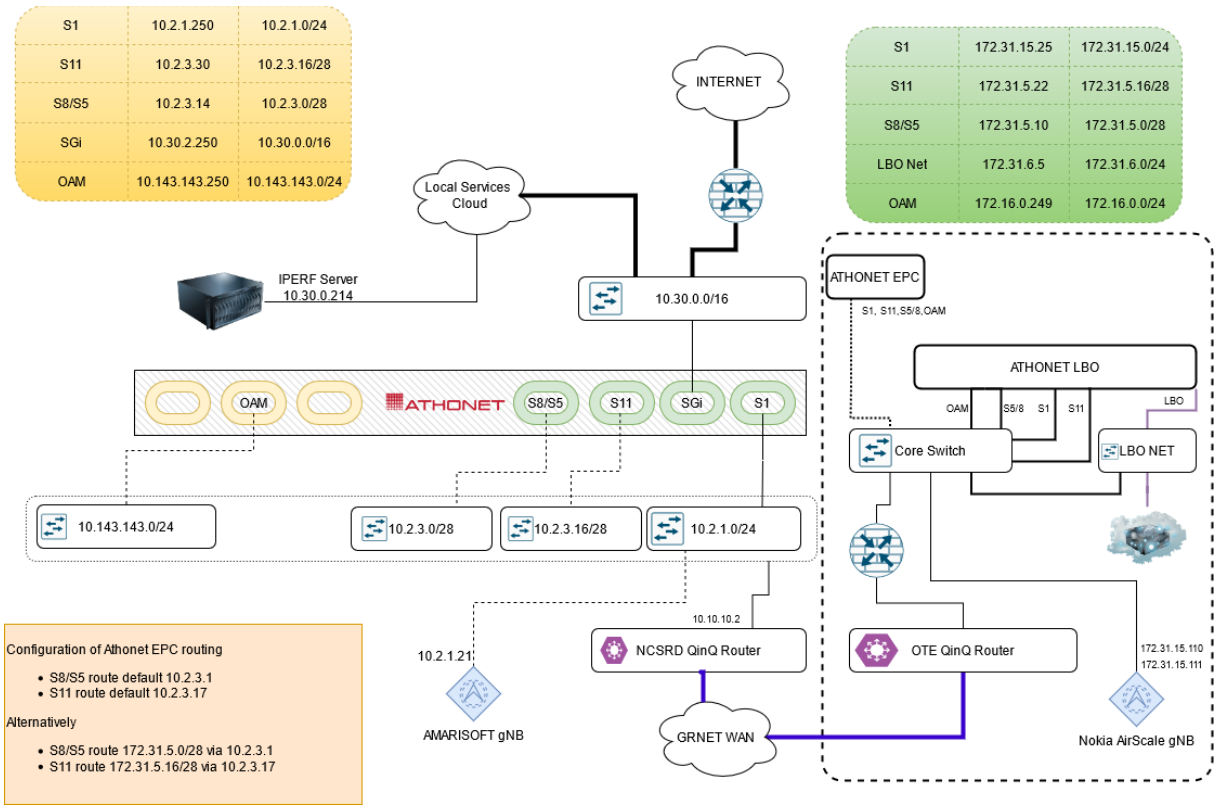


Figure 18 NCSRD-COSMOTE Local Break Out Topology

2.3.2.4. User Equipment (UEs)

Athens platform has a wide variety of COTS UEs available for mobile network testing and deployments like LTE mobile phones, USB dongles and LTE Customer Premises Equipment (CPE) routers. Table 6 briefly presents the list of available UEs.

Table 6 UEs available in Athens Platform

UEs	Features
2 x Huawei P40 Pro	4G LTE Bands: 1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 17, 18, 19, 20, 26, 28, 32, 34, 38, 39, 40, 41 5G Bands (SA/NSA): 1, 3, 28, 38, 41, 77, 78, 79
1 x OnePlus 8 Pro	4G LTE Bands: 1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 34, 38, 39, 40, 41, 42, 46, 66 5G Bands (SA/NSA): 1, 3, 7, 28, 78 SA/NSA
2 x Samsung A40	Cat12 (DL: 600 Mbps/UL: 150 Mbps at 20 MHz) Bands: 1, 3, 5, 7, 8, 20, 38, 40, 41
2 x Xiaomi Mi9	Cat18 (DL: 1200 Mbps/UL: 150 Mbps) Bands: 1, 2, 3, 4, 5, 7, 8, 12, 20, 38, 40
2 x Huawei E3327h (USB Dongle)	Cat4 (DL: 150 Mbps/UL: 50 Mbps at 20 MHz), LTE FDD Bands: 800/900/1800/2100/2600, can be fully configured via AT commands

4 x ALCATEL One touch 4G+ L850 (USB Dongle)	Cat4 (DL: 150 Mbps/UL: 50 Mbps at 20 MHz), LTE FDD Bands: 800/900/1800/2100/2600
1 x Samsung A5	Cat4 compatible Smart Phones (150/50)
1 x LG Nexus 5	Cat4 compatible Smart Phones (150/50)
2 x Xiaomi Redmi Note 4	Cat6 compatible Smart Phones (300/50)
2 x srsUE based on B210 (USRP)	Up to 100 Mbps DL in 20 MHz MIMO TM4 configuration
1 x D-Link LTE Router	Cat 4: Band 1/3/7/8/20, Up to 150 Mbps download, four 100 Ethernet LAN ports to connect wired devices
3 x Bittium Tough Mobile	Cat4 compatible Smart Phones (150/50)

Figure 19 presents the UE while streaming video using the 5G mobile network operated by Athonet vEPC core and Amarisoft 5G RAN.

Figure 19 Samsung A90 5G

The UE is registered to Amarisoft's, ATH and OAI EPC Core Networks using (U)SIMs provided by Sysmocom. Athonet provides pre-registered SIM cards with every Core component sent to be deployed in the project. Amarisoft also provides pre-programmed SIM cards to use in their 5G NR network.

Sysmocom (U)SIMs can be programmed using pySim-prog, a command line utility that is used to modify any identity (IMSI, ICCID, MSISDN) stored on the (U)SIM, as well as the private key data (K, OPC) in all programmable SIM cards.

During the trials at OTE Academy using the NOKIA Airscale gNB deployment, a variety of commercially available UEs were tested, using the 3.5GHz band and NR TDD DDDSUUDDDD (4+2+4) SFS 3:8:3, namely:

- Xiaomi Mimix3 (x2)
- Xiaomi M10
- Samsung S20
- Samsung Note 20 (x2)

There is also a list of prototype 5G UEs available in the Athens platform currently based on ECM's OAI implementation with SDRs, namely:

- ECM's OAI 5G NR-UE implementation with N310 USRP as radio frontend.
- ECM's OAI 5G NR-UE implementation with N300 USRP as radio frontend. This will be deployed along with RunEL 5G NR implementation.

Both solutions above are a prototype implementation and currently only operate in a testing mode and only in tandem with a similar setup of OAI running as gNB. Figure 20 presents the current implementation of OAI 5G-NR UE.

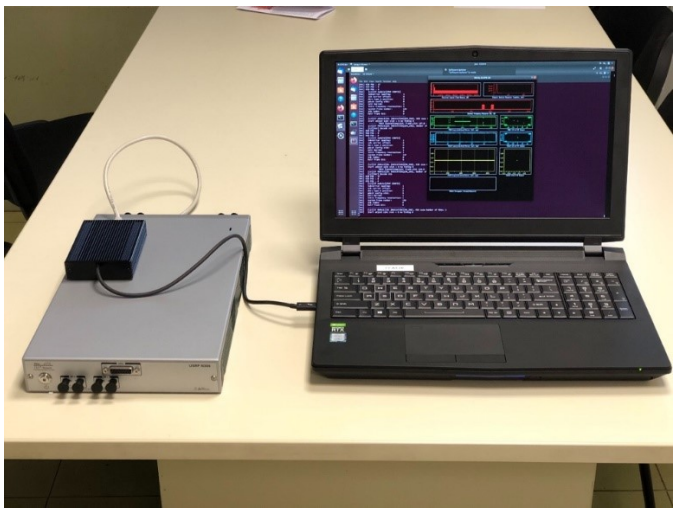


Figure 20 5G NR UE using USRP N300

2.3.3. Management & Orchestration Layer

Table 7 provides an overview of the Management and Orchestration layer components and associated technologies deployed in the Athens platform.

Table 7 Management and Monitoring tools

Component	Product/Technology	Mode of Implementation
Slice Manager	Katana (Open source implementation)	Custom development of a slice manager supporting 3GPP slicing information model
VIM	OpenStack/K8s	OpenStack at the core / K8s and OpenStack at the edge (all-in-one)
WIM	WAN Infrastructure Manager	Custom made, operate over SDN based WANs.
NFV Orchestrator	Open-Source MANO	OSM v6 supported – 2 instances
SDN Controller	OpenDaylight	ODL Fluorine Release
NMS	LibreNMS	Rel. 1.59
Amarisoft EMS	Amarisoft eNB/gNB configuration and management	Ansible / python scripts used to set the configuration according to the slice
gNB EMS	Open Air Interface Management	Single instance
EPC/5GC NMS	Athonet EMS	SNMP based / Open API
Monitoring	Prometheus/Grafana/InfluxDB	Time-series based monitoring, alerting and visualisation

2.3.3.1. Slice Manager

The Slice Manager is the component that mediates between the Coordination layer components of the 5GENESIS architecture and the MANO layer [5], [16]. The 5GENESIS Slice Manager is responsible for the lifecycle of network slices, *i.e.,* it manages the creation and provision of network slices over the infrastructure. The Slice Manager provides an API in order to communicate with the Coordination Layer and receive requests for network slices in the form of Generic Slice Template (GST). The GST is mapped to the Network Slice Template (NEST) by filling in the technical specification of the GST according to the slice requirements.

In the Athens platform Slice Manager, Katana version 2.1.0 is deployed. Release B of Katana is described in detail in deliverable D3.4 [7]. Katana is already configured to operate on top of the

NFV Orchestrator instance, WIM and multiple edge and core NFVIs. In addition, specific interfaces have been developed to allow the provision of resources in the RAN and core via the supported EMS.

2.3.3.2. NFV Management and Orchestration

NFV is a critical part of the 5G deployments. The purpose of the NFV Management and Orchestration is to allow the provision of NSs over the managed NFV infrastructures. In the Athens platform NFVIs are available in all sites of the platform. It is expected that in those locations various NSs will be provisioned and in some cases even the core network functions could be virtualised and orchestrated as a NS.

Starting from the top, the NFV Orchestrator in the Athens platform is OSM release 6. 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.

The infrastructure virtualisation and management of the physical resources is achieved via the VIM. This component is based on OpenStack Cloud distribution when virtualisation is achieved by VMs and on Kubernetes when the virtualisation is achieved by means of containers. The latter will be exploited mainly at the edge in order to provide computing resources at the edge using smaller footprint computing equipment. Currently, in the Athens platform, the OpenStack Rocky release is deployed. The containerised infrastructure VIM is Kubernetes version 1.17.0. Recently OSM has released version 7.0 which enhances the support for Kubernetes-based VIMs.

2.3.3.3. Network Management System (NMS)

To enable the creation of network slices, the 5GENESIS Slice Manager depends on the network management system (NMS) to provision resources, control the network and establish the appropriate paths within the WAN topology. The 5GENESIS NMS comprises of the following components:

- WAN Infrastructure Manager (WIM), a platform specific component that has the overview of the Wide Area Network (WAN), the physical network that is used to provide connectivity to any physical and virtual component of the Platform. It keeps track on the way that all networking devices (SDN switches, routers), NFV Infrastructures and physical devices on the platform are connected, in the form of a network graph. The WAN implementation depends on the existence of an SDN capable WAN infrastructure. Current WIM version support ODL Fluorine API in order to manage the network infrastructure.
- LibreNMS is used to measure state, health, configuration (Ports, VLANs, Neighbours, STP, Inventory and Logs) and performance (throughput, traffic, latency, packet? loss) on networking devices (switches, routers, etc.). It supports SNMP protocol and allows topology and infrastructure discovery for all network elements that support this protocol.
- Prometheus servers deployed in hierarchical mode are collecting aggregated time series data from a larger number of subordinated servers and can be used to take

measurements from any device on the platform by creating custom exporters that use the SNMP protocol. The visualization is taken care by Grafana which supports a scripted way of producing an intuitive dashboard for presenting time series data and monitoring information

2.3.3.4. Element Management System (EMS)

Most Mobile Network elements deployed in the platform provide proprietary solutions that allow operations like configuration and monitoring for the respective devices. These systems are exploited to perform configuration management and retrieve status information per case. In the case of the Athens platform, EMS specifically built for use with OAI and Amarisoft solutions are developed and used. These EMS allow proper configuration and resource provisioning for the mobile network.

2.3.3.5. SDN Controller

The Athens platform has integrated network control based on an ODL SDN Controller. The ODL controller is one of the most broadly used and integrates well with OpenStack environments. The version currently integrated in the Athens platform is “Fluorine” which enhances the support for network virtualization within cloud and edge computing environments. This includes improved IPv6 support, support for both stateful and stateless security groups, and SR-IOV hardware offload for Open vSwitch (OVS). Much of this work has been developed for OpenStack environments, and is now being leveraged to integrate ODL with the Container Orchestration Engine for Kubernetes environments.

Integration of Management and Orchestration Components

The deployment of the MANO Layer components in the Athens Platform is realized on the NCSRD Main DC running OpenStack. More specifically, a dedicated tenant has been created in order to partially host components of the MANO Layer. These components are listed in Table 8 along with the provisioned resources per VM.

Table 8 Athens Platform MANO Components (OpenStack)

Component	Resources	IP Address
Katana Slice Manager	VCPUs: 4, RAM: 4GB, Disk: 40GB	10.30.0.180
OSM Rel 6	VCPUs: 2, RAM: 8GB, Disk: 40GB	10.30.0.267
WIM	VCPUs: 1, RAM: 2GB, Disk: 20GB	10.30.0.173
Amarisoft EMS	VCPUs: 2, RAM: 2GB, Disk: 80GB	10.30.0.175

The actual instantiation of these components is depicted in Figure 21.

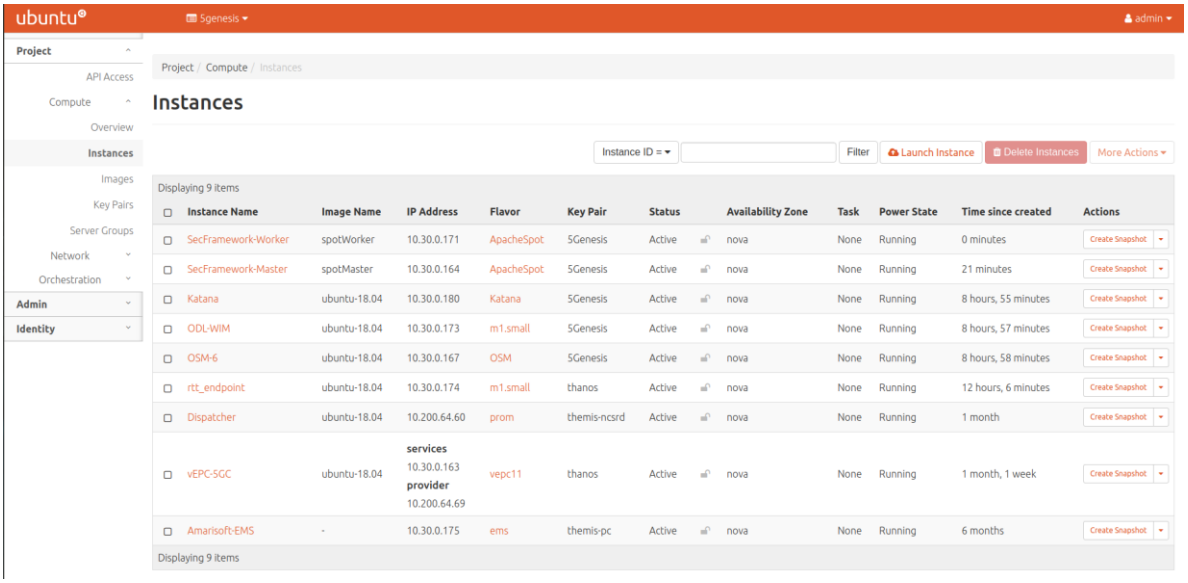


Figure 21 Deployment of MANO Components in OpenStack

The rest of the MANO components, notably those associated with the infrastructure monitoring, were deployed in VMware ESXi environment for load balancing of the cloud infrastructure, as the OpenStack MainDC will be also utilized as NFVI. The list of the rest MANO layer components is presented in Table 9.

Table 9 Athens Platform MANO Components (ESXi)

Component	Resources	IP Address
Master Prometheus Monitoring	VCPUs: 4, RAM: 4GB, Disk: 400GB	10.30.0.215
Cloud Prometheus Monitoring	VCPUs: 2, RAM: 2GB, Disk: 150GB	10.30.0.224
WAN Prometheus Monitoring	VCPUs: 2, RAM: 2GB, Disk: 200GB	10.30.0.248
Radio Prometheus Monitoring	VCPUs: 2, RAM: 2GB, Disk: 200GB	10.30.0.249
Grafana	VCPUs: 2, RAM: 2GB, Disk: 40GB	10.30.0.205
Influx DB	VCPUs: 2, RAM: 2GB, Disk: 256GB	10.30.0.238

The Monitoring components of the MANO Layer are organized in a hierarchical approach, assigning a low-level Prometheus instance per technology domain (i.e., Cloud, WAN, RAN, etc.) controlled by a centralized Prometheus instance, which exposes interfaces to the Coordination Layer and other consumers. The ESXi instantiation of monitoring components is presented in Figure 22.

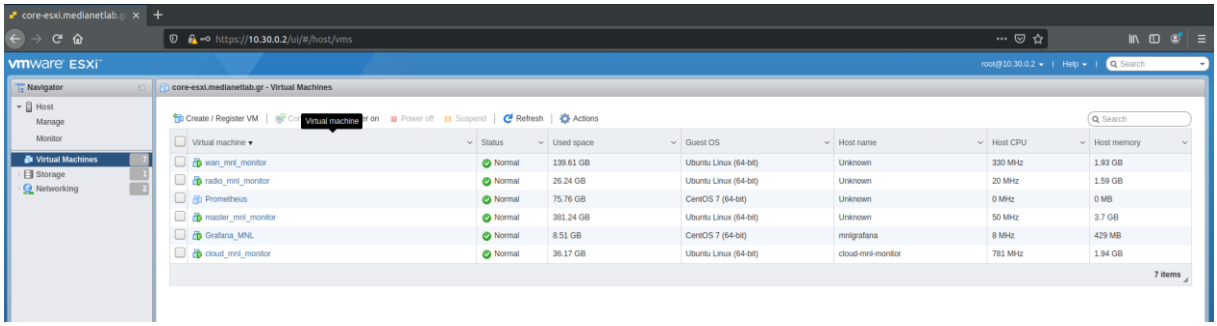


Figure 22 Deployment of MANO Monitoring Components in ESXi

The MANO layer is fully operational across the Athens platform and is able to provision resources E2E employing the Katana Slice Manager.

2.3.4. Coordination Layer

The capabilities at the network, infrastructure and management level including the orchestration provided by the Slice manager are the building blocks for the dynamic provisioning of resources envisaged in the 5G era. On top of this, the 5GENESIS Athens platform addresses the capability to interact efficiently with the "verticals" -the clients of these services, through user-oriented coordination components that collect the end experimenter requirements and translate them to artefacts that can be effectively implemented through the Slice Manager through the underlying management systems on the available infrastructure components.

The fundamental components of the coordination capability of the Athens Platform are summarized in Table 10:

Table 10 Coordination Layer Components

Experiments Coordination	Description
5GENESIS Portal	WP3 Release B implementation of the Experimenter access portal, a graphical user interface to the experimenter, facilitating configuration and monitoring of experiments, as well as access to their results.
Experiment Life Cycle Management	Lifecycle Management of the experiment exploiting Keysight's TAP commercial-off-the-self testing automation tool, which interfaces southbound with the underlying element and network management components of the MANO layer as well as the Slice Manager.
Results Repository	InfluxDB is the open-source storage engine provided within the InfluxData framework and handles in particular time series data and is used to store all monitoring events and metrics that are necessary for the generation of the end-reports and Key Performance Indicators (KPIs) validation.

Analytics	The 5GENESIS M&A framework includes advanced Monitoring tools and both statistical and Machine Learning (ML)-based Analytics, and it is devoted to the collection and analysis of the heterogeneous data produced during the usage of the 5GENESIS Facility. Its main goal, within the project scope, is to verify the status of the infrastructure components during the execution of experiments for the validation of 5G KPIs, including the ones related to vertical use cases.
5G Security Analytics Framework	5G Security Analytics refers to the collection and joint analysis of massive amounts of heterogeneous data from multiple points of the 5G infrastructure utilized for integrated monitoring. The ultimate aim is the detection and classification of anomalies associated with security incidents, using state-of-the-art ML techniques.

For the deployment of the Coordination Layer components (Release B) the choice of VMware environment was promoted as shown in Figure 23. The choice was made because some of the Coordination Layer components require Microsoft Windows hosts. For Release B the developed coordination layer components are integrated in a single Microsoft Windows machine which is connected to the internet and the lower layers through the ESXi hosts. The VM provides:

- Keysight OpenTAP
- ELCM
- 5GENESIS Portal

In addition to the above components, Linux based VMs were deployed in OpenStack environment as described in Section 2.3.1.1 - Main Data Center (Main DC). The VMs instantiates the following components:

- InfluxDB – as Analytics Result Repository
- Python script library for statistical analysis requirements for results presentation and KPI validation.

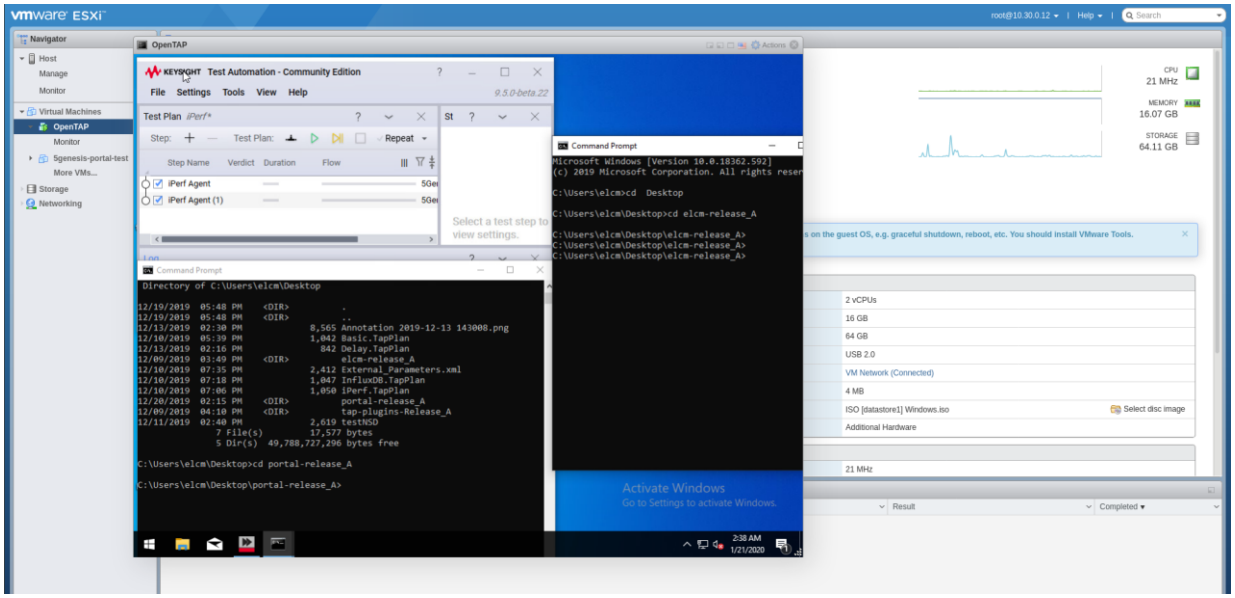


Figure 23 Coordination Layer Components

Release B of the 5GENESIS Security Analytics platform, as described in detail in D3.14 [17], has been deployed and fully integrated in the Athens Platform. More specifically, two VMs have been deployed in the OpenStack-based infrastructure at the platform core:

- VM1 – Master node (4 vCPUs, 16 GB RAM, 50 GB storage)
- VM2 – Worker node (4 vCPUs, 16 GB RAM, 50 GB storage)

The Release B of the Security Analytics platform includes two independent pipelines, which both employ Machine Learning/Deep Learning approaches to infer suspicious behaviors:

- The network flow (NetFlow) processing pipeline ingests and analyses NetFlow streams at various points in the network and focuses on network-level attacks. This was the main component of the Release A of the framework (as described in D3.13 [18]).
- The metrics processing pipeline analyses infrastructure metrics from various nodes of the infrastructure (RAN, core, network and compute elements) and identifies anomalies which might point to breaches to the compute infrastructure and/or the virtual network functions (VNFs). The metrics processing pipeline is tightly integrated with the 5GENESIS monitoring framework, directly ingesting metrics from there. The metrics processing pipeline was developed during the second phase of the activity and is now integrated in Release B.

3. ATHENS USE CASES-SPECIFIC EXTENSIONS

3.1. Use Cases Target Deployment

This section provides updated information on the target deployment for the use cases managed by the Athens Platform. The actual deployment and testing of the use cases is part of WP6 activities. However, the support of the activities regarding the infrastructure preparation is in WP4 jurisdiction. During Phase 3 of 5GENESIS with the impact of COVID-19 being significant in demonstration events, there have been some trials as a preparation towards the final KPIs validation targeted in WP6 for December 2021.

During 29-30/06/2021, a demonstration of the use Case "Eye in the Sky" took place on OTE-Academy's Campus in liaison with the 5G!Drones[5] Project. In addition, two of the use cases supported at the Athens platform, namely "Big Event" and "Security as a service", have already been showcased in previous 5G-PPP projects with more minimal deployments, while their final demonstrations in the course of 5GENESIS are scheduled during the second semester of 2021.

3.1.1. Use Case Big Event in a soccer stadium

The motivation of the "Big Event" Use Case is to demonstrate the 5G capabilities of 5GENESIS live in front of a crowd during a big sports event in the Egaleo Municipal Stadium "Stavros Mavrothalassitis". The scenario entails the support of a location-based augmented reality (AR) application in a MEC enabled environment, where user generated data will be ingested, processed and re-shared among the audience. The Target KPIs of this Use Case are mainly related to:

- The latency exhibited by the end-users
- The capacity of the network
- The maximum bandwidth that may be available for the consumer and the producer of the multimedia content.

The Big event Use Case intents to exploit resources available concurrently in two sites of the Athens Platform. The main site where core components of the system are held is the NCSRD Campus site, while the big event is going to take place in the Egaleo Stadium, utilizing resources available on-premises, constituting the edge cloud of the infrastructure. The components of the AR application will be implemented either as VNFs or as netapps, running on the available edge resources. It is expected to employ different scenarios during integration and testing, in order to fine tune the system and extract valuable data on the impact of edge processing at the exhibited latency.

For the needs of this use case, multiple IP cameras are going to be installed at the perimeter of the stadium in order to cover the events from various angles. The upstream content from the cameras will be transmitted via the 5G network, aiming to evaluate the fronthaul requirements of 5G (in delay and jitter). This configuration/setup would allow lowering the costs required to

[5] https://5gdrones.eu/

support the event, as no extra wiring or network setup is needed for the connection of the cameras.

The anticipated deployment of the components is depicted in Figure 24. As illustrated, the use case components will be deployed in a single eMBB slice. The configuration of the slice is required to provide the necessary capacity in order to allow ingestion of content produced both by the fixed media equipment (i.e., 360 camera), as well as by the connected users. In addition, the deployment needs to provide the necessary resources for ingesting and processing of video streams, as well as for producing the AR content towards the end consumers. The consumers and prosumers will be located at the stadium (where the AR content makes sense), while processed content will also be fed to consumers in other locations.

The Slice Manager includes the dynamic scaling feature and is capable of responding to service requests for provisioning additional resources in cases of increased network load. It is anticipated that not all big events will have the same scale in terms of end users and volume of user generated content. Therefore, this Use Case will also showcase the dynamic scaling feature of the Slice Manager with respect to the eMBB slice, in order to demonstrate the efficient use of the platform resources, while offering an enriched event experience.

Figure 24 Components and deployment of the Big Event use case

During experimentation different configurations will be taken under consideration in order to refine the deployment and installation of the components and prepare them for the envisioned big event. An Insta360 Pro 2 Camera has been added to the testbed and will be employed in the use case, allowing streaming up to 8K 360° video while performing live stitching internally. Optimal bit-rates for streaming to end-users will be tested while the streaming service will be supported by edge VNFs. A virtual reality (VR) application will also allow the use of VR headset for immersion to the event to remote or local users. This use case can be considered an extension of the 5G-ESSENCE[6] demonstration.

[6] https://www.5g-essence-h2020.eu/ https://www.5g-essence-h2020.eu/

3.1.2. Use Case "Eye in the sky" applications

The Athens Platform utilizes the components and technologies developed during 5GENESIS to showcase the capabilities of mobile networks in supporting various requirements of UAV applications. These applications range from low latency to high bandwidth scenarios, while requiring reliable communication channels for the security and safety of the related operations.

The use case scenario and components are illustrated in Figure 25, where components from two ICT Projects, namely 5GENESIS and 5G!Drones are used to instantiate the depicted scenario. The UAV control link requires low latency and reliability ensuring uninterrupted control of the UAV. At the same time, the UAV provides multimedia streaming services which in turn require high bandwidth and increased data volumes.

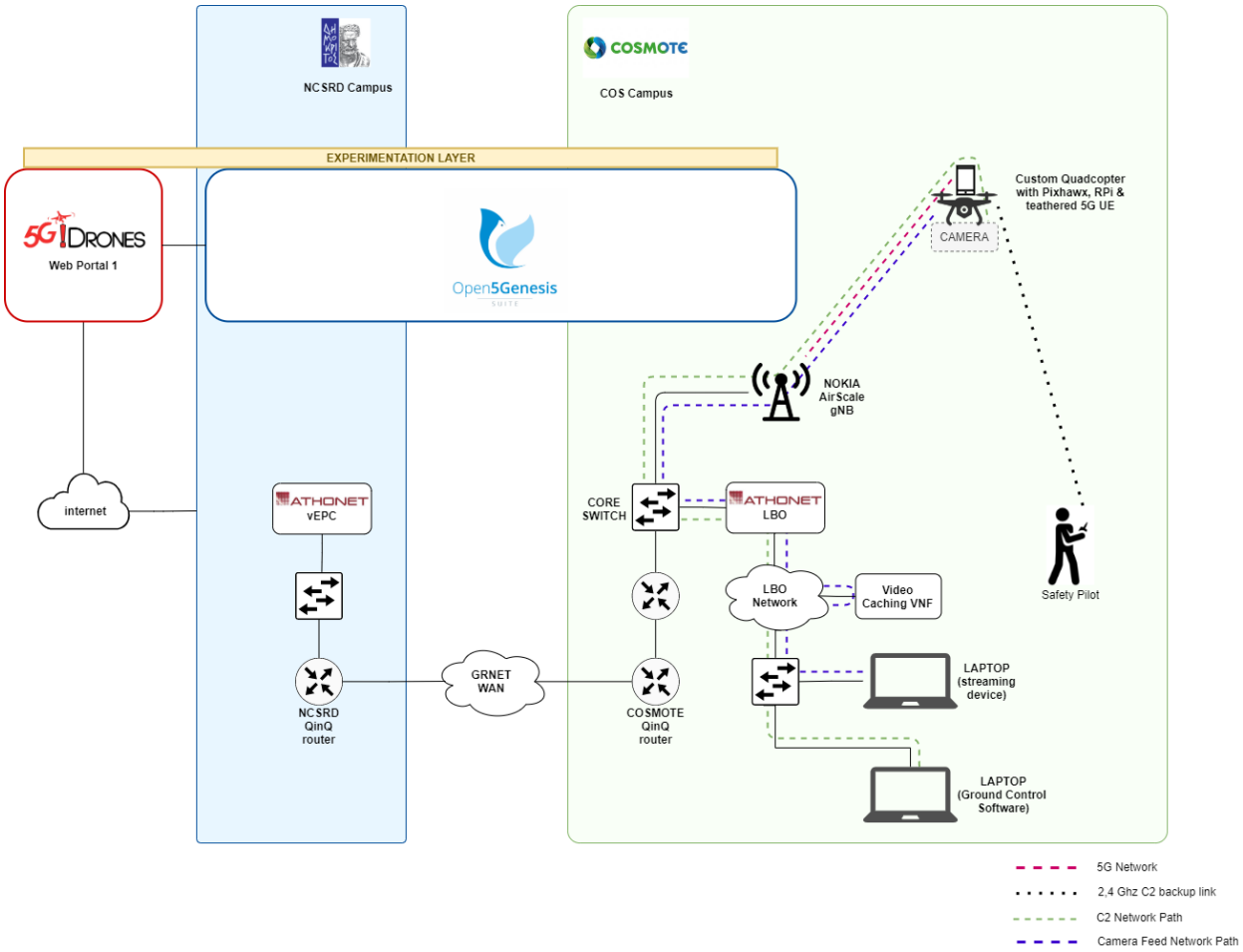


Figure 25 Use Case "Eye in the Sky" Implementation

As described in Section 2.3.2.3. , the LBO-SGW has been connected to Athonet's vEPC located in NCSRD for the purpose of serving 5GENESIS subscribers, with the capability to either break-out the traffic in the local COSMOTE edge cloud or to route SGi traffic to the PGW at the NCSRD site, depending on the traffic characteristics.

The experiment can be configured and initiated using the 5G!Drones Portal and the Open5GENESIS Suite Framework. We register the UAV flight plan desired to execute for this experiment through the 5G!Drones Portal (which is still in development phase). The 5GENESIS Slice Manager, Katana, deployed a slice at NCSRD Campus and COSMOTE OTE-Academy

premises. A Video Cache VNF is deployed over this slice at the COSMOTE Edge cloud, utilizing the LBO-SGW.

The UAV used for the use case, was equipped with a Raspberry Pi 4 (RPi) and a plugin HD camera, depicted in Figure 26. The RPi is tethered via USB to a 5G Mobile Phone, so as to communicate with the Ground Control Software over the 5G network provided by NOKIA Airscale gNB. After the flight is initiated, the on-board HD camera is activated and subsequently configured to stream the video at the Video Cache VNF using FFMPEG[7] software via the 5G Network.

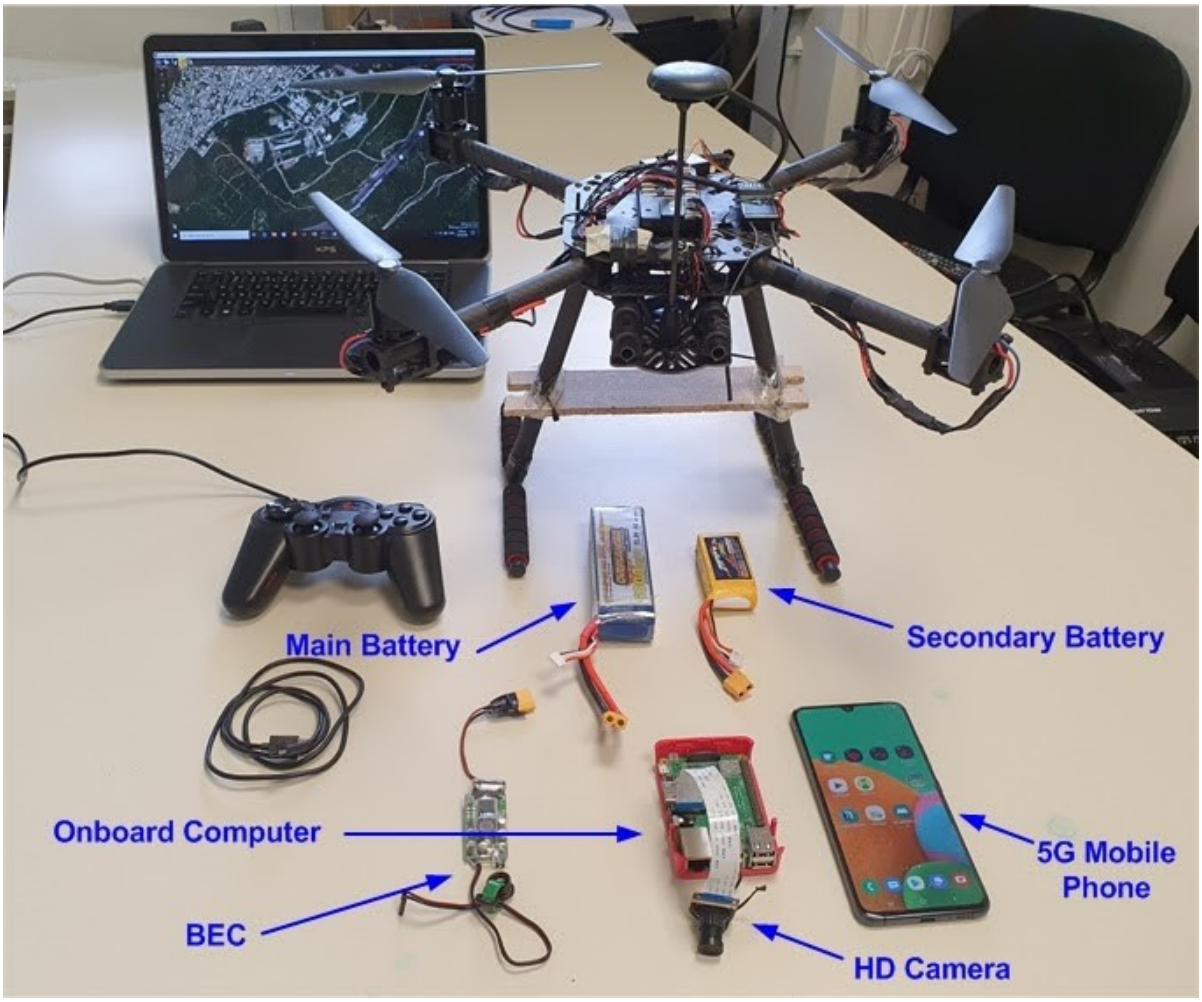


Figure 26 UAV Components

3.1.3. Use Case Security-as-a-Service (SeCaas)

OTEAcademy is an educational and examinations center offering a variety of short courses and on-line certifications to a wide and diverse audience, spanning from students sitting for foreign language accreditation to senior managers requiring specialized training. Therefore, ensuring transparent, accurate and unhindered examination and assessment processes, as well as high-quality, undisturbed digital courses and interactive lessons is obviously of paramount importance. To protect the credibility of the offered accreditation services, OTEAcademy must

[7] https://ffmpeg.org/

make sure the campus is not an attractive setup for anonymous visitors to attack remote examination centers and labs that OTEAcademy audience is provided access to.

A SeCaas Service is deployed in OTEAcademy edge network, as depicted in Figure 27, allowing the detection of suspicious or unauthorized traffic generated within its premises, during certain time-periods where examinations take place. The deployed service blocks any malicious network flows before reaching the boundaries of the institutions that OTEAcademy cooperates with, ensuring an unobstructed conduct of examinations.

SeCaas is about enhancing any slice with security services and is based on the 5GENESIS Security Framework [18], [17]. It will be demonstrated on the deployed 5G infrastructure of COSMOTE and NCSRD and will exploit ML algorithms that use monitoring data from the edge cloud and the gNB (Amarisoft) to detect various attacks, followed by appropriate mitigation actions based on the attack scenario.

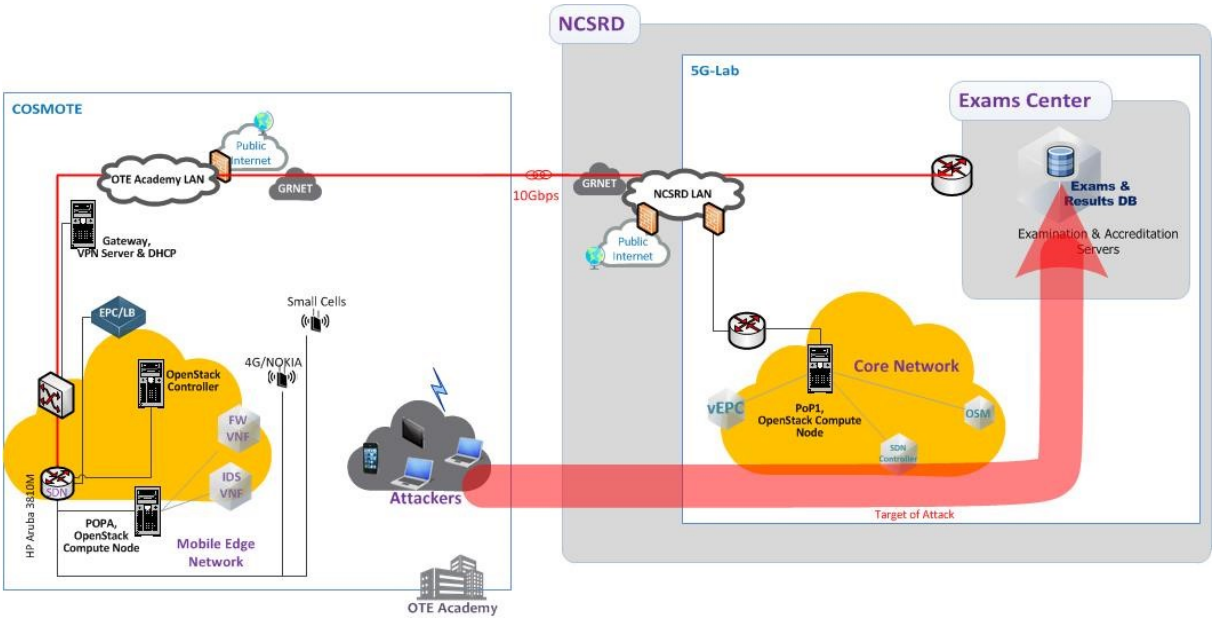


Figure 27: SeCaas Service at OTEAcademy Use Case Topology

4. ATHENS PLATFORM EVOLUTION IN 5GENESIS

4.1. Evolution Timeline

The Athens platform is deployed according to the 5GENESIS Architecture template as set in D2.2 [1]. Figure 28 presents the progress of the Athens Platform components integration per phase. It should be noted though that this diagram serves as an overview and minor deviations are not covered by its illustration.

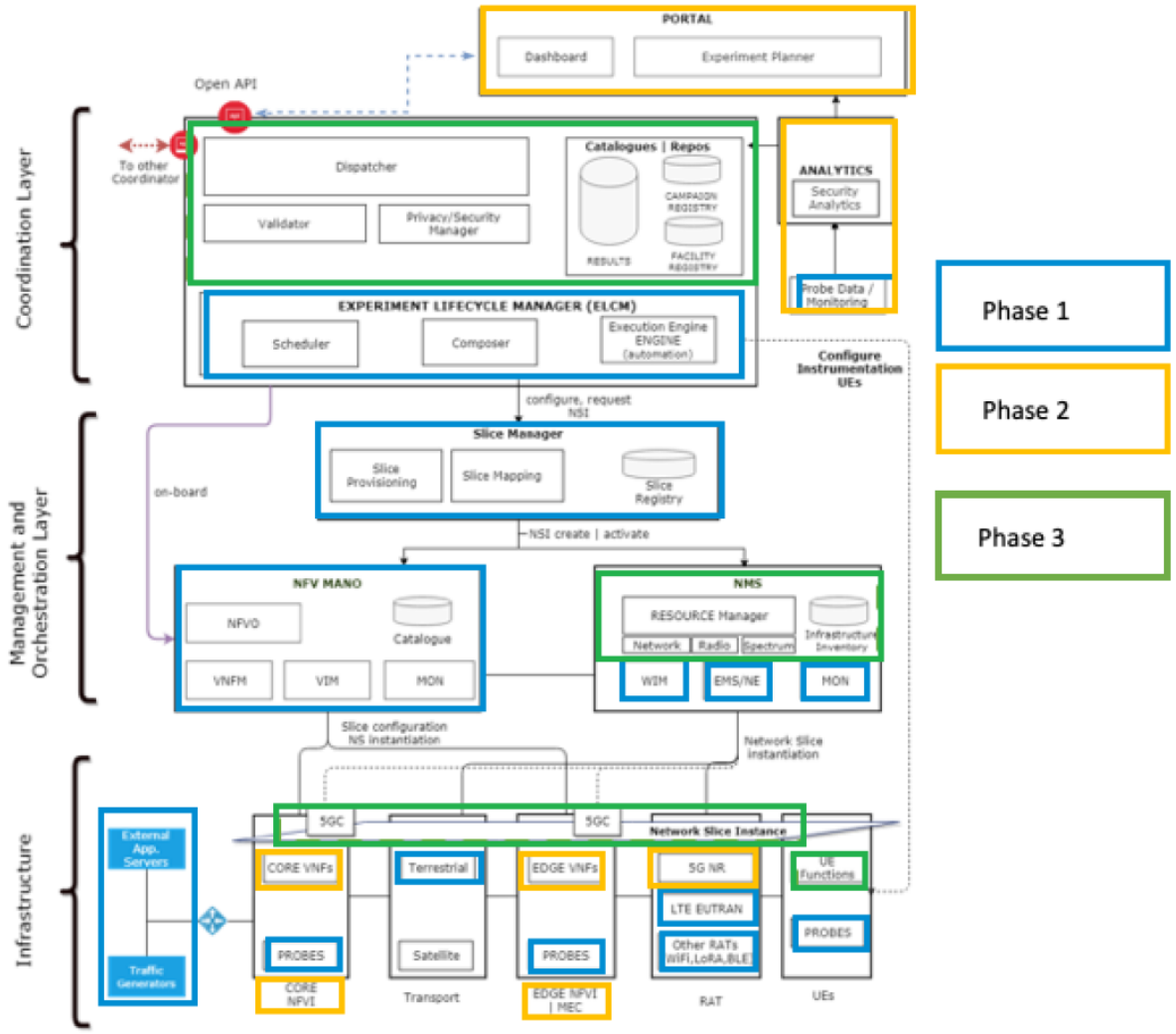


Figure 28 Per-phase instantiation of the 5GENESIS architectural blueprint in the Athens Platform

Taking into account that the Athens platform was already well developed in the area of software networks and various radio technologies were already available, the objectives of Phase 1 were to redesign the platform in order to fit to the purpose of 5GENESIS and introduce as many new components as possible in a cohesive manner. This would allow the platform to respond quickly to the first phase of experimentation within 5GENESIS and test a variety of possible solutions. At the same time, it would be possible to test new components and provide feedback on the design or features. The NCSRD Athens platform had already deployed and

tested a fully operational 4G LTE based infrastructure that has been successfully exploited in previous 5G-PPP Phase 1 and 2 projects (SONATA, 5GTANGO, SESAME, and 5G ESSENCE). At the same time, the COSMOTE site operated an autonomous 4G LTE experimental network. In Release A of 5GENESIS, the initially deployed infrastructure was re-designed and re-deployed in order to be able to support the new 5G RAN and Core components and allow for the interconnection of the two isolated networks for experimental purposes. The deployment roadmap of the mobile network technologies in Phase 1 is summarized as follows:

- Network planning and redesign of mobile network
- Installation and deployment of all available elements (4G Core and RAN as well as non-3GPP)
- E2E testing with 4G LTE equipment

Moving forwards, in Phase 2 the main focus areas were:

i. Integrate as much 5G radio and core technologies that are available
ii. Test the deployment of network slices and network services at the core and the edge NFVIs
iii. Integrate the experiment monitoring and analytics components
iv. Integrate the performance measurement probes based on MONROE project
v. Upgrade the Slice Manager
vi. Integrate the Experimenter Portal and the OpenAPIs

The finalization of Phase 2 allowed the deployment of a variety of mobile network configurations. In Release B, new features in the 5G RAN and Core were integrated as the technology matured and components were made available. Simultaneous operation of the 5GENESIS and COSMOTE network implementing - (MORAN) at the NOKIA Airscale gNBs and MOCN - at the LBO node in the COSMOTE edge has also been an integral implementation of Release B. The deployment roadmap of the mobile network technologies in Phase 2 is summarized as follows:

- Deployment of 5G RAN elements
  - Commercial Solutions: Nokia 5G NR, Amarisoft 5GNR and 5GC
  - Partners Solutions: Athonet vEPC, OAI 5GNR
- Amarisoft 5GC – Amarisoft 5G gNB – COTS UE (NSA)
- Installation of Athonet's LBO, integration with COSMOTE and 5GENESIS PLMNs

4.2. Phase 3 Accomplishments

During Phase 3, the WP4 activities in the Athens Platform revolved around integrating the final version of components and technologies comprising the 5GENESIS Architecture, in order to provide the necessary functionalities for conducting experimentation in the context of the designated use cases, described in detail in Section 3. Such functionalities include the automated configuration and execution of experiments, the recording of primary and

complementary metrics, results evaluation through statistical analysis and data visualization. The Phase 3 accomplishments are summarized below and are further explained in the following subsections:

- Interconnection between Athens and Malaga Platforms
- Upgrade of 5G infrastructure in Standalone (SA) mode
- Use Case 1 "Big event in soccer stadium" pilot demonstrations
- Use Case 2 "Eye in the sky" trials in liaison with 5G!Drones
- Integration of Open5GENESIS Suite Release B

It is also important to note that the evolution of the Athens Platform has resulted in the publication of several scientific papers and contributions in conferences and journals, while the Athens Platform is also utilized as a 5G testbed by other ICT projects, including 5G!Drones and INSPIRE-5Gplus[8] and RESPOND-A[9].

4.2.1. Interconnection between Athens and Malaga Platforms

During Phase 3, the Athens and Malaga Platforms successfully established a network interconnection in order to support Cross-Platform Experimentation, which will be reported in the upcoming Deliverable D6.4 "Multiplatform trial and interworking experimentation". Cross-Platform Experimentation includes a set of actions that enable the distributed execution of experiments for KPIs validation between two different Platforms (Platform A and Platform B) [4].

Such actions include: *i)* cross-platform experiment customization, where Platform A requests the execution of an experiment to Platform B, *ii)* experiment customization, where the experimenter defines a custom cross-platform experiment, *iii)* execution synchronization, where Platform A asks for the experiment status on the side of Platform B, *iv)* information exchange, where Platform A shall request for information on specific variables provisioned in Platform B, and *vi)* results retrieval, where Platform A may retrieve the results generated by Platform B.

In this context, Athens and Malaga Platforms achieved successful interconnection between NCSRD and UMA Campuses through GÉANT, which has been validated through a series of network performance tests, depicted in Table 11. The tests include ping, UDP/TCP iPerf measurements, resulting in approximately 60ms round-trip time latency between the designated endpoints and 600MBps maximum UDP performance without any packet loss. This interconnection will be used in the context of cross-platform experimentation between Athens and Malaga during the second semester of 2021.

[8] https://www.inspire-5gplus.eu/
[9] https://respond-a-project.eu/

Table 11 Network performance tests between Athens and Malaga Platforms

Source	Destination	Test	Results
Malaga	Athens	Ping	63 packets transmitted, 63 received, 0% packet loss, time 62083ms RTT min/avg/max/mdev = 57.783/58.628/60.203/0.665 ms
Malaga	Athens	UDP iPerf	600Mbits/sec – 0% loss 650Mbits/sec – 0.5% loss 700Mbits/sec – 17% loss 800Mbits/sec – 30% loss
Malaga	Athens	TCP iPerf	1 connection – 200Mbits/sec 5 connections – 400-600Mbits/sec

4.2.2. Upgrade of 5G infrastructure in Standalone (SA) Mode

For 5G technologies, the integration of Amarisoft and Athonet was completed, providing multiple working 5G RAN with NSA and SA 5GC configurations (Table 2). On the other hand, integration of solutions brought from ECM (OAI) and RuNEL were delayed due to COVID19 and were removed from the plans for Athens Platform.

Another significant milestone was achieved with the successful integration of the Local Break Out Node utilizing the interconnection of NCSRD-COSMOTE. Specifically, at the main data center of COSMOTE an LBO (Local break Out) SGW node was installed based on Athonet's MEC interconnection. Then, the LBO-SGW has been connected to the NCSRD Athonet's vEPC for the purpose of serving 5GENESIS subscribers, with the capability either to break-out the traffic in the local COSMOTE edge cloud, or to route SGi traffic to the PGW at the NCSRD site, depending on the traffic characteristics. This milestone allowed the interconnection of the previously independent mobile networks operated by NCSRD and COSMOTE. The setup has been used for showcasing in liaison with 5G!Drones project.

The deployment roadmap of the mobile network technologies in Phase 3 is summarized as follows:

- Upgrades and enhancements of deployed components
- 5G SA and NSA deployment integration with the MANO and Coordinator Layers
- Implementation and testing of MOCN & MORAN for the Athonet's LBO and Nokia Airscale
- Full E2E operation
    - Athonet vEPC@NCSRD – Athonet LBO@COSMOTE – Nokia Airscale gNB@COSMOTE
    - Amarisoft 5GC – Amarisoft gNB – Commercial UEs (5G SA)

- Athonet vEPC – Amarisoft eNB/gNB – Commercial UEs (5G NSA)

4.2.3. Use Case 1 “Big Event in soccer stadium” pilot demonstrations

During Phase 3, the partners of the Athens Platform conducted a set of preparatory trials using UAVs controlled through the installed 5G infrastructure in the context of the designated Use Cases “Big Event in Stadium” to support the final experimentation campaigns in the context of WP6 during the second semester of 2021.

To evaluate the needs of the final use case demonstration on the Egaleo Stadium, an initial test was performed in the NCSRD Campus to assess the functionality of the overall implementation (Figure 29), considering the imposed COVID-19 restrictions. For this demonstration, the Amarisoft 5G NR Callbox was employed, that communicated with a Samsung A90 5G tethered over the UAV controller board on-board. The control of the UAV took place successfully over the 5G link without any latency issues, supporting the planned scenario of controlling the UAV over the deployed 5G infrastructure (Figure 29, Figure 30).

Figure 29 Amarisoft 5G test setup in NCSRD Campus

Figure 30 UAV flying over NCSRD Campus controlled through the deployed 5G network

As a next step, another pilot demonstration took place this time on the Egaleo Stadium, in order to test, troubleshoot and evaluate the functionality of a 360-degree camera (Insta360 Pro 2 Camera) that is able to deliver 360° streaming video to spectators. This experimental activity showcased an eMBMS-enabled video streaming service of a live football event that delivered the stream to the spectators via Bittium[10] UEs over the deployed LTE network, maintaining a fixed bit-rate independent of the number of viewers (Figure 31 - Figure 33).

In this case, 5GENESIS incorporates essential functionalities showcased in the context of the 5G-ESSENCE project, namely delivering locally generated video content to spectators via high

[10] https://www.bittium.com

quality and resilient transmission in real-time conditions. 5GENESIS transfers these functionalities under the 5G umbrella, to be used as a case study for KPIs validation.

Figure 31 Insta-360 Pro Camera

Figure 32 Deployed Base Station on the Egaleo Stadium

Figure 33 eMBMS reception of the 360º Camera feed

4.2.4. Use Case 2 "Eye in the Sky"

During 28/6-2/7/2021, a demonstration of the "Eye in the sky" use case in liaison with 5G!Drones project tested and validated a solution conveying both control and multimedia streaming data in real-time using a UAV over the 5G infrastructure located in both the NCSRD Campus and COSMOTE OTE-Academy premises. The 5GENESIS Athens Platform was used by the 5G!Drones project for supporting its trials at COSMOTE Academy premises in Athens. These trials were an opportunity to test flights and 5G KPIs, such as latency, under different flight scenarios, while the 5GENESIS Athens platform services were showcased.

To assess the functionality of the deployment, we connected to COSMOTE's private LBO network via a laptop, acting as a video-client device. The laptop was configured to receive the stream from the Video Cache VNF server, and we were able to watch in real time the video stream of the UAV camera through VLC media player[11] with minimal latency, illustrated in Figure 35.

During this demonstration, we verified the benefits from utilizing LBO and routing the SGi traffic through the edge cloud, compared to routing traffic to centralized nodes. It was feasible to deliver a real-time video streaming service from a flying UAV to video clients connected to different private networks. The Video Cache VNF on the edge cloud was re-streaming the video with low latency and high quality. Finally, an important milestone was reached, since components from two European H2020 projects, 5GENESIS and 5G!Drones, were combined in order to successfully co-operate and demonstrate the use case.

[11] https://www.videolan.org/

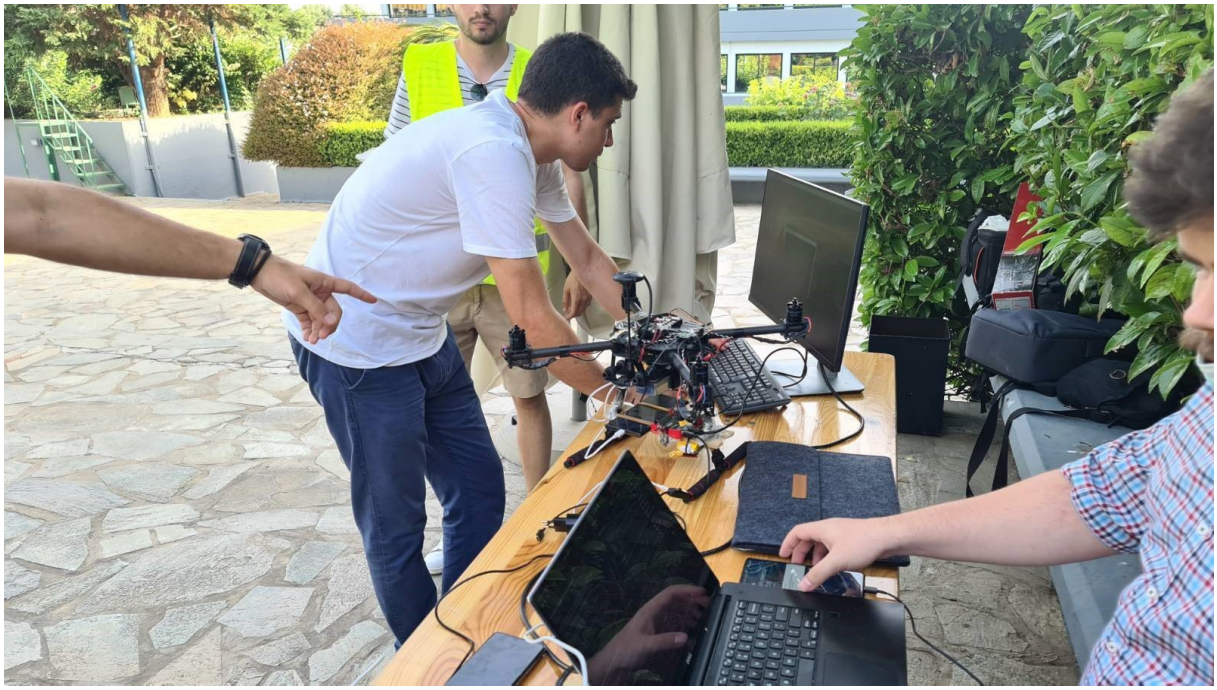


Figure 34 Trials at COSMOTE Academy

Figure 35 Video feed of the UAV Camera received from video clients showing the minimal latency

4.2.5. Integration of Open5GENESIS Suite Release B

Phase 3 activities mainly focused on finalizing the integration of Release B components of the Open5GENESIS Suite and preparing the platform for the E2E experimentation support. During this period, the Athens Platform partners finalized the integration of the Coordination Layer, Slice Manager, Analytics framework, NMS Resource and Infrastructure Inventory. The

Coordination Layer provides access to the experimenter in the underlying mobile network and cloud computing infrastructure, allowing the configuration of experiments and the automated analysis of results via various statistical tools through its 5GENESIS Portal (Figure 36). In addition, the Release B of the Slice Manager was successfully deployed in the Athens Platform, providing per-slice monitoring and concurrent slicing capabilities.

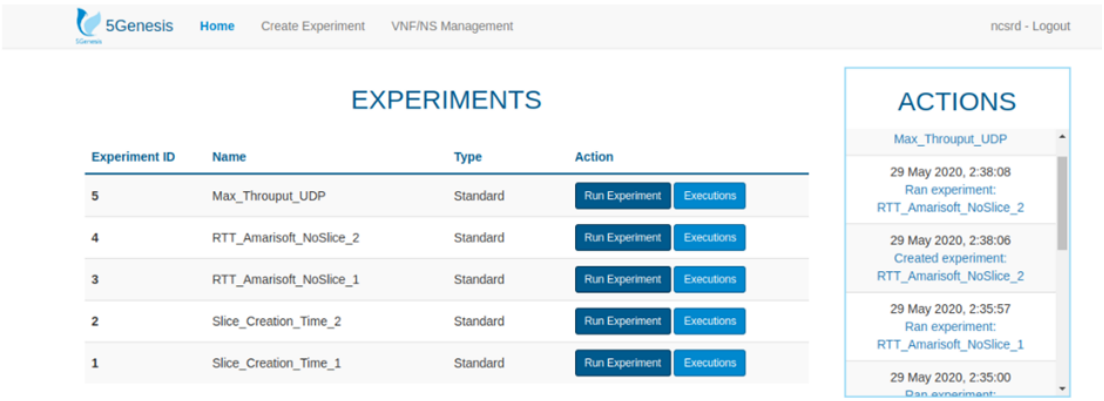


Figure 36 Portal Interface to the Athens Platform

Another significant component of the Coordination Layer, the 5G Security Analytics Framework Rel. B has been successfully deployed over the Athens Platform. The initial deployment of the Framework was based on the Apache Spot [18] that supported Netflow, DNS and Proxy data, resulting in monitoring attacks in strictly networking infrastructure (Figure 37). However, due to the significant evolution of the Security Analytics Framework throughout 5GENESIS, as described in [17], there are additional functionalities that allow monitoring and analysis of infrastructure metrics from RAN, core and compute elements through a well-established metrics processing pipeline. As a result, the Rel. B of the Framework will support the instantiation of Use Case 3 “Security as a Service” during the second semester of 2021.

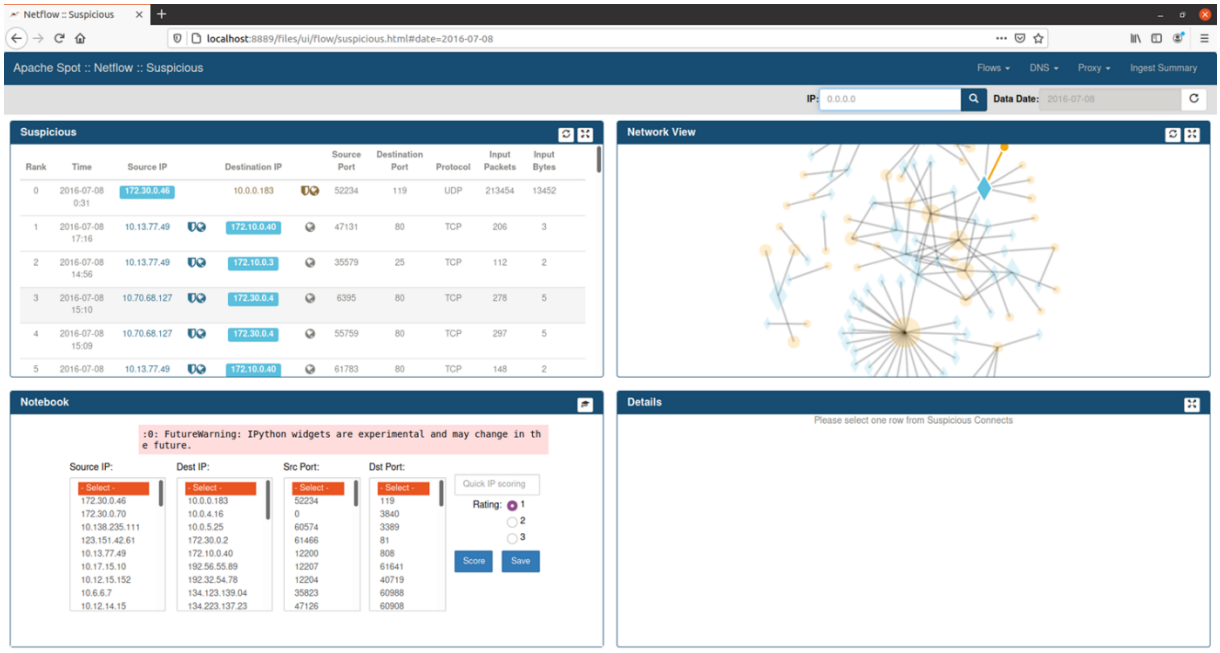


Figure 37 Security Analytics Framework initial deployment based on Apache Spot

5. CONCLUSIONS

This document presented the Release C of the Athens Platform which serves as the final implementation in the course of 5GENESIS. The Sections provided a general overview of the design, the technologies and components spanning over the three logical layers of the 5GENESIS Architecture, namely the Infrastructure, MANO and Coordination Layers. The Infrastructure of the Athens Platform provides a variety of mobile network configurations, including both SA and NSA modes with edge cloud and slice management capabilities, based mainly on commercial solutions to allow stability over the experimentation activities. Open-source solutions have also been deployed mostly for research and development purposes. The MANO Layer was extended to integrate additional infrastructure equipment, while the Coordination Layer was upgraded with newer versions of the existing components, developed as part of Release B of the Open5GENESIS Suite, including the Portal, the Analytics Tools and Security Framework.

By the end of Phase 3 of 5GENESIS, the Athens Platform provides end-to-end 5G operation and has managed to allow the interconnection of the previously independent mobile networks deployed in NCSRD and COSMOTE over the LBO functionality. The significant evolution of the Athens Platform all along from Phase 1 to Phase 3 will allow the automated validation of KPIs in specified use case trials over various environments and configurations as part of WP6 activities until December 2021. Finally, the Athens Platform will hopefully serve as a testbed of choice for interested vertical industries, wishing to enter the 5G experimentation field in the future.

6. REFERENCES

[1] 5GENESIS Consortium, "D2.2 5GENESIS Overall Facility Design and Specifications," December 2018. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/12/5GENESIS_D2.2_v1.0.pdf. [Accessed 19 July 2021].

[2] 5GENESIS Consortium, "D2.1 Requirements of the Facility," October 2018. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/12/5GENESIS_D2.1_v1.0.pdf. [Accessed 19 July 2021].

[3] 5GENESIS Consortium, "D2.3 Initial planning of tests and experimentation," February 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/12/5GENESIS_D2.3_v1.0.pdf. [Accessed 19 July 2021].

[4] 5GENESIS Consortium, "D2.4 Final report on facility design and experimentation planning," July 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/07/5GENESIS_D2.4_v1.0.pdf. [Accessed 29 July 2021].

[5] 5GENESIS Consortium, "D3.1 Management and Orchestration (Release A)," October 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.1_v1.0.pdf. [Accessed 2021 July 19].

[6] 5GENESIS Consortium, "D3.3 Slice Management (Release A)," October 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.3_v1.0.pdf. [Accessed 19 July 2021].

[7] 5GENESIS Consortium, "D3.4 Slice Management (Release B)," 2021. [Online]. Available: https://5genesis.eu/wp-content/uploads/2021/05/5GENESIS_D3.4_v1.0.pdf. [Accessed 19 July 2021].

[8] 5GENESIS Consortium, "D3.5 Monitoring and Analytics (Release A)," October 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.5_v1.0.pdf. [Accessed 19 July 2021].

[9] 5GENESIS Consortium, "D3.9 5G Core Network Functions (Release A)," October 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.9_v1.0.pdf. [Accessed 19 July 2021].

[10] 5GENESIS Consortium, "D3.11 5G Access Components and User Equipment (Release A)," October 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.11_v1.0.pdf. [Accessed 19 July 2021].

[11] 5GENESIS Consortium, "D4.2 The Athens Platform (Release B)," January 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.2_v1.0.pdf. [Accessed 19 July 2021].

[12] 5GENESIS Consortium, "D5.1 System-Level Tests and Verification," March 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/03/5GENESIS_D5.1_v1.0.pdf. [Accessed 19 July 2021].

[13] 5GENESIS Consortium, "D4.5 The Malaga Platform (Release B)," January 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.5_v1.0.pdf. [Accessed 19 July 2021].

[14] 5GENESIS Consortium, "D4.17 Potable 5G Demonstrator (Release B)," June 2020. [Online]. Available: https://5genesis.eu/wp-content/uploads/2020/02/5GENESIS_D4.17_v1.0.pdf. [Accessed 19 July 2021].

[15] 5GENESIS Consortium, "D3.10 5G Core Network Functions (Release B)," July 2021. [Online].

[16] 5GENESIs Consortium, "D3.2 Management and Orchestration (Release B)," March 2021. [Online]. Available: https://5genesis.eu/wp-content/uploads/2021/03/5GENESIS_D3.2-v1.0.pdf. [Accessed 19 July 2021].

[17] 5GENESIS Consortium, "D3.14 5G Security Framework (Release B)," March 2021. [Online]. Available: https://5genesis.eu/wp-content/uploads/2021/03/5GENESIS_D3.14_v.1.0.pdf. [Accessed 19 July 2021].

[18] 5GENESIS Consortium, "D3.13 5G Security Framework (Release A)," October 2019. [Online]. Available: https://5genesis.eu/wp-content/uploads/2019/10/5GENESIS_D3.13_v1.0.pdf. [Accessed 19 July 2021].

[19] 5GENESIS Consortium, "D3.6 Monitoring and Analytics (Release B)," April 2021. [Online]. Available: https://5genesis.eu/wp-content/uploads/2021/05/5GENESIS_D3.6_v1.0_FINAL.pdf. [Accessed 19 July 2021].