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

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Deliverable D4.2

The Athens Platform (Release B)

Editor G. Xilouris (NCSRD)

Contributors COS (COSMOTE), NCSRD (NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"), FOG (FOGUS), REL (RUNEL), ATH (ATHONET), ECM (EURECOM)

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List of Authors

NCSRD	National Center for Scientific Research "Demokritos"
G. Xilouris, T. Anagnostopoulos, T. Sarlas, M. Christopoulou, H. Koumaras, S. Kolometsos	
COS	COSMOTE
F. Setaki, I. Mesogiti	
FOG	FOGUS
D. Tsolkas	
ECM	EURECOM
F. Kaltenberger, P. Matzakos	
ATH	ATHONET SRL
D.Munaretto, F. Giust	
REL	RUNEL NGMT LTD
I. Koffman	

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TELEFONICA INVESTIGACION Y DESARROLLO SA	Spain
UNIVERSIDAD DE MALAGA	Spain
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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
AP	Access Point
AR	Augmented Reality
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
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution - Advanced

Acronym	Meaning
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
MONROE	Measuring Mobile Broadband Networks in Europe.
MPTCP	MultiPath TCP
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NSMF	Network Slice Management Function
NR	New Radio
OAI	Open Air Interface
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
RAN	Radio Access Network
RRH	Remote Radio Head
RRM	Radio Resource management
RU	Radio Unit
SDN	Software Defined Network
SDR	Software Defined Radio
SGW	Serving Gateway (3GPP)
STA	Station
TCP	Transmission Control Protocol
UAV	Unmanned Aerial Vehicles
UDP	User Datagram Protocol
UE	User Equipment
UPF	User Plane Function
uRLLC	Ultra-Reliable, Low-Latency Communications
VIM	Virtualised Infrastructure Manager

Acronym	Meaning
WIM	WAN Infrastructure Manager
WSMP	Wifi Service Management Platform

Executive Summary

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. This document extends the content of the previous deliverable D4.1 and describes the advances of the platform. The Athens platform is one of the 5GENESIS six 5G 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", in response to the project requirements identified in deliverable D2.1 "Requirements of the facility".

The Athens platform is comprised of the NCSRD Campus, the OTE Academy facilities and the "Stavros Mavrothalasitis" Municipal Stadium of Egaleo. The evolution of the Athens platform is achieved through a series of optimizations as new specifications and components are being made available either commercially or within the consortium. In this context, each 5GENESIS facility will follow a 3-phase integration and testing regime, where new features, functionalities and HW components will be 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) to phase 2 (Release B) and the next steps towards the final deployment and operation of 5GENESIS facility.

Release B (Rel. B) of the Athens platform has the privilege of deploying an integrated Coordination Layer and Slice Manager (Release B). This is a very significant advancement compared to Release A of the platform. It instantiates an operation Coordination Layer and includes a full blown 4G based deployment with a series of enhancements. These enhancements allow the demonstration of some early 5G features. Moreover, there is progress in terms of availability of 5G radio components, some being provided by consortium partners and others that are commercially available. All enhancements are thoroughly discussed in the document. Delays in acquiring certain 5G radio components and 5G Core functions (out of the consortium partners) has prolonged the integration process beyond the deliverable due date. According to the plan, the deployed configurations will be used during WP6 experimentation and validation phase. If further integrations happen during that period, they will be annexed to D6.2 WP6 deliverable. More specifically, the following were achieved during the second integration phase:

- Deployment of Release A of Coordination Layer components
- Deployment of Release A of Slice Manager
- Partial installation of commercial 5G RAN at OTEAcademy

- Partial installation of commercial 5G RAN and Core Non-Stand Alone (NSA) - NCSR Demokritos
- Upgrade of MANO Layer components
    - Network Function Virtualisation Orchestrator (NFVO) OSM v6 upgrade
- Additions and enhancement at the Infrastructure Monitoring.
- Integration of MONROE probes

Furthermore, the document presents a summary of the supported use cases, namely “Big Event”, “Eye in the Sky” and “Security-as-a-Service”, and their relevance to the Athens platform sites and their components.

During the last three months of this cycle, extensive tests will be performed to ensure that all the newly integrated services and components work as expected and, in parallel, the platform partners will continue their efforts towards integrating any pending elements and technologies.

The platform will be used for the second round of experiments until March 2020, and the report on the KPIs will be available in deliverable D6.2 in March 2020. This document will be followed by the deliverable describing the Release C of the platform in December 2020 (deliverable D4.3).

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

1.1. Purpose of the document

This document presents the work in progress for the integration activities currently underway in the Athens Platform. More specifically, the purpose of this deliverable is to meet the following WP4 objectives:

- Accommodate WP2 requirements and specifications.
- Integrate the components that will be implemented in WP3 within each platform in order to constitute the 5GENESIS facility.
- Support and facilitate the deployment of the described Use Cases.
- 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 for this document (see Table 1).

Table 1 Document interdependencies

id	Document title	Relevance
D2.1 [1]	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 [2]	5GENESIS Overall Facility Design and Specifications	The 5GENESIS facility architecture is defined in this document. The list of functional components to be deployed in each testbed is defined.
D2.3 [3]	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D3.1 [4]	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 [5]	Slice management WP3 (Release A)	The document details the Slice Manager solution, its interfaces towards the MANO and NMS components.
D3.5 [6]	Monitoring and WP3 analytics (Release A)	The document details the Infrastructure Monitoring components and the interfaces with infrastructure elements.

D3.9 [7]	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 [8]	5G Access Components and User Equipment (Release A)	The document details the 5G Radio Access components and UE devices.
D4.1 [10]	The Athens Platform	This is the initial deliverable for the Athens platform.
D5.1 [11]	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 target topology of the Athens platform, the platform sites, as well as the technologies used for the platform components at the three logical layers (Coordination Layer, MANO Layer, Infrastructure Layer).

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

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

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 may help 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 as presented in deliverable D4.1 [10].

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 [2].

2.1. Platform Sites Overview

2.1.1. Overall topology

The Athens 5G platform comprises three dispersed sites in the Athens metropolitan area forming an E2E (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 will be 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 the city, is a multi-functional complex, combining various indoor and outdoor usage scenarios; It is also directly connected to GRNET which provides for access to GÉANT. Internet access is provided by OTE network. This site will host infrastructure components, radio access components and NFV/Edge Computing infrastructure.
- **Site 3: The stadium of Egaleo (Stavros Mavrothalasitis)**, in west Athens, that will be 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. This site will host infrastructure components that will 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

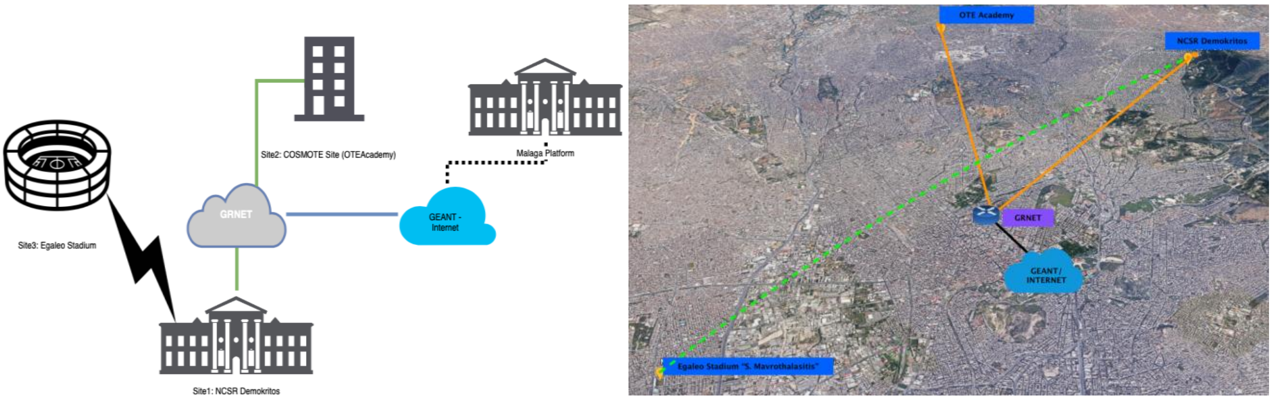


Figure 1: Athens Platform Sites Overview

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. NCSRD provides to the Athens platform a reliable operation of the network, computing and 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.

In order to cater for outdoor coverage, a MacroCell is installed at a high mast, providing coverage to the whole campus area. 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 is granted an experimental license for 5G trials for transmission in the 3.6 GHz spectrum with 100 MHz bandwidth. 5G RAN and 5G New Core elements will be developed and deployed from RunEL andOAI and Athonet respectively, in parallel with Amarisoft commercial 5G RAN and Core.

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 Frequency Band using the IEEE 802.11ac standard.

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

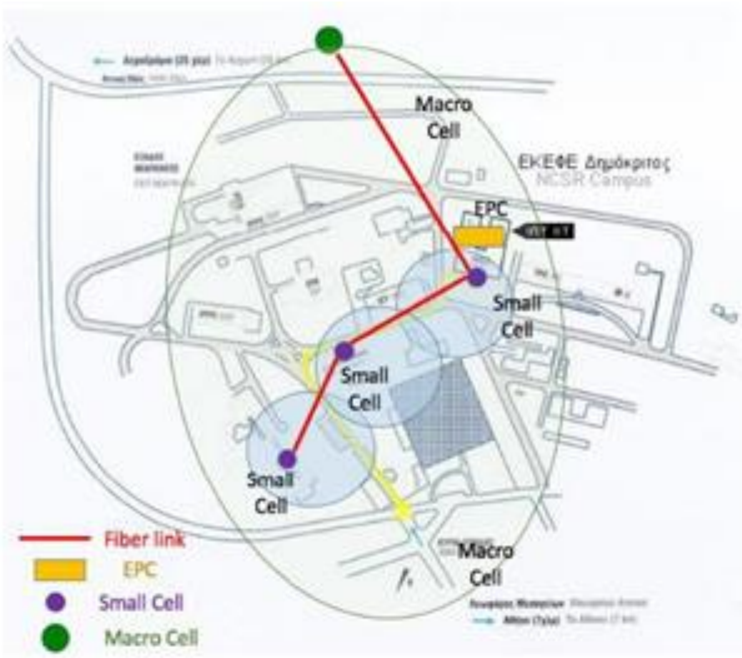


Figure 2: NCSRD Site

2.1.3. Site 2 - COSMOTE Site

COSMOTE’s testbeds for supporting research and development activities are located in OTEAcademy’s site in 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 shall host edge network capabilities empowered by the lab’s cloud infrastructure and 5G outdoor and indoor deployments based on commercial equipment. The COSMOTE’s OpenStack implementation provides to 5GENESIS 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 Security as a Service (SecaaS use case 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. Recently installation and configuration activities for the 5G Nokia Airscale indoor/outdoor NSA (option 3) system has started 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 break out (LBO) to enable MEC traffic redirection.

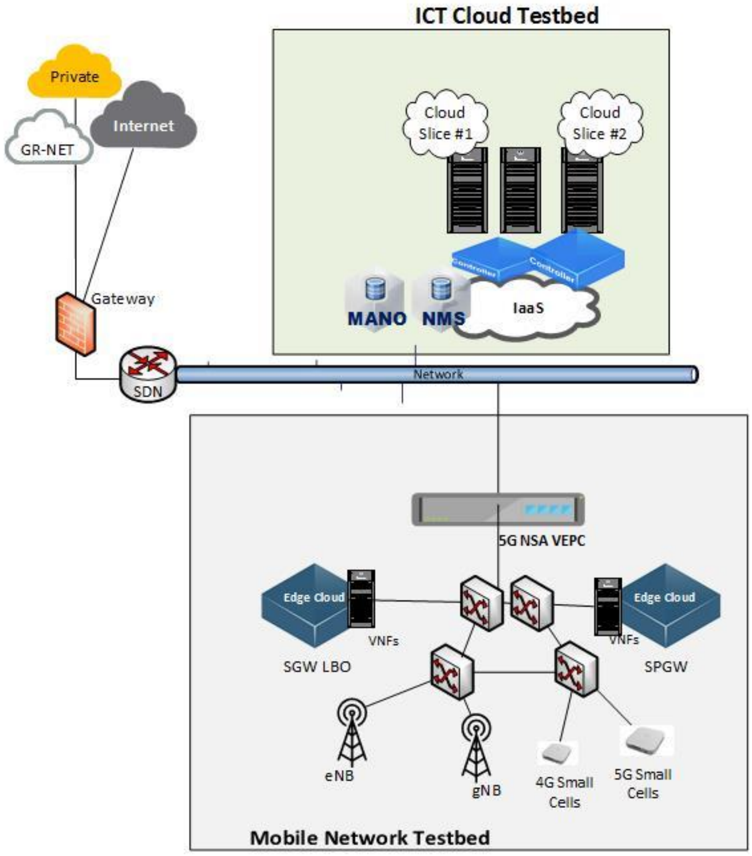


Figure 3: COSMOTE Site

2.1.4. Site 3 - Egaleo 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 will accommodate the 5G gNB components are already installed at the stadium. The stadium premises will be also equipped by small footprint edge computing infrastructure for the use case demonstration.

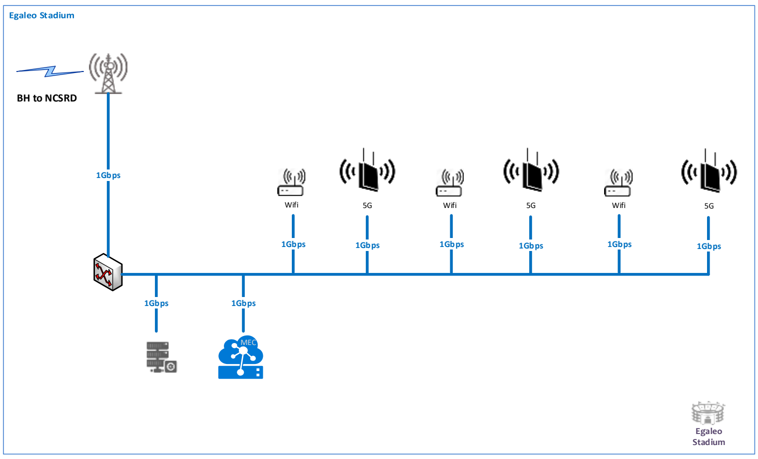


Figure 4 Egaleo Site

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. Target Deployment

The target physical topology of the Athens platform is depicted in Figure 5. The platform has already most of the main components deployed and inter-connecting links are in place, exploiting NCSRD site as the central node.

The core of the platform is supported by two OpenStack installations, one at NCSRD premises and one at the COSMOTE premises. Both installations may be seen as NFV Infrastructure with OpenStack Virtualisation Infrastructure Manager (VIM), able to instantiate NFV services.

The Slice Manager and the Management and Orchestration layer (MANO) are able to provision network slices and manage and orchestrate infrastructure resources. These components along with the Coordination layer components are deployed in the infrastructure core data center as virtual machines.

The 4G and 5G Core network functions are deployed at the available NFVIs, in the case where the virtualized instantiation is available, otherwise in stand-alone servers.

Finally, a small cluster is exploited by the infrastructure monitoring platform that monitors all components and collects performance monitoring data. The monitoring platform utilizes opensource software for the Network Management System (NMS), the time series monitoring database and alert system.

On the interconnection part among remote sites, the link between NCSRD and COSMOTE sites is realized on top of GRNET optical fiber infrastructure at rates up to 1 Gbps, whereas the link between NCSRD and Egaleo stadium is realized via terrestrial wireless backhaul technology using a microwave link at 5 GHz. The link supports speeds up to 200 Mbps depending on the link quality.

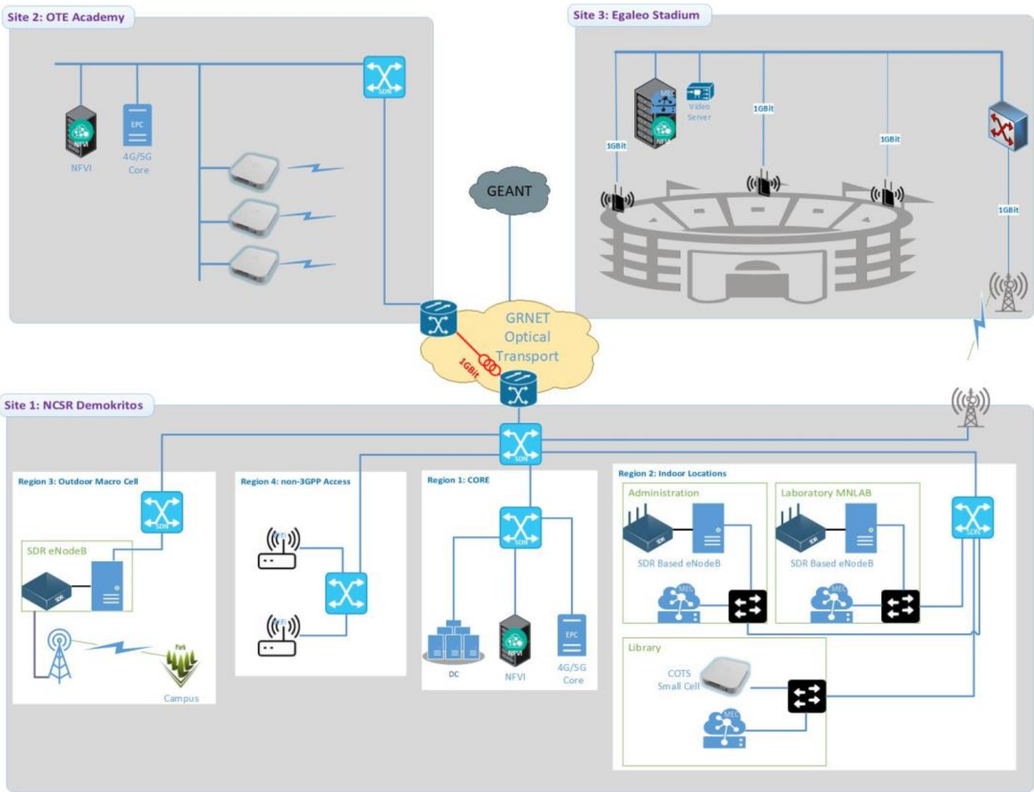


Figure 5: 5GENESIS Athens platform physical topology

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

2.2.1. Platform Infrastructure Layer

Table 2 below provides an overview of the infrastructure layer components and associated technologies deployed in the Athens platform.

Table 2 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	ECM OAI Core Athonet 5GC (constant evolution) Amarisoft Rel 15.5 5GC Amarisoft Rel 14 4G LTE	Multiple instances
5GNR	Prototypes from REL and ECM Amarisoft NSA/SA Nokia Airscale System and 5G Small Cell (RRH) Commercial 5G smartphones	Multiple instances & SDR HW

LTE EUTRAN	Eurecom OAI / Amarisoft / Nokia AirScale / Nokia FlexiZone Commercial 4G mobile phones compatible with OAI (Samsung A40, A90) and commercial 5G mobile phones (Samsung A90) plus USB dongles	multiple instances & SDR HW
Non-3GPP Access Networks	WiFi 802.11ac	Bespoke devices
Probes	MONROE	Multiple instances deployed across the network
Traffic Generator	Open-source traffic generator (e.g. Ostinato, Seagull, WARP17, TRex) IxChariot	COTS devices and SW

2.2.1.1. 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 / OpenAir Interface EPC) as well as commercial ones (i.e. Athonet/Amarisoft). The evolved 5G version of the platform uses Athonet and Amarisoft 5G Core and OAI, Amarisoft and RunEL 5G radio.

The Athens platform has 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 5GESSENCE). 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 for experimental purposes). In Release B, new features in the 5G RAN and Core are being integrated as the technology matures and components are made available.

The roadmap for deploying the mobile network technologies deployment in the Athens platform is tentatively defined as follows:

- Phase1 (integration of Release A):
  - 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
- Phase 2 (integration of Release B):
  - Deployment of 5G RAN elements
    - Commercial Solutions: Nokia 5G NR, Amarisoft 5G NR and 5GC
    - Partners Solutions: Athonet 5GC, RunEL 5GNR, OAI 5GNR, OAI 5GC.
  - RunEL 5G (no 5GCore supported), testing
  - OAI 5GNR and UE (no 5GCore supported), testing
  - Amarisoft 5G NC – Amarisoft 5G gNB – COTS UE (NSA)

- Phase 3:
    - Upgrades and enhancements over deployed components
    - 5G SA and NSA deployment integration with the MANO and Coordinator
    - Full E2E operation
        - Athonet 5GC – RunEL 5G gNB – OAI UE (SA)/Commercial UE (SA)
        - Athonet 5GC – OAI 5G gNB – OAI UE (NSA)/Commercial UE (NSA)
        - Athonet 5GC – Amarisoft 5G gNB – Commercial UE (SA)

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 spectrum. 5GENESIS proposes two alternative implementations of 5GNR, provided by the vendors RunEL and ECM (i.e. OAI). In addition, the Athens platform integrates two commercial solutions Amarisoft 5G CallBox which supports both NSA and SA 5G Core and RAN deployments and Nokia Airscale 5G Macro Cell. With respect to Release 2 of the Athens platform, Table 3 summarises the Radio Access components currently deployed in the Athens platform.

Table 3 Athens Platform 5G Release B Radio Equipment Deployment

Site	Deployed Radio Access Equipment
NCSRD	• 2 NOKIA “Flexi Zone Multiband Indoor Pico BTS” (FZ MBI) small cells – IIT building / • 1 Amarisoft eNB running on x86 server (SDR) – administration building • 1 Amarisoft eNB (USRP B210) on x86 server (SDR) – library building • 1 Amarisoft eNB (N210) for the Macro Cell at outdoor location (high mast) providing coverage to a large part of NCSRD campus. • 1 Amarisoft Callbox Classic 5G NSA (3.5 GHz, N78 Band) • 1 OAI gNB (USRP N310) and x86 server (prototype) – 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.

<u>Outdoor LTE Deployments</u>

The Athens platform has installed an antenna array at 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 6. Moving to Phase 3 the antenna array will be upgraded with an array suitable for 5GNR operation at 3.5GHz.

Figure 6 Macro Cell at NCSRD Site

Indoor LTE Deployments

The Indoor LTE deployments of the Athens platform are based initially on OAI stable software implementation combined with Ettus SDR cards. Details on the implementation are provided in APPENDIX 2: 5GENESIS Athens Platform Radio Access Products. 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.

Detailed specifications of the products in use, are provided in APPENDIX 2: 5GENESIS Athens Platform Radio Access Products.

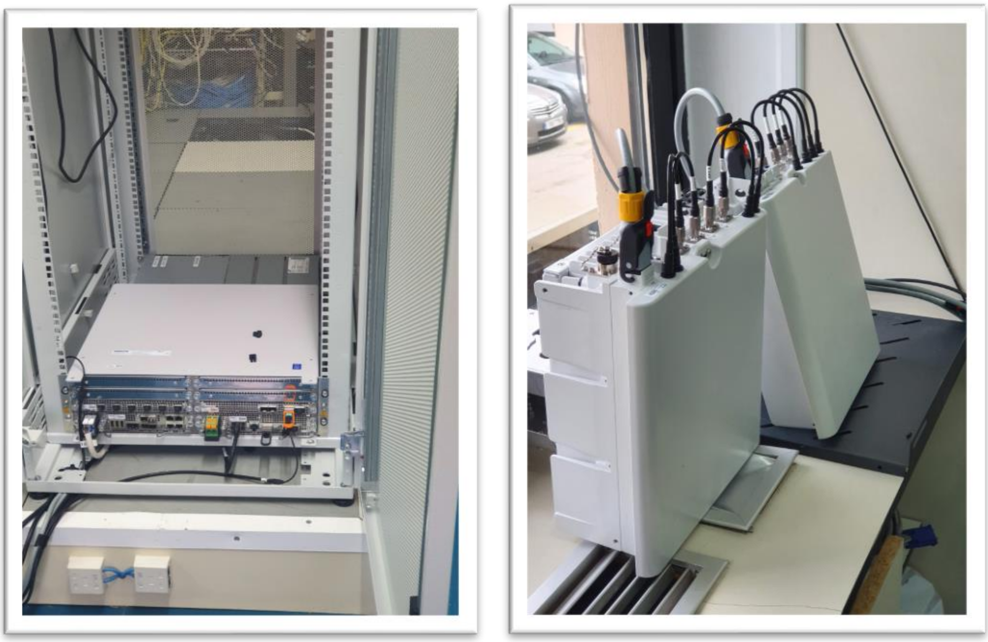
Outdoor 5GNR Deployments

At the COSMOTE site, commercial 5G equipment based on Nokia AirScale platform has been procured and is now being installed at OTE Academy premises. So far the electrical and physical installations have taken place. However, as there is a need for equipment configuration in order to become operational as well as proper setup of the already operational radio network, this deliverable will not provide details on the deployment.

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 AirScale Micro RRH 4T/4R 20W (AWHQF)
- 2 x AirScale Micro 4T4R B7 20W (AHHA)

Figure 7 a) and b) present the equipment currently installed at COSMOTE premises.



(a) (b)

Figure 7 a. Nokia AirScale 5G BBU, b. AirScale Micro 4T4R

In addition to the above described system at NCSRD premises an upgrade of the MacroCell antenna will allow outdoor transmission for testing.

<u>Indoor 5GNR Deployments</u>

NCSRD is using two USRPs N310 for the OAI based 5G NR implementation as depicted in Figure 8.

Figure 8 USRPs N310 utilized as gNB and nr-UE in NCSRD

In the context of the Athens Platform, these USRPs will be integrated in a server grade deployment of OAI to support the future MIMO configurations in NSA and SA mode once they become available in 5GENESIS. In the picture, the initial 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 deliverable *D4.17 – Portable 5G Demonstrator*[2]. The Portable demonstrator is considered as a spin-off of the Athens Platform and as such it integrates components that are tested and validated within the Athens platform environment.

Additionally, during this phase the Amarisoft 5G CallBox solutions has been installed in the Athens Platform (Figure 9).

[2] https://5genesis.eu/deliverables/

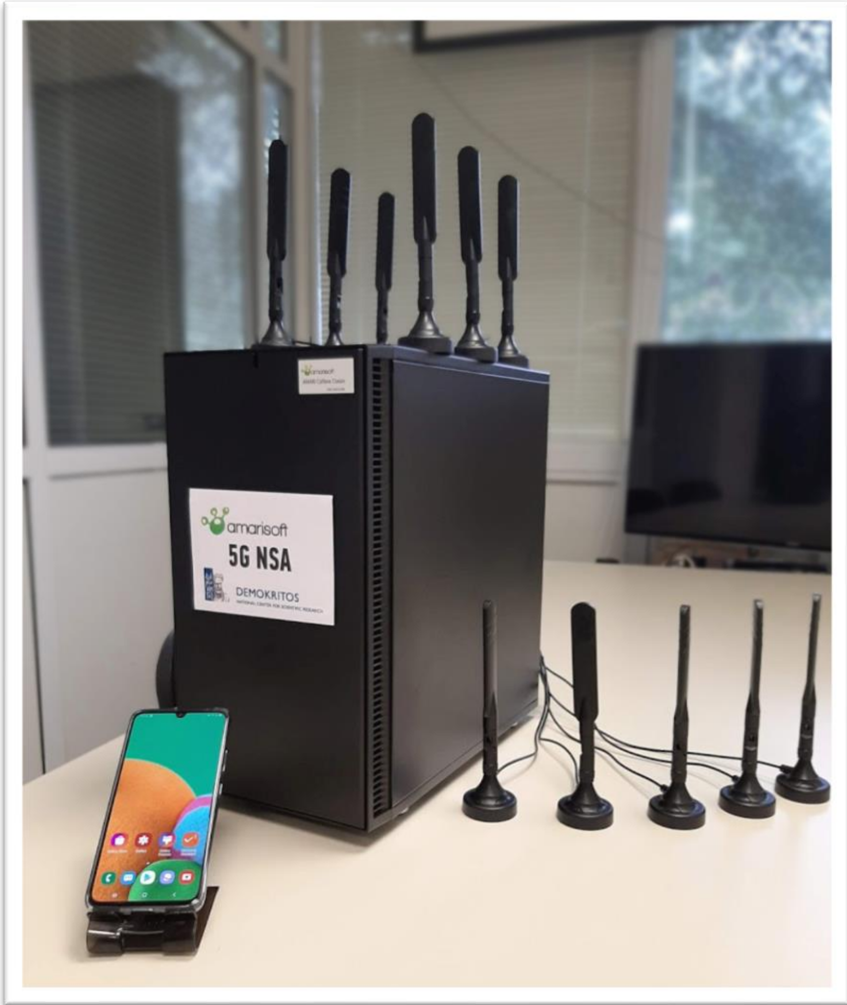


Figure 9 Amarisoft Callbox 5G NSA/SA Solution

Detailed specification of the products involved is provided in APPENDIX 2: 5GENESIS Athens Platform Radio Access Products.

Mobile Core Network

The existing mobile core establishment of Athens Platform is a full 4G mobile core that implements 3GPP defined network functions including MME, PGW, SGW, PCRF and HSS. Various products are part of the solution based on their technology readiness, and the proper integration with respective radio access components is respectively trialed per phase. The targeted implementation considers the Athonet's 5GC solution, which as a commercial product, then can be connected to commercial OSS/BSS systems to enforce regulatory obligations and billing by means of standard interfaces, i.e., X1, X2 and X3 for lawful intercept and Bx and Gy for charging.

In the course of the project, the core component will be continuously enhanced with the latest features needed for the fifth-generation network deployment. Currently the running version at the Athens platform fully supports NSA 5G deployment.

Detailed information on the capabilities of the core products that are part of Athens platform can be found in [1] and [2].

User Equipment (UEs)

The LTE UEs used in Athens platform experiments are listed in APPENDIX 2: 5GENESIS Athens Platform Radio Access Products-User Equipment (UE).

The list of prototypes 5G UEs available in the Athens platform currently is as follows:

- 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 operates is a testing mode and only in tandem with a similar setup of OAI running as gNB. Figure 10 presents the current implementation of OAI 5G-NR UE.

Figure 10 5G NR UE using USRP N300

As defined in the project's WP3 implementation roadmap, the protocol stack extensions for 5G-NR UE will be made gradually available throughout the different phases of 5GENESIS, starting from the physical layer (phase 1) and continuing with the rest of the RAN protocol stack (MAC, RRC, PDCP). The current implementation supports operation without a core (i.e. no S1 interface) between a set of OAI equipment running gNB and UE respectively.

In addition, a commercial 5G UE is available, namely a Samsung A90 5G mobile device that supports 5G NSA configurations with TDD transmission at frequency bands n41(2500 MHz) and n78 (3500 MHz). Figure 11, presents the UE while under video streaming using 5G mobile network operated by Athonet core and Amarisoft 5G RAN.

Figure 11 Samsung A90 5G (NSA)

2.2.1.2. Main Data Center

The Main Data Center (DC) of the Athens platform (see **Figure 12**) lifts the burden of hosting all the Coordination Layer components, the Slice Manager and all the MANO Layer components (i.e. NMS, EMS, NFVO etc). In addition, the Main DC also hosts the integration environment that will used during WP5 integration activities. Moreover, it is also hosting an NFV infrastructure

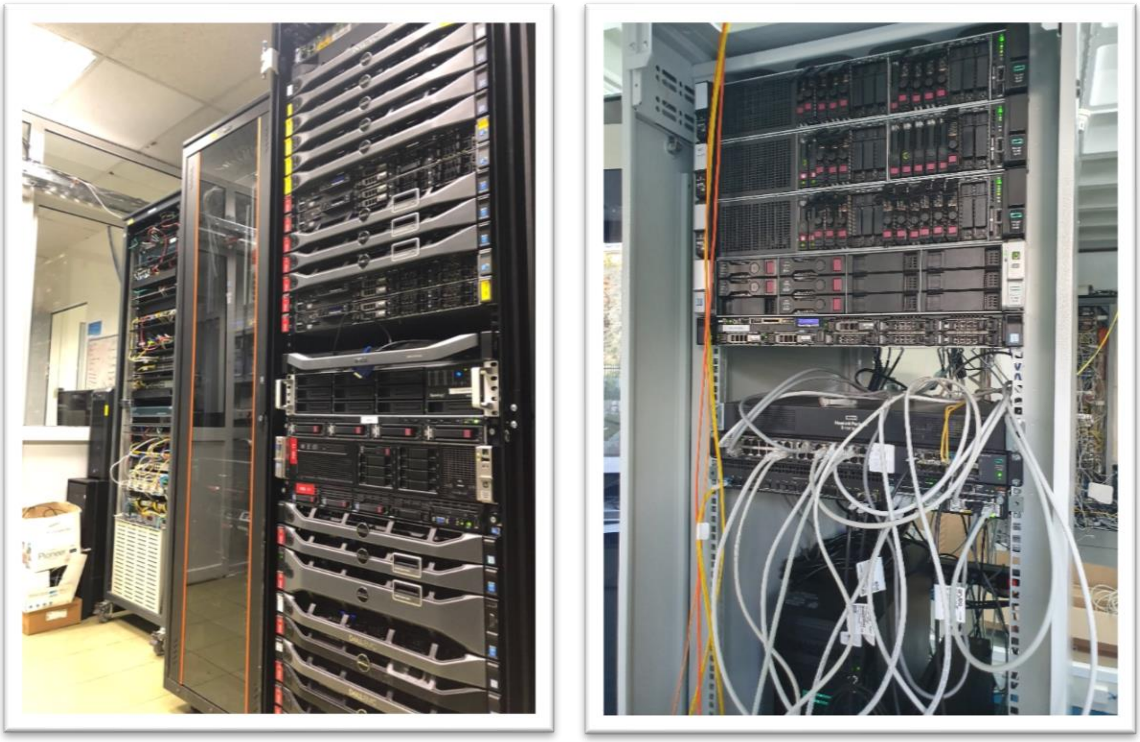


Figure 12 NCSRD Site (left) and COSMOTE Site (right) Main DC

(NFVI) that is orchestrated by the NFVO in order to instantiate network services and/or VNFs that relate to the test cases. For example, it is capable of hosting a 5GC instance or a proxy VNF.

Currently the Main DC comprises of 3 compute nodes, operating with OpenStack[3] release "Queens" providing multiple tenants (OpenStack Projects) in order to respond to both roles of Virtual 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 for Virtual Machines that have more stringent requirements (i.e. Windows based) two VMware ESXi (2 x Intel Xeon CPU X5677 @ 3.47GHz, 4C/8T, 96GB RAM) nodes are provided also. These nodes are running Ixia IxChariot traffic generation 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.

2.2.1.3. 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 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 behavior. 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.

Figure 13 Edge Computing Infrastructure at NCSRD (left) and COSMOTE (right)

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

The sites of NCSRD and COSMOTE stand primarily as permanent edge sites of the Athens Platform. In NCSRD there are two types of edge computing infrastructures that are deployed. As shown in Figure 13, on one side is an all-in-one installation of OpenStack small form factor (SFF) x86 PCs and on the other side K8s based docker orchestration infrastructure.

In COSMOTE site the edge cloud is implemented using OpenStack Rocky installation over x86 workstation equipment as illustrated in Figure 13.

An edge cloud domain is also activated in the Egaleo campus, supported by an all-in-one OpenStack NUC based nodes. The edge nodes are installed in the permanent cabinets that are installed at the Egaleo stadium for this purpose. As depicted in Figure 14, three cabinets, are available to host the gNB components as well as the edge computing infrastructure to support the 5GENESIS activities.

Figure 14: Egaleo Site Cabinets for edge equipment

2.2.1.4. Transport Network

A. SDN Spine - Leaf Network

The WAN backbone network on the NCSRD site is composed by several physical SDN Switches forming a spine – leaf architecture. All the switches are OpenFlow enabled and support OpenFlow protocol version 1.3. They are controlled by a centralized OpenDayLight (ODL) SDN controller, which is responsible for installing forwarding rules (flows) on each switch. Figure 15 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 QoS policies for each network slice instantiated on the platform.

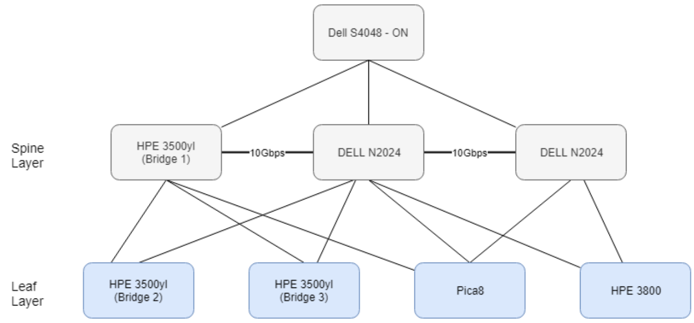


Figure 15 NCSRD spine – leaf network topology

The physical topology of this transport network along with its interconnections is depicted in Figure 16.

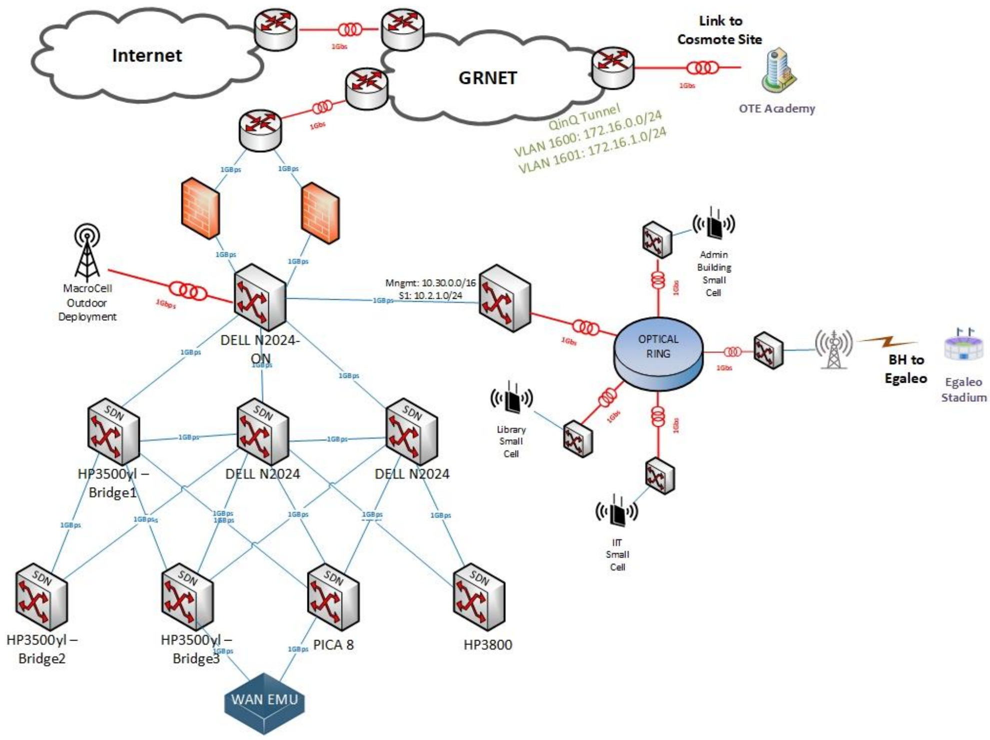


Figure 16: Transport Network at NCSRD Site

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 (Mininet, n.d.) 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.

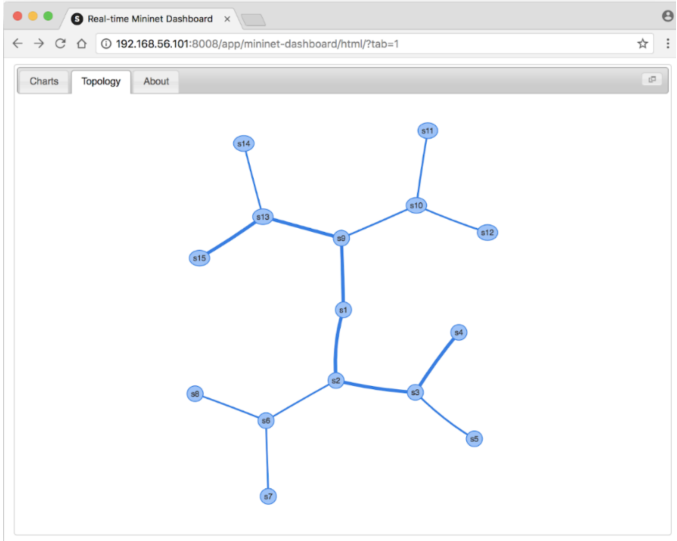


Figure 17 WAN Emulator example simulated network topology

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 17 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.

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 (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 60-meter-high mast dish antenna was installed at the NCSRD campus (see Figure 18a), while a similar dish antenna was installed at the stadium area (Figure 18b). Both antennas are powered with a Power Over Ethernet (POE) cable

Figure 18: a) High-Mast Antenna at NCSRD Campus and b) Egaleo Stadium antenna

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.

2.2.2. Management & Orchestration Layer

Table 2 below provides an overview of the Management and Orchestration layer components and associated technologies deployed in the Athens platform.

Table 4 Management and Monitoring tools

Component	Product/Technology	Mode of Implementation
Slice Manager	Katana (Opensource implementation)	From scratch implementation 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	Timeseries based monitoring, alerting and visualisation

2.2.2.1. Slice Manager

The Slice Manager is the component that mediates between the Coordination layer components of the 5GENESIS architecture and the MANO layer. 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 A of Katana is described in detail in Deliverable D3.3 [5]. 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.

2.2.2.2. NFV Management and Orchestration

Network Function Virtualisation (NFV) is critical part of the 5G deployments. The purpose of the NFV Management and Orchestration is to allow the provision of Network Services (NS) 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 Virtualisation Infrastructure Manager (VIM). This component is based on Opestack 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 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.

Network Management System

In order 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 system 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, loss) on networking devices (Switches, Routers, etc.) [13]. 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 intuitive dashboard for presenting time series data and monitoring information

2.2.2.3. Element Management System

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 build for use with OAI and Amarisoft solutions are developed and used. These EMS allow proper configuration and resource provisioning for the mobile network.

2.2.2.4. SDN Controller

The Athens platform has integrated network control based on OpenDaylight 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 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.

2.2.3. 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 summarised in Table 5:

Table 5 Coordination Layer Components

Experiments Coordination	**Description**
5GENESIS Portal	WP3 Release A 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 KPIs validation.
Analytics	Custom Python scripts are developed to support the statistical analysis requirements for results presentation and KPI validation. The scripts are utilizing the native Influx DB capabilities to support Python.

3. ATHENS PLATFORM EVOLUTION

3.1. Phase 2 Instantiation of the 5GENESIS Architecture

The Athens platform is deployed according to the 5GENESIS Architecture template as set in D.2.2 [2]. Figure 19 presents the per-phase 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.

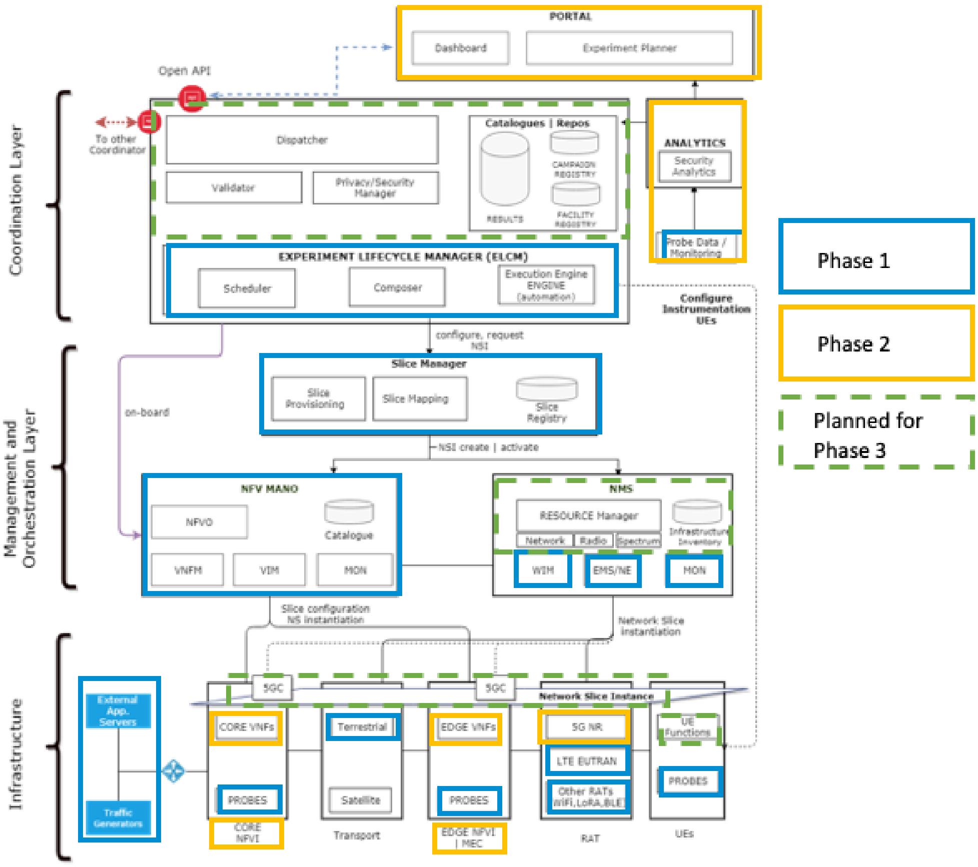


Figure 19 Per-phase instantiation of the 5GENESIS architectural blueprint in the Athens Platform

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.

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

(i) Integrate as much as available 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 [31]
(v) Upgrade the Slice Manager
(vi) Integrate the Experimenter Portal and the OpenAPIs

Finally, Phase 3 activities will mainly focus on finalizing the integration and preparing the platform for the E2E experimentation support. Phase 3 should finalise the integration of the Coordination Layer, Slice Manager, Analytics framework, NMS Resource and Infrastructure Inventory. For 5G technologies, the integration of RunEL, ECM and Athonet should be finalized and the platform will provide a working 5G RAN with NSA and SA 5GC.

The finalization of Phase 2 allowed the deployment of a variety of mobile network configurations. Table 6 provides a summary of the achieved 4G LTE deployment configurations. The configuration makes use of the aforementioned radio components as well as in some cases NFVI at the edge and core that provide the capability of E2E service deployment. 4G.3.core and 4G.4.edge configurations also support network slicing.

Table 6 4G LTE Legacy Deployment Configurations

Deployment Parameters	Deployment Flavors			
ID	4G.1.SDR	4G.2.COM	4G.3.core	4G.4.edge
Description	OpenSource SDR w 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)

On the other side, as 5G radio and core technologies were made available at the beginning of this year, the 5G configuration presented in Table 7, lacks the notion of E2E service deployment. At this stage the 5G.1.noS1 and 5G.2.noS1 provide setups useful mainly for physical layer testing of the radio interface. On the other side, using 5G radio from Amarisoft implementation, it was possible to deploy and test a 5G NR and 5GC mobile network configuration. In fact, besides using the 5GC that is shipped with the Amarisoft solution, initial integration with Athonet 5GC was achieved. Both configurations were tested with commercial UE equipment.

Table 7 Athens Platform Deployment Configurations

Deployment Parameters	Deployment Flavors			
ID	5G.1.noS1	5G.2.noS1	5G.3.Option3	5G.4.Option3
Status	Under deployment	Planning	Operational	Operational
Description	No Core and NR proprietary	No Core, Vendor NR	Vendor Core/gNB	Vendor All-in-one deployment
Core Cloud	NA	NA	NA	NA
Edge Cloud	NA	NA	NA	NA
# Edge Locations	1	1	1	1
WAN/Network	NA	NA	SDN	SDN
Slice Manager	NA	NA	NA	NA
MANO	NA	NA	NA	NA
NMS	NA	NA	NA	NA
Monitoring	NA	NA	Prometheus	Prometheus
3GPP Technology	5G	5G	5G	5G
3GPP Option	noS1	noS1	NSA	NSA
Non-3GPP Technology	NA	NA	NA	NA
Core Network	NA	NA	Athonet	Amarisoft
RAN	OAI gNB	RunEL DRAN	Amarisoft gNB (SDR)	Amarisoft gNB (SDR)
UE	OAI nr-UE (SDR)	OAI nr-UE (SDR)	Samsung A90 5G	Samsung A90 5G

3.2. Phase 1 Accomplishments

The following tasks have been successfully fulfilled in Phase 1 of the Athens platform integration.

- Infrastructure Layer
  - Interconnection of NCSRD with COSMOTE and Egaleo via optical and radio links respectively.

  - Integration of Amarisoft 4G (LTE, eNB)
  - Integration of OAI 4G (LTE, eNB)
  - Integration of Athonet 4G
  - Integration of a 4G based outdoor Macro Cell
  - Deployment of additional edge locations in NCSRD Campus
  - Installation of NFVI-PoP at NCSRD and COSMOTE
  - Integration of WAN infrastructure and configuration of equipment
  - Edge Computing nodes (OpenStack/K8s) deployed, co-located with Small Cells
  - Infrastructure to host the equipment (edge computing, radio) at Egaleo stadium
- MANO Layer
  - Monitoring based on Prometheus deployed in hierarchical mode.
  - Athonet vEPC Simple Network Management Protocol (SNMP) MIB integration with monitoring
  - Integration of Amarisoft eNodeB monitoring metrics exporter with Prometheus
  - NFVO based on OSM v5 deployed
  - Deployment and integration of the Slice Manager (preliminary version)
- Coordination Layer
  - Integration with ELCM (Keysight TAP)

3.3. Phase 2 Accomplishments

3.3.1. 5GNR and 5GC integration and testing

As mentioned in the beginning of this section, an integration was achieved between the 5GC provided by Athonet and the 5G-NR provided by Amarisoft. The configuration that is referenced here is 5G.3.Option3. Athonet 5GC was used in NSA option 3 and the Amarisoft e/gNB was configured to register to the 5GC.

Preliminary tests of 5G.4.Option3 were conducted. The configuration used is utilizing eNB/gNB with 5GC NSA deployment option 3. The deployment comprises of 2 cells, with the first using LTE technology at Band 7 with 10 MHz of bandwidth and a 2x2 MIMO SDR card as RF front-end. The second cell is the 5G cell, using Band n78 and 50 MHz bandwidth with another SDR card at 2x1 MIMO. Control and signaling messages are transmitted and received using the LTE cell. Requested data traffic from the UE is transmitted through the 5G cell.

A Downlink throughput result is shown in Figure 20. The test TCP traffic was generated by IxChariot tool.

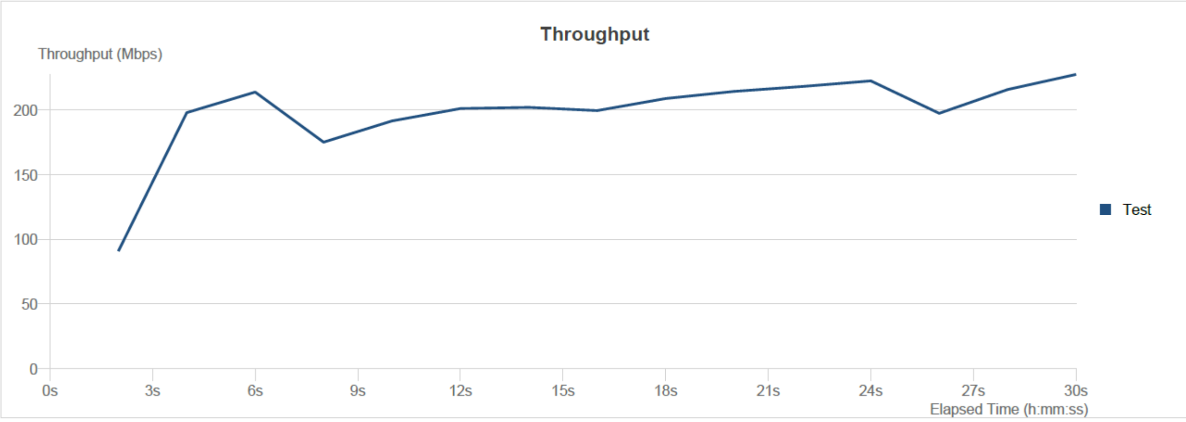


Figure 20 Throughput Test (Athonet Core, Amarisoft RAN)

The achieved transfer rate is approaching 200Mbps, which based on the configuration and the capabilities of the UE is the maximum attainable.

3.3.2. Integration of 5GENESIS 5GNR solutions

The 5GENESIS partners RunEL and ECM develop prototypes for the support of 5G-NR features. Currently, the 5G-NR solution from RunEL and the OAI 5G-NR from ECM are being integrated within various platforms of 5GENESIS. For the first implementation, the equipment was not yet available in the Athens platform since some critical components, such as a server grade hardware with top of the notch specification, was not procured yet. Therefore, the reader is redirected to Deliverable D4.4 – The Malaga Platform (Release B) that details the current activities. For the latter implementation, which is the one that will be utilized for the Portable Demonstrator, the configuration and integration information and operability status is detailed in the respective deliverable D4.17 – Portable Demonstrator (Release B).

3.3.3. Integration of 5GENESIS Management and Orchestration Layer

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
Security Framework Master Node	VCPUs: 4, RAM: 16GB, Disk: 50GB	10.30.0.164
Security Framework Worker Node	VCPUs: 4, RAM: 16GB, Disk: 50GB	10.30.0.171

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

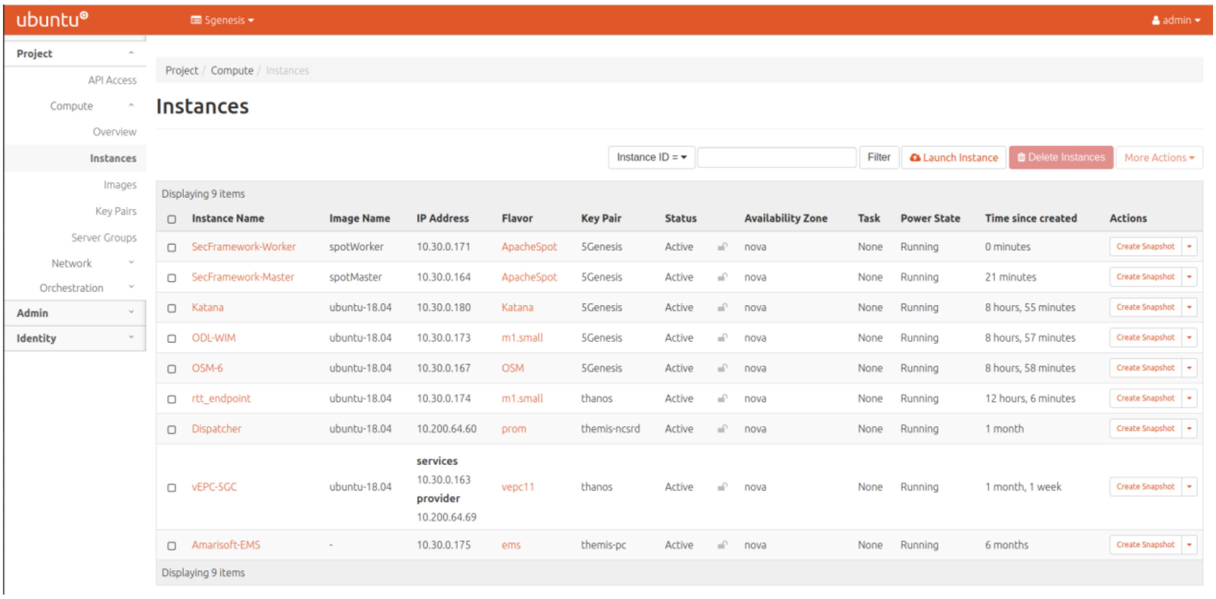


Figure 21 Deployment of MANO Components in OpenStack

Release A of the 5GENESIS Security Analytics platform (as described in detail in deliverable D3.13 [9]) 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 A of the Security Analytics platform is able to process network flow information in NetFlow 9 format. For this purpose, the central router of the Athens platform was configured to dispatch real-time NetFlow information to the Master node, where it is ingested, preprocessed and subject to analysis. As this effort is led by integrations activities that are executed in the Limassol platform, the reader is redirected to the respective deliverable (D4.8 The Limassol Platform (Release B)).

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. Details on the structuring of Infrastructure Monitoring based on Prometheus is available in [6]. The ESXi instantiation of monitoring components is presented in Figure 22.

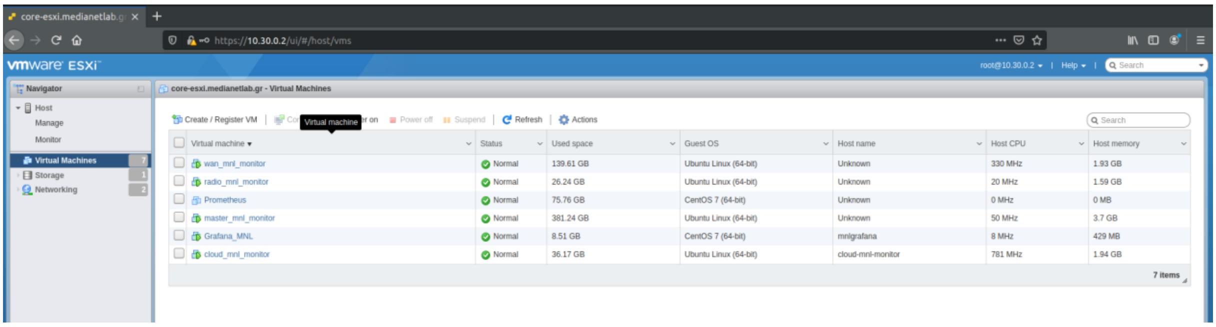


Figure 22 Deployment of MANO Monitoring Components in ESXi

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

3.3.4. Integration 5GENESIS Coordination Layer

For the deployment of coordination layer components (Release A) 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 A the developed coordination layer components are integrated in a single Microsoft Windows machine, that is connected with the internet and the lower layers through the ESXi hosts. The VM provides:

- Keysights OpenTAP
- ELCM
- 5GENESIS Portal

In addition, the above components, Linux based VM was deployed in OpenStack environment as described in Section 2.2.1.2. (Main DC). The VM instantiates the following components:

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

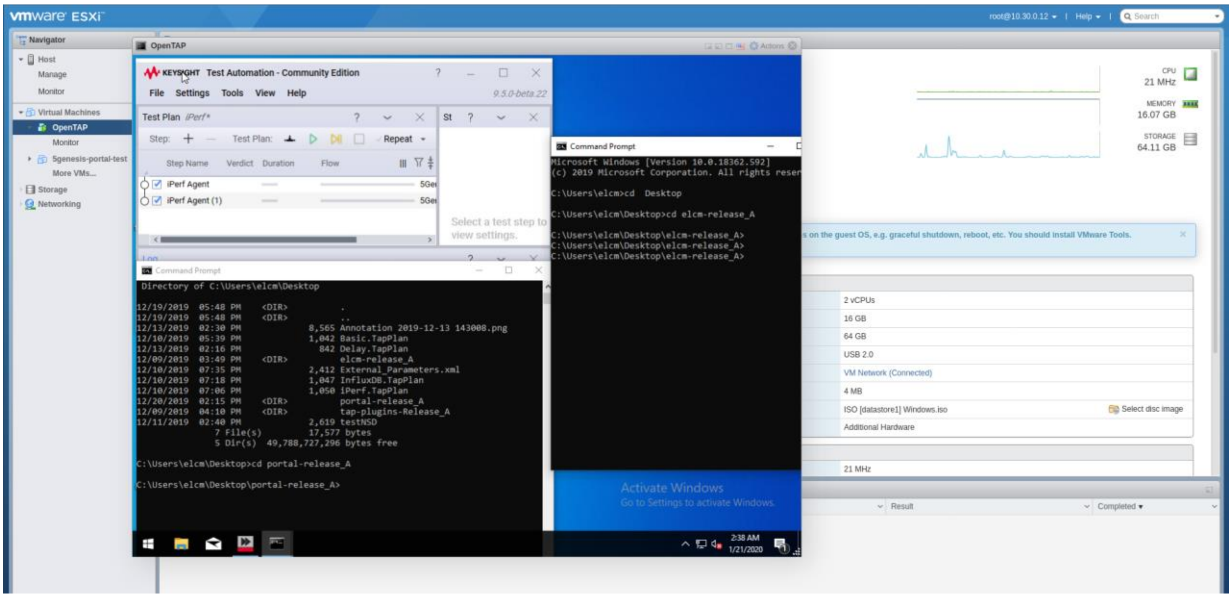


Figure 23 Coordination Layer Components

3.4. Next Milestones

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

- 5GNR upgrade and integration in the platform. It is anticipated that both NSA and SA modes will be enabled. The upgrades in the prototype implementations of the 5G RAN will be continuously upgraded and the infrastructure will continuously evolve.
- 5GC upgrade and integration in the platform, in order to support SA deployments.
- Integration of Release B of the Katana Slice Manager and interconnection with all relevant Infrastructure layer functions of the platform. The upgrade will provide better mapping from Generic Slice Template (GST) to Network Slice Template (NEST), providing better support for the deployment at the edges and the provision of radio resources.
- Integration of the MONROE probes and interconnection with the MONROE monitoring framework.
- Integration of Release B (upgrade) of all Coordination Layer components.
- Implementation and execution of UC1, UC2 and UC3 in the field.

4. Athens Use Cases-Specific Extensions

4.1. Use Cases Target Deployment

This section provides updated information on the target deployment for the use cases managed by 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. Furthermore, two of the use cases supported at the Athens platform, namely "Big Event" and "Security as a service", have been demonstrated in previous 5G-PPP projects using a more minimal deployment and with 4G LTE or no radio.

4.1.1. 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 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, , 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. The detailed installation and experimentation procedure and logistics will be defined and implemented during Phase 3.

4.1.2. Use Case “Eye in the sky” applications

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

Mobile networks are a promising candidate for serving the diverse requirements of UAVs deployment, providing a handful of advantages regarding latency and throughput compared to other solutions, such as satellite technology. Existing terrestrial mobile networks already provide adequate coverage, while the licensed spectrum is an important factor for reliable and secure communications for UAVs management and operations. It is also worth mentioning that

UAVs have been brought into the scope of the latest 3GPP releases, in order to study and address the related needs and requirements (e.g. TS22.125, TS22.261, TR 36.777, TS 22.125).[4]

In this context, the Athens Platform will leverage on the 5GENESIS 5G facility capabilities to demonstrate the "Eye in the sky" Use Case, aiming at testing and validating a solution conveying both control and multimedia streaming data in real-time using a UAV over the 5G infrastructure in the NCSRD Campus. The main VNFs and deployment is illustrated in Figure 25. Specifically, the UAV control link requires low latency and reliability (URLLC slice) ensuring uninterrupted control of the UAV. On the other hand, the UAV will provide multimedia streaming services (HD and 4K real-time video) which in turn require high bandwidth and increased data volumes (eMBB slice).

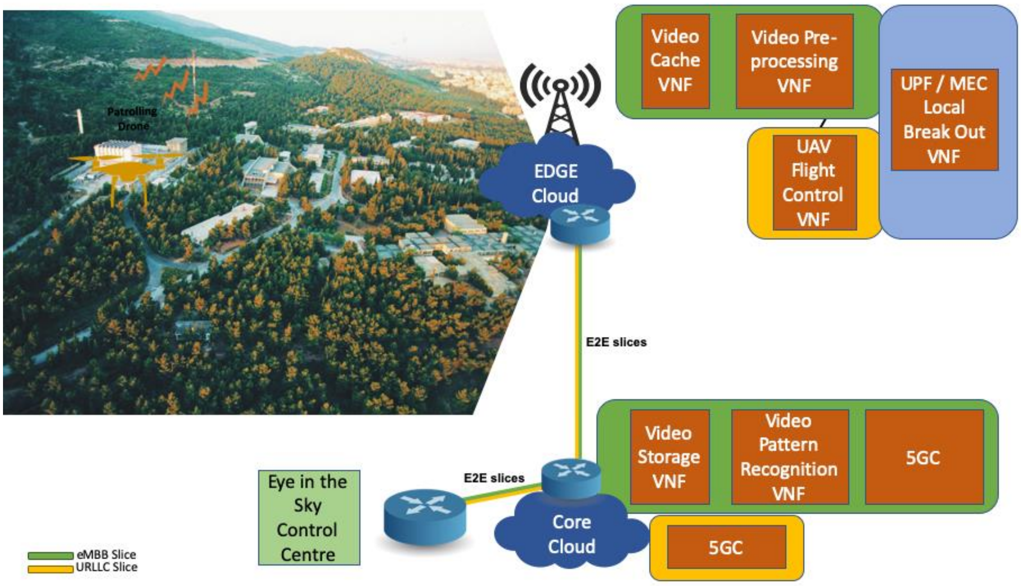


Figure 25 Components and deployment of the "eye in the sky" use case

The slice manager, which is actively developed and extended by NCSRD in 5GENESIS and is described in detail in *D3.3 – The Slice Manager*, will provision both network slices in an isolated manner, while imposing traffic steering across the infrastructure. Furthermore, the Use Case will measure latency and service creation time in scenarios with and without edge computing components, in order to examine differences in responsiveness of the control operations, as well as in the quality of the transmitted video streams.

The "Eye in the Sky" Use Case will utilize both components developed by 5GENESIS Partners and commercial solutions acquired in the course of the project, which are expected to interoperate in the final phase of the project.

4.1.3. Use Case Security-as-a-Service

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-

[4] https://www.3gpp.org/uas-uav

quality, undisturbed digital courses and interactive lessons is obviously of paramount importance. To protect the credibility of the offered accreditation services, OTEAcademy must 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 26, 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.

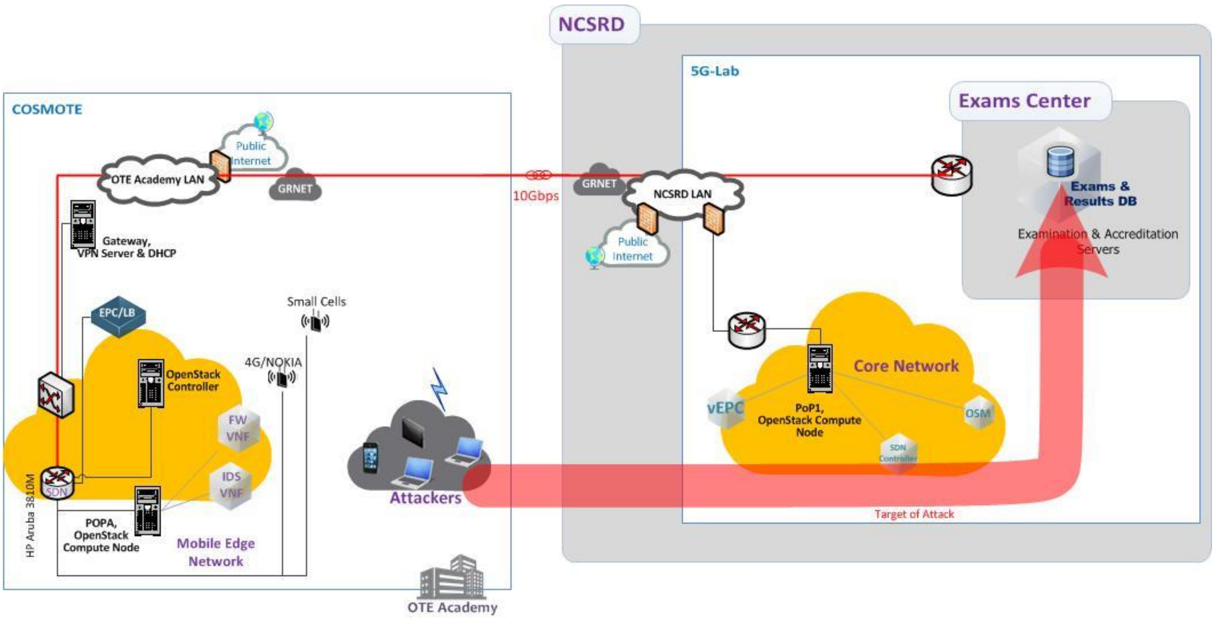


Figure 26: SeCaas Service at OTEAcademy Use Case Topology

4.2. Use Cases Phase 1 Accomplishments

For the first phase of WP4 activities related to WP4, the initial assessment of the deployment requirements has been made. The use cases description evolved from the initial descriptions provided in the project DoW. In detail for the first phase the following tasks have taken place:

- UC1 description refinement, topology update and components listing
- UC2 description refinement, topology update and components listing
- UC3 description refinement, topology update and components listing

4.3. Use Cases Phase 2 Accomplishments

During the second phase of the 5GENESIS iteration, the main focus was still enhancements in the platform. However, some of the components of the use case were further developed or new features were added. Specifically, for the Big Event multimedia coverage, tests and proof of concept deployment have been executed in conjunction with 5GESSENSE demonstrations. Both use cases use the same venue and part of the backbone infrastructure, however the latter is mostly focused in 4G core and RAN. However, the successful execution of the demonstrations in the stadium that entailed the deployment of equipment, configuration and setup of the networking increased the experience is such deployments and verified the feasibility of this endeavor. provided as proof of demonstration within the stadium environment during a local team's game.

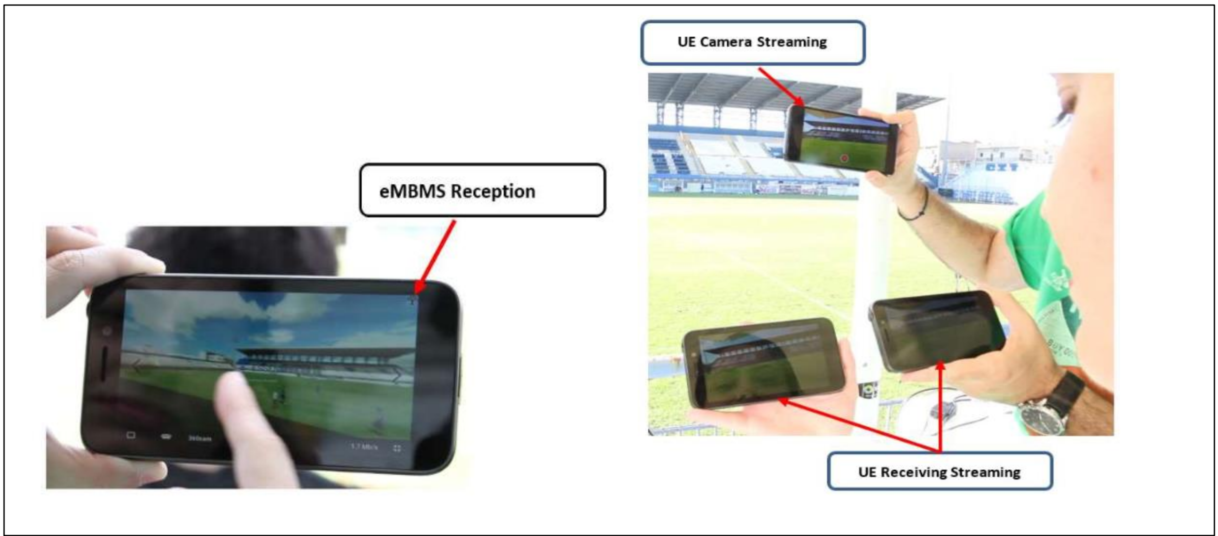


Figure 27 360 multimedia video streaming

The progress regarding the "eye in the sky" use case mostly involves development of the drone control application in order to be deployable as a VNF at the edge. Further tests are conducted during this period in order to test latency impact on drone flight behavior. In addition, the drone platform is being designed and implemented taking into account the payload for the drone and the battery and weight limitations.

Finally, regarding the security as a service use case, the development and preparation of the security VNFs foreseen, took place. In addition, following the deployment of the Security Analytics and Anomaly Detection framework in the Athens platform, means to exploit the information in favor of aiding the decision-making process and providing better remedial actions in case of an event have been considered.

4.4. Next Steps

As previously said the WP4 relation to the use cases is mostly for providing the necessary infrastructure and the upper layers of 5GENESIS in order to be able to extensively test, validate and showcase the aforementioned use cases. The next steps in assessing the feasibility of use case realization, will follow after the successful integration of release C of the 5GENESIS Athens platform. In the meantime, development of the components for each use case will continue in order to provide the anticipated E2E operation. In addition, integration tests and partial validations will be executed during the KPI validation and experimentation phase 2 and reported at D6.2.

5. CONCLUSIONS

The second release (Rel. 2) of the Athens platform has been presented in this document. The design and technical choices have been discussed and the achieved integrations and deployments have been presented. The approach followed during the second iteration of the Athens platform activities was to focus in the integration of more 5G radio and core components. In addition, given the first release of WP3 Coordination Layer, efforts for currying on the integration with the platform infrastructure took place. Finally, to avoid integration problems, all available software components from Release A were upgraded fitting the dependencies and requirements of the new components.

During the last three months of this cycle, extensive tests will be performed to ensure that all the newly integrated services and components work as expected and, in parallel, the platform partners will continue their efforts toward integrating elements and technologies.

The platform will be used for the second round of experiments until early March 2020, and the report on the KPIs will be available in deliverable D6.2 in late March 2020. This document will be followed by the Deliverable describing the Release C of the platform (deliverable D4.3) in December 2020.

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APPENDIX 1: 5GENESIS ATHENS PLATFORM MOBILE CORE NETWORK

ATHONET Core

Athonet's mobile core is based on a highly efficient and effective software-only implementation. The expensive, proprietary, hardware centric capex of traditional mobile core solutions has been replaced with a wholly 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 has implemented a web-based Element Management System (EMS) that caters for performance, configuration and fault management. The EMS includes the following main features:

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

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

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

Figure 28: ATHONET Virtualised EPC Server

Athonet provides the main Core Network component of the Athens platform deployment. Athonet's 4G+ Core supports some additional functionalities to those provided by the 4G such as:

- 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. Since most traffic load, in some cases 60-70%, is video traffic, this solution allows content to be cached and served locally. This improves user perceived quality and reduces the amount of backhaul required in a network. It may also enable new business with content providers and other low latency services. The SGW-LBO is a modified SGW function which has been enhanced by Athonet to allow traffic to be broken-out and steered locally to support
  - caching of video and other content
  - other applications that require low latency or local offload (smart city, autonomous cars, etc.).

  The benefit of this approach is that it allows specific traffic (not all traffic) to be offloaded for key applications that are implemented at the network edge without impacting the existing network or breaking network security. It also provides a bridge and upgrade path to 5G where the User Plane Function can be deployed flexibly at the network edge.

- Control and User Plane Separation (CUPS), which means that control plane and user plane functionalities can be distributed between central and edge-clouds or hardware nodes to enable hybrid-cloud, fog-computing or MEC type deployments.

OpenAirInterface Evolved Packet Core (EPC)

ECM’s OAI-EPC[5] is an open source experimentation platform licensed under Apache v2, implementing Rel.14 Mobility Management Entity (MME), Rel. 14 Home Subscriber Server (HSS) with Cassandra-based database management, as well as the Serving and Packet Gateways (S-GW & P-GW). ECM’s OAI-EPC is part of the 4G.1.SDR configuration (Open Source SDR with virtualized core) deployed in the Athens Platform. It has been deployed on a virtual machine, utilizing the Kernel-based Virtual Machine (KVM) solution.

OAI EPC has been deployed in NCSRD on an Intel NUC6i7KYK with Ubuntu 16.04 LTS as the Host OS and Ubuntu 18.04 LTS as the Guest OS. The current deployment utilizes the OpenvSwitch (OVS) based SPGW, therefore the Guest OS uses Linux Kernel v4.9, due to OVS constraints. The VM specifications include 2vCPUs, 4GB RAM and 10GB disk space. The OAI-EPC physical host (IP: 10.2.1.250) has one physical connection to the OAI eNB Host (IP: 10.2.1.50), serving the following interfaces:

- S1-MME control interface for exchanging S1AP signaling messages with the MME
- S1-U data plane interface for data packets transmission with the SPGW

The respective virtual interfaces of the MME and SPGW are bridged to the interface of the physical host, in order to provide connectivity between the eNB and the OAI EPC VM.

Figure 29 Intel NUC6i7KYK (left) hosting OAI vEPC

The network allocates the IP addresses 10.21.1.2 – 10.21.1.224 to the UEs and since the specific version of OAI vEPC does not support NAT, there have been internal configurations to appropriate route the packets to external data networks via SGi. The COTS UEs are registered to OAI EPC using (U)SIMs provided by Sysmocom.

The deployment is fully operational and the COTS UEs connect and use the network successfully, as shown in the following figures:

[5] https://github.com/OPENAIRINTERFACE/openair-cn

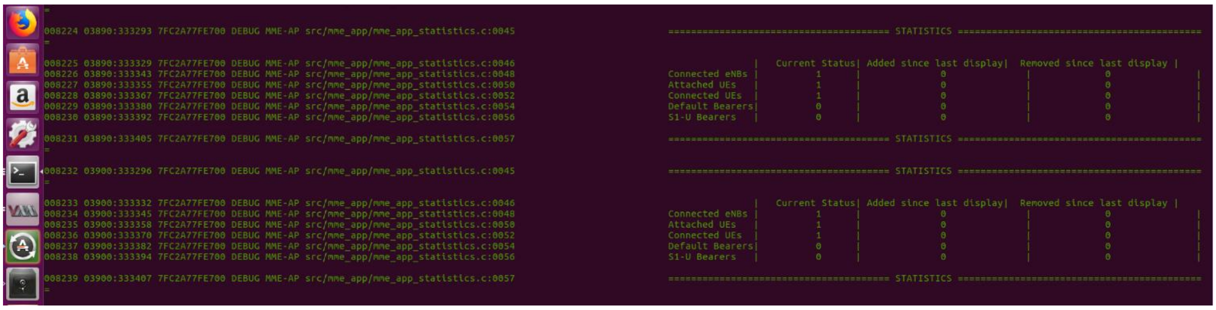

Figure 30 OAI MME console depicting successful COTS UE connection

```
                             \Desktop\iperf-3.1.3-win64>iperf3 -c 10.21.1.2 -u -b 30M
Connecting to host 10.21.1.2, port 5201
[  4] local 10.143.0.234 port 50750 connected to 10.21.1.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec  3.30 MBytes  27.6 Mbits/sec  423
[  4]   1.00-2.01   sec  3.66 MBytes  30.6 Mbits/sec  468
[  4]   2.01-3.00   sec  3.52 MBytes  29.7 Mbits/sec  451
[  4]   3.00-4.01   sec  3.61 MBytes  30.1 Mbits/sec  462
[  4]   4.01-5.01   sec  3.55 MBytes  29.7 Mbits/sec  455
[  4]   5.01-6.01   sec  3.59 MBytes  30.0 Mbits/sec  459
[  4]   6.01-7.00   sec  3.55 MBytes  30.2 Mbits/sec  455
[  4]   7.00-8.03   sec  3.60 MBytes  29.5 Mbits/sec  461
[  4]   8.03-9.00   sec  3.57 MBytes  30.7 Mbits/sec  457
[  4]   9.00-10.01  sec  3.52 MBytes  29.2 Mbits/sec  450
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-10.01  sec  35.5 MBytes  29.7 Mbits/sec  5.023 ms  1703/4520 (38%)
[  4] Sent 4520 datagrams

iperf Done.
```

Figure 31 Iperf3 results using a COTS UE with IP 10.21.1.2 over the OAI based network

Amarisoft Evolved Packet Core

Amarisoft Core Network is a proprietary solution which is widely used at NCSRD campus LTE deployment. This solution implements the MME component with built-in SGW, PGW and HSS and supports several eNBs with standard S1 interface (S1AP & GTP-U protocols). Handling of UE procedures like attach, authentication, security configuration, detach, tracking area update, service access, radio bearer establishment, paging is also supported. UEs can use USIM cards with XOR, Milenage and TUAK algorithms for identity authentication.

Amarisoft software can be deployed in all commercial servers and virtualized cloud environments.

Amarisoft Core supports lots of features such as Multimedia Broadcast Multicast Service (MBMS), Multi-Operator Core Network (MOCN) and Narrow-Band IoT. MOCN in particular is a key capability that shall be used widely in our future deployments about LTE Network Slicing. In this sharing approach the Amarisoft Access Network is shared between two Cores (EPCs) by broadcasting several Mobile Country Codes (MCC) and Mobile Network Codes (MNC) in the System Information of a radio channel.

The Core component can also be accessed via a remote API. The protocol used is WebSocket as defined in RFC 6455 and the messages exchanged are in JSON format. API can be used for monitoring and configuring the Amarisoft EPC.

Amarisoft 5GC

Amarisoft Core Release 15 is 5G NR Release 15 compliant. Connectivity with gNBs is implemented through the standard NG interface using NGAP and GTP-U protocols. The 5GC includes built-in AMF, AUSF, SMF, UPF modules handling UE procedures and providing direct access to the IP network. This 5G Core implementation is now operation in the Athens platform.

APPENDIX 2: 5GENESIS ATHENS PLATFORM RADIO ACCESS PRODUCTS

4G Radio Access

Nokia Flexi Zone Multiband Indoor Pico BTS (FZ MBI) eNB

The Small cells provided by Nokia called Flexi Zone Multiband Indoor Pico BTS (FZ MBI) comprise an "all-in-one" RAN solution deployed in the Athens platform. Nokia RAN provides a cost-effective LTE and Wi-Fi solution that can handle capacity growth, without all the deployment complexity and costs typically incurred using traditional macrocells. The cell's modules support Power-over-Ethernet evolution (PoE++) technology to supply the unit with power. The PoE solution allows electrical power to pass along with data on Ethernet cabling. PoE++ offers several benefits to the user, including flexibility at relocation, easy installation and cost savings. Synchronization of the transmissions is primarily provided by a Global Positioning System (GPS) timing receiver. These cells support eMBMS service for video multicast transmission through Athonet's eMBMS Gateway. Table 10 summarizes the Nokia Small Cell key features.

Table 10 Nokia Small Cell Key Features

Device Parameters	Nokia Small Cell
LTE Band Support	Band-3 (1800), Band-7 (2600)
RF Output Power	50 mW to 250 mW per Tx branch
LTE Carriers	Up to one 20 MHz
Wi-Fi Band Support	Optional dual-band integrated Wi-Fi access 2.4 GHz / 5 GHz 802.11b/g/n/ac
Connected User Support	Up to 400 simultaneous users per unit
Backhaul	Two 100/1000 Base-T Copper Port Types: 2 RJ45 Ethernet
Antenna	LTE: 2Tx / 2Rx MIMO Type: Integrated omni

Amarisoft eNB

Amarisoft eNB is a widely used solution for LTE RAN in NCSRD campus. The 4G eNB are implemented using the following RF frontends:

- USRP N210 SDR by National Instruments.
- PCIe SDR board.
- USRP B210 SDR by National Instruments.

Key features supported by Amarisoft eNB are the following:

- 2x2 MIMO multiplexing with PCIe SDR frontend.

- NB-IoT cells. They use a 200 kHz bandwidth which can be inside an existing LTE cell (in-band operation mode), at its edge (guard band mode) or completely independent (standalone mode).
- Carrier Aggregation, which is currently supported with PCIe SDR radio frontend.
- Monitoring and configuration through a remote API. Messages sent and received in JSON format.

Figure 32 presents a National Instruments USRP N210. Via its Ethernet interface it may be connected to a host PC, running Amarisoft software in order to realize a fully functional 4G eNB platform.

Figure 32 USRP N210

In addition to interoperating with N210, Amarisoft 4G eNB implementation is also achieved via the PCIe SDR boards (also provided by Amarisoft). Each board supports 2x2 RF transceiver with integrated 12-bit DACs and ADCs.

OpenairInterface eNB

OAI eNB solution is an open-source software and hardware platform developed by ECM, providing a standard-aligned LTE implementation (3GPP Rel. 10/14).

The OAI software is freely distributed by the OAI Software Aliance (OSA) and it can be deployed using standard off-the-shelf Linux-based computing equipment (Intel x86 PC architecture) and standard RF equipment (e.g., National Instruments/Ettus USRP) [7]. In this context, OAI offers a flexible framework for experimentation with prototype 4G/5G implementations of the UE and base station components.

The current deployment in NCSRD utilizes a x86 server with CPU i7-7700 (3.60GHz x 4) and 32Gb RAM, configured with Ubuntu 16.04 LTS and low latency kernel to support the real time requirements of the OAI application. The S1-U and S1-MME interfaces between the eNB and the deployed OAI EPC are served by the same physical interface (10.2.1.50).

The radio frontend is implemented with a USRP B210 and transmission takes place on band 7 (2600 MHz) with FDD mode. The supported configurations include 5, 10 and 20 MHz SISO.

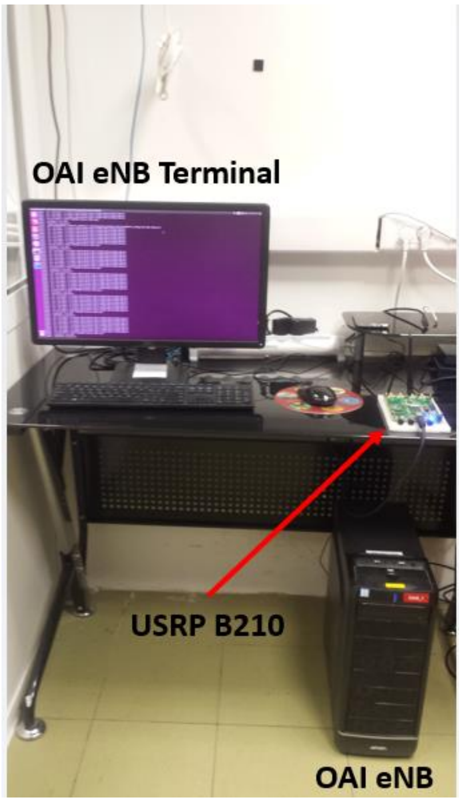

Figure 33 OAI eNB implementation

NCSRD has also validated the interoperability between OAI eNB and ATH EPC with COTS UEs.

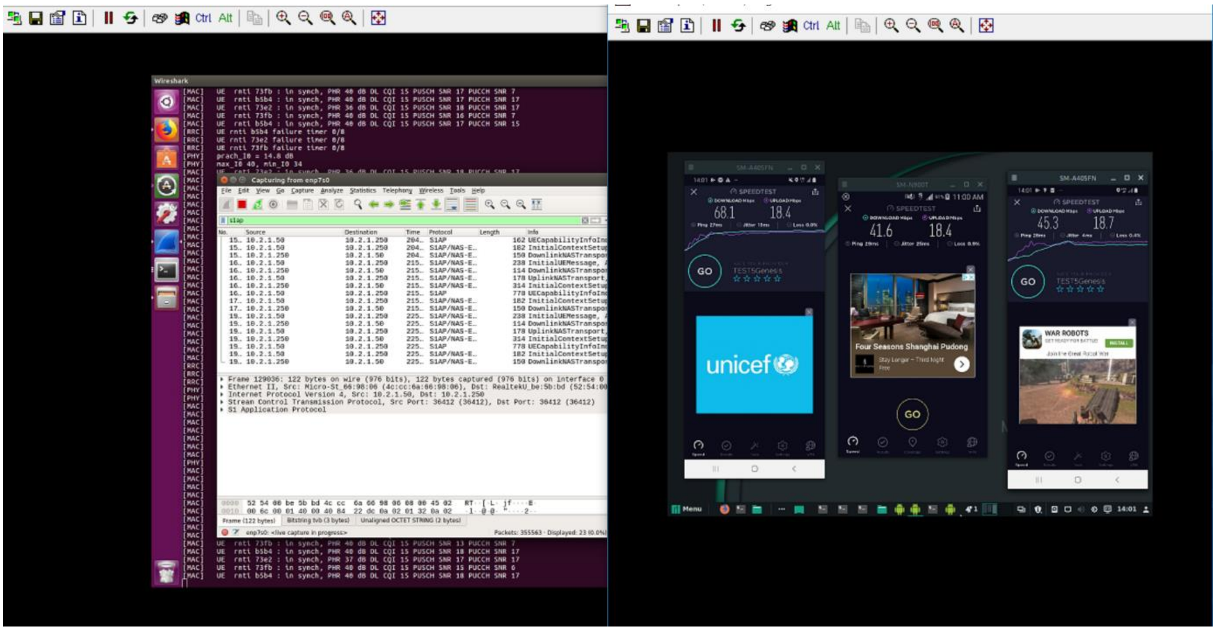

Figure 34 OAI eNB interoperating with ATH EPC while serving multiple COTS UEs

5G Radio Access

Amarisoft 5G NR

During Phase 2 Amarisoft's 5G solution was integrated into Athens platform providing a stable mobile network system for testing and experimenting. Both the Core and RAN functions are software defined and can be hosted on Linux-based systems. Core and RAN Networks provide the option to be hosted separately, enabling the capability of an EPC/5GC cloud deployment. Currently, an all-in-one system is deployed and operating in Athens platform, running on a x86 node, using Fedora 30 operating system.

5G Radio Front-End

Amarisoft NR operates PCIe SDR boards provided by Amarisoft as RF front end. The eNB/gNB can run several cells, which can be configured individually and share the same S1 interface with the Core Network. The acquired system includes 3 PCIe SDR cards, providing the option to run simultaneously up to three LTE 2x2 cells or two cells of which the first uses LTE and the second 5G technology.

RAN Description & Supported Features

Amarisoft Radio Solution is an LTE/NR base station (eNodeB/gNodeB) implemented entirely in software and running on an x86 Linux-based host. The host generates a baseband signal which is sent to a radio front end doing the digital to analog conversion. The reverse is done for the reception. Amarisoft RAN interfaces with the LTE Core Network through the standard S1 interface and with a 5GS Core Network through the standard NG interface. In particular, the Amarisoft Core Network software can easily be connected to it to build a highly configurable test network.

Amarisoft NR is release 15 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[6]. 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.

Management – Monitoring Tools

Amarisoft has included a variety of options to monitor, manage and configure the Mobile RAN. A Remote API endpoint is available to monitor and configure the Amarisoft Networks, providing requested information by using the WebSocket protocol. Amarisoft also provides a Web GUI that contains logs of messages exchanged between the Core, RAN and UE. It also visualizes the statistics exposed by the API endpoint and the command line interface.

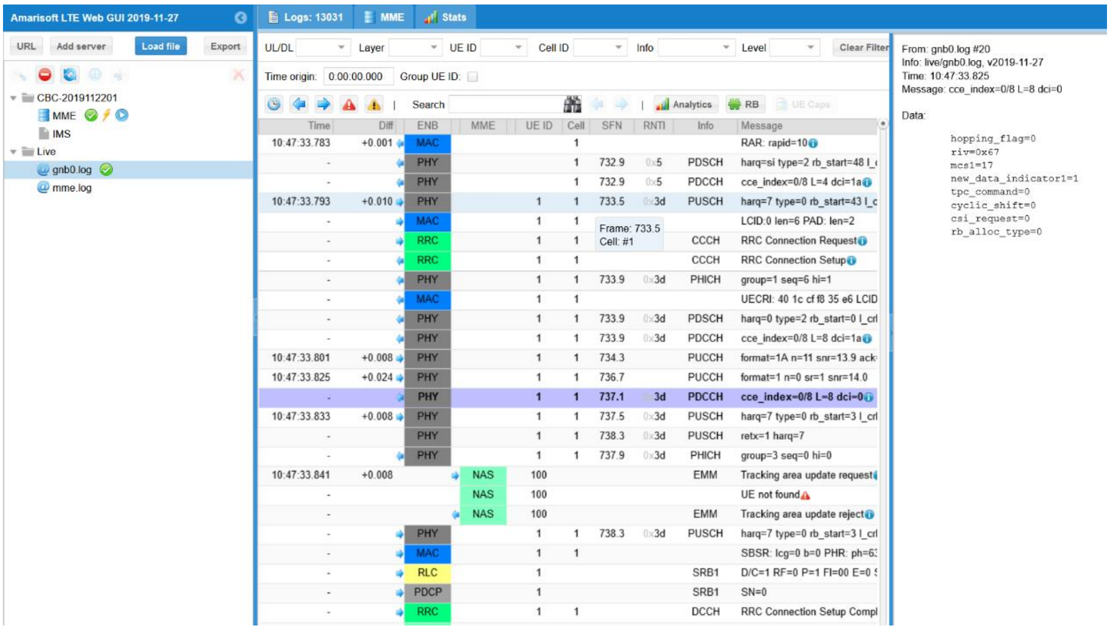

Figure 35 Amarisoft Monitoring GUI Overview

[6] Depending on the paid license

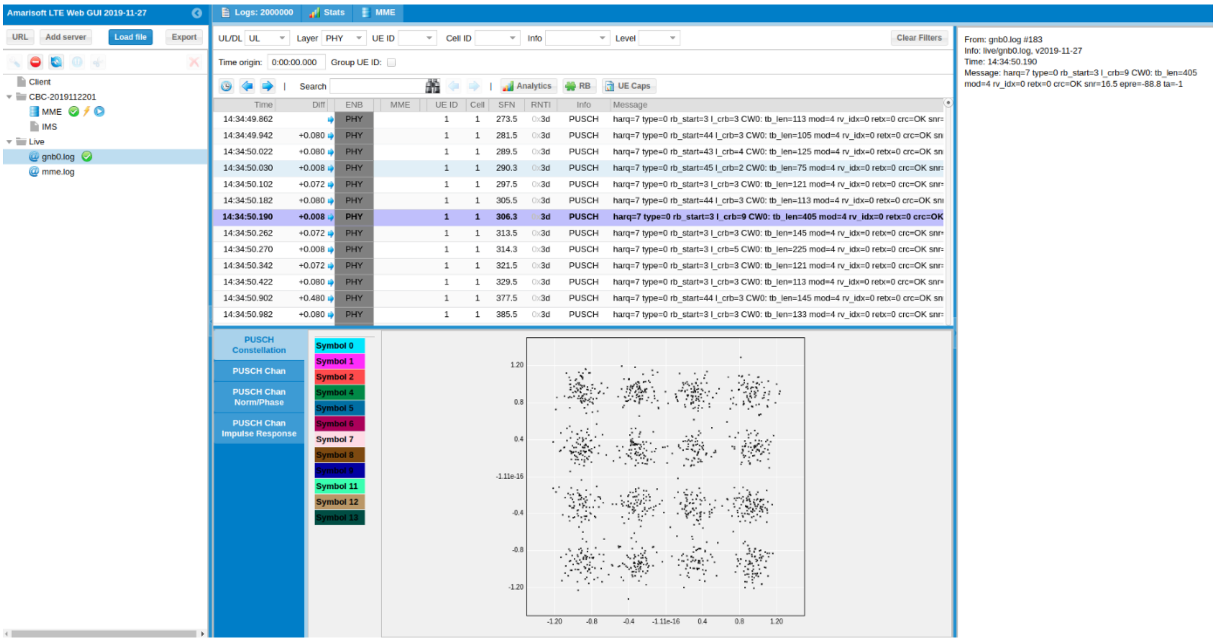

Figure 36 Constellation Report of Uplink 16 QAM Transmission

OpenAirInterface (OAI)

NCSRD has acquired two USRPs N310 in order to be utilized with ECM’s OAI 5G gNB and nr UE implementations. The initial setup configuration is called the “noS1 mode”, where traffic is injected directly at the level of PDCP using a virtual TUN interface in both OAI hosts. The initial tests are performed using two powerful i9 laptops (used in the context of the Portable Demonstrator) connected to the USRPs via Thunderbolt3-To-Ethernet Adapters, in order to support the required sampling rates. The clocks of the USRPs are synchronized by the ETTUS Octoclock-G Clock Distribution Module, providing the common PPS and 10Mhz signals to both devices.

The connection between the two USRPs takes place either over-the-air or wire with proper attenuators to protect the radio frequency units. OAI 5G-NR supports bandwidths of 40, 80 and 100 MHz (106, 217 and 273 PRBs respectively) and the frequency band of operation is 3.5GHz on TDD mode. When transmitting over-the-air, the USRPs utilize a set of omnidirectional antennas, while the proper transmission and reception gains of the SDRs are configured through OAI.

OAI 5G-NR provides a set of debugging and monitoring tools, such as the T-Tracer and Xforms. The figure below depicts the XForms application running on the nrUE laptop, providing information on the received signal, the PBCH, PDCCH and PDSCH:

Figure 37 OAI 5G-NR Xforms utility for RAN monitoring

RunEL 5G NR

RunEL will provide a 5G gNB for the Athens platform that will consist of the Distributed Architecture with PHY layer split (ORAN like) as depicted in the yellow marked area in the figure below.

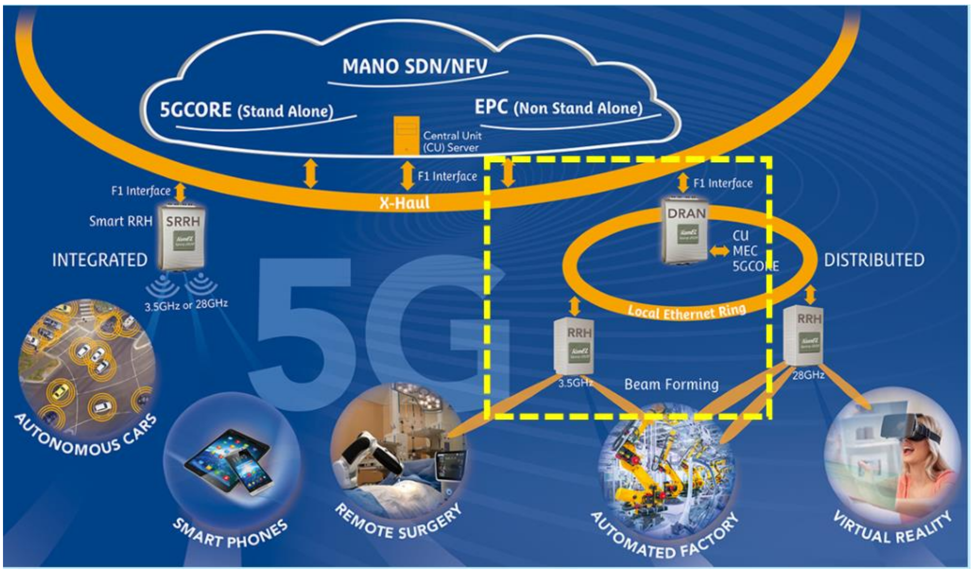

Figure 38 RunEL 5G distributed Architecture.

The 5G NR consists of two units, which are depicted in the figure below. The first unit is the Distributed Radio Access Network (DRAN) with Light MAC (Layer -2) and High PHY. The second unit is the Remote Radio Head at 3.5 GHz (RRH) with Low PHY and RF module with embedded beam forming antenna (4 beams).

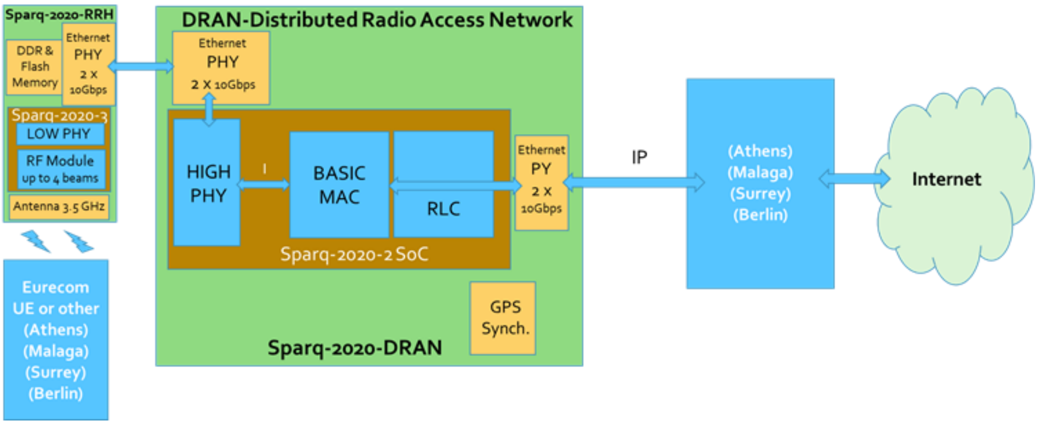

Figure 39 DRAN and RRH Block diagram

The RRH will connect with 5G UEs that will be working at the same frequency band of the RRH (3.3-3.8 GHz) and the DRAN will be connected via standard IP (WLAN) Ethernet port (2 x 10 Gbps). The Connection between the DRAN and the RRH will be via a Fast Ethernet link (via fiber cables). The gNB will be able to interface with Athonet 5G Core, OAI UEs, Network Management System and Monitoring Server used by each platform.
NCSRD has received a Dell XMG laptop, a USRP N300 and a Thunderbolt3-Ethernet adapter by ECM, in order to be used as a nr-UE with the RunEL gNB until a complete E2E becomes available in the course of 5GENESIS.

User Equipment (UE)

Athens platform has a wide variety of COTS UEs available for mobile network testing and deployments like LTE mobile phones, USB dongles and LTE CPE routers. Table 11 briefly presents the list of available UEs.

Table 11 UEs available in Athens Platform

UEs	Features
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 S4 mini	Cat3 compatible Smart Phones (100/50)
1 x Samsung Galaxy Note 3	Cat4 compatible Smart Phones (150/50)
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)
1 x Samsung A90 5G	4G LTE band 1(2100), 3(1800), 5(850), 7(2600), 8(900), 20(800), 34(2000), 38(2600), 39(1900), 40(2300), 41(2500) 5G band 41(2500), 78(3500); NSA

User equipment is registered to Amarisoft Core Network and OAI EPC using (U)SIMs provided by Sysmocom. Athonet provides already registered sim cards with every Core component sent to be deployed in the project.

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.