EXPERIMENTATION AND VALIDATION OPENNESS FOR LONGTERM EVOLUTION OF VERTICAL INDUSTRIES IN 5G ERA AND BEYOND

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Deliverable D2.2

Design of NetApps development and evaluation environments

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GLOSSARY

Abbreviations/Acronym	***Description***
3GPP	*3rd Generation Partnership Project*
5GC	*5G core*
5G PPP	*5G Public Private Partnership*
5GS	*5G System*
AEF	*API Exposing Function*
AMF	*API Management Function*
APF	*API Publishing Function*
CCF	*CAPIF Core Function*
CLI	*Command Line Interface*
CAPIF	*Common API Framework*
CI/CD	*Continuous Integration/Continuous Development*
DCSP	*Data Centre Service Provider*
DoS	*Denial-of-Service*
eMBB	*Enhanced Mobile Broadband*
FoF	*Factory of the Future*
IaaS	*Infrastructure as a Service*
IEM	*Interaction of Employees and Machines*
mMTC	*Massive Machine Type Communications*
MNO	*Mobile Network Operator*
NetApps	*Network Application*
NWDAF	*Network data analytics function*
NEF	*Network Exposure Function*
NF	*Network Functions*
NOP	*Network Operator*
NRF	*Network Repository Function*
NSaaS	*Network Slice as a Service*

NR	*New Radio*
NPN	*Non-Public networks*
OS	*Operating System*
PLMN	*Public Land Mobile Network*
PNI	*Public Network Integrated*
SEC	*Security guarantees and risk analysis*
SaaP	*Service As a Product*
SBA	*Service Based Architecture*
SBI	*Service Based Interface*
SEAL	*Service Enabler Architecture Layer*
SP	*Service Provider*
SME	*Small Medium Companies*
SDK	*Software Development Kit*
UHD	*Ultra-High Definition*
URLLC	*Ultra-Reliable and Low-Latency Communications*
UE	*User Equipment*
vAPP	*Vertical Application*
VAE	*Vertical Application Enabler*
VAS	*Vertical Application Server*
VISP	*Virtualization Infrastructure Service Provider*

EXECUTIVE SUMMARY

The purpose of this document is to serve as an entry point to the implementation of the EVOLVED-5G experimental facility that will serve as the development and evaluation reference architecture for the realisation of the NetApp ecosystem. The deliverable is a result of work carried out in Tasks 2.3 and 2.4 of the EVOLVED-5G project, where main goals are to completely design all the various environments and components of the facility blueprint following the general lifecycle of a NetApp inside the ecosystem.

In the light of the above, the main contribution of this deliverable is to provide a description towards the workspace for NetApps development and to share details for the validation and certification phase, as well as for the proposed Marketplace and publication phase.

In more details the main contributions of this deliverable are the following:

- Description of the NetApp principles, including the definition the design and the implementation
- Description of the EVOLVED 5G facility and its main building blocks along with the NEF and CAPIF services on top of the infrastructure
- Detailed presentation and analysis of all the environments that are part of the overall lifecycle of the NetApp. Those are the Workspace, the Validation and Certification environment, and the Marketplace.

The deliverable is divided into two parts. The first part expands some content that has been already provided in D2.1 and further describes in detail the NetApp concept and the principles towards the design and the implementation. Moreover, additional details regarding the EVOLVED 5G facility are provided in the first part.

The second part focuses on the overall NetApp lifecycle and the workflow from the development to the marketplace publication. Based on such lifecycle, each one of the various defined environments are presented in greater detail, following a descriptive and logical structure based on 3 basic principles of work:

- Objectives and expected functionality of the environment.
- Main and core architectural components.
- Process design and methodology based on steps or phases.

The work presented in this deliverable will guide the project towards the implementation and accomplishment of the EVOLVED-5G Facility and provides the very fundamental design and realization principles by which said implementation shall be governed, including all the different stages and phases that any NetApp must go through until its final release. Future deliverable, D2.3 "Overall framework for NetApp development and evaluation" (to be delivered in M17), will support the updated holistic picture on the design as well as the execution of the various phases.

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1. INTRODUCTION

1.1. DOCUMENT PURPOSE

The main goal of this document, named “Design of NetApps development and Evaluations Environments”, is to present the complete view of the EVOLVED-5G ecosystem and NetApps lifecycle, as envisioned by the EVOLVED-5G project consortium through the intricate design of its reference architecture and the various environments where development and evaluation activities will take place. Through the identification of the NetApp main development principles, the analysis of the NetApps lifecycle and the identification of the related environments is showcased, together with the overall workflow that will act as spearhead and guidance for Industry 4.0 NetApp developers to create NetApps until its eventual publication to the Marketplace.

Valuable work conducted in T2.3 (Workspace design and development process definition) and T2.4 (Validation methodology and Certification process design) of the EVOLVED-5G project is reported in this document. The specifications described stand as the basis of the implementation work taking place in WP3 (Overall Framework Development and Integration Activities) and provide imperative input to WP4 (NetApps Development and Verification) and WP5 (Overall Evaluation process, NetApp Validation, Certification and Release) where NetApp Lifecycle activities will actually be executed.

1.2. DOCUMENT STRUCTURE

The document follows a chronological descriptive approach, starting from the NetApp concept initialization to the beginning and end of its lifecycle:

- **Section 2. NetApps Principles:** A brief re-introduction to NetApps concept and design principles is given along with core ideas concerning their implementation in the EVOLVED-5G facility.
- **Section 3. NetApps Development Process:** In this section the EVOLVED-5G facility and the proposed reference architecture is presented in greater detail. It also describes extensively all the Environments, namely the Workspace, Validation, Certification, Marketplace and 5G-NPN (Non-Public Network) that EVOLVED-5G designs in response to the need for a NetApp deployment and validation facility. A step-by-step high-level description of each NetApp Lifecycle phases is also included, along with a detailed description of the 5G-NPN infrastructure environment.
- **Section 4. 5G NPN Infrastructure:** In this section an overview of the 5G NPN infrastructure as the underlaying layer for NetApps, to be provided with the necessary 5G native or northbound APIs as well as with the connectivity infrastructure, is given. The overall infrastructure architecture and the functional blocks it consists of are described, completing the section with the presentation of the two available platform sites, Athens and Malaga site.
- **Section 5. The Workspace:** Starting from this section, a more detailed description of each Environment is given, beginning with the Workspace, which will act as host for the Development and Verification phases. The overall workflow for NetApps to be developed and verified is presented along with the description of those tools that are going to also be developed and used in the context of this environment.

- **<u>Section 6. Validation Environment:</u>** The Validation environment, targeting to validate the NetApps through a series of tests against real 5G infrastructure during the validation phase, is described in this section. The environment's objectives and architecture are presented along with the process and methodology that is going to be followed in this step, presenting to the reader its intricacies.
- **<u>Section 7. Certification Environment:</u>** This section, starting from the state of art of certification in telecommunications to identify the gap on the status quo, presents a methodology to develop the certification of NetApps from the appropriate certification process creation up to the certification execution. In this context, the certification objectives, in the form of criteria to be audited, are analysed, together with a description of the environment and supporting tools necessary to automate the assessment in a systemic, repeatable and transparent manner.
- **<u>Section 8. The Marketplace:</u>** The marketplace is outlined in this section beginning with the status and evolution of marketplaces in the telecommunications market. This analysis serves as reference for the design of the EVOLVED-5G marketplace. The objectives to be fulfilled are then presented, followed by the marketplace's architecture and the process to be followed during the NetApp publication phase.

1.3. Target Audience

The release of the deliverable is public, intending to expose the overall EVOLVED-5G ecosystem and NetApps Lifecycle design to a wide variety of research individuals and communities.

From specific to broader, different target audiences for D2.2 are identified as detailed below:

- **Project Consortium**: To validate that all objectives and proposed technological advancements have been analysed and to ensure that, through the proposed NetApp Lifecycle phases and the various Environments, further work can be concretely derived. Furthermore, the deliverable sets to establish a common understanding among the consortium with regards to:
  - The NetApp core principles, implementation proposal and lifecycle in the context of EVOLVED-5G project.
  - The detailed project architecture along with the Environments and various lifecycle steps to be set for future implementation from the relevant Work Packages, including tools and technologies to be utilized.
- **Industry 4.0 and FoF (factories of the future) vertical groups:** To crystallise a common understanding of technologies, and design principles that underline the architectural design of EVOLVED-5G and the NetApps' Lifecycle, and to understand the main phases the application is going to have to go through, the various phases and stages. A non-exhaustive list of Industry 4.0-related groups is as follows:
  - Manufacturing industries (including both large and SMEs) and IIoT technology providers.
  - European, national, and regional manufacturing initiatives, including funding programs, 5G-related research projects, public bodies and policy makers.
  - Technology transfer organizations and market-uptake experts, researchers, and individuals.
  - Standardisation Bodies and Open-Source Communities.

- Industry 4.0 professionals and researchers with technical knowledge and expertise, who have an industrial professional background and work on industry 4.0-related areas.
- Industry 4.0 Investors and business angels.

- **Other vertical industries and groups**: To seek impact on other 5G-enabled vertical industries and groups in the long run. Indeed, all the architectural components of the facility are designed to secure interoperability beyond vendor specific implementation and across multiple domains. The same categorization as the above but beyond Industry 4.0 can be of application.
- **The scientific audience, general public and the funding EC Organisation**: To document the work performed and justify the effort reported for the relevant activities. The scientific audience can also get an insight of the underlying components and design approach behind the EVOLVED-5G ecosystem and NetApps Lifecycle.

2. NetApps Principles

2.1. Definition & Concept

The motivation for the creation, design, and development of NetApps has been described extensively in the previous deliverable D2.1[1]. In short, it refers to the need for a separated middleware layer in order to ease the implementation of vertical systems at large scale as well as their deployment on top of 5G. Therefore, Network Applications or, in its shortest form, NetApps were born.

As described in D2.1, a **NetApp** is a software component designed to interact with the control plane of a mobile network by consuming exposed APIs (e.g., Northbound APIs of 5G core) in a standardized and trusted way (i.e., for a 5G network a NetApp should be CAPIF[2] compliant) in order to compose services for the vertical industries. As presented in Figure 1, NetApps can either provide services to a vertical system either as an integrated part of the Vertical Application (vAPP) (Option A) or expose APIs, which are referred to as business APIs in order to interface with vAPPs, increasing by this way the reusability of the NetApp by different vAPPs (Option B).

2.2. Design Principles

From a functional perspective, a NetApp is designed to abstract and streamline the communication of vAPPs with the 5G Core (5GC) as well as to execute additional functions by using control data received from the 5GC in order to perform an intelligent computational task.

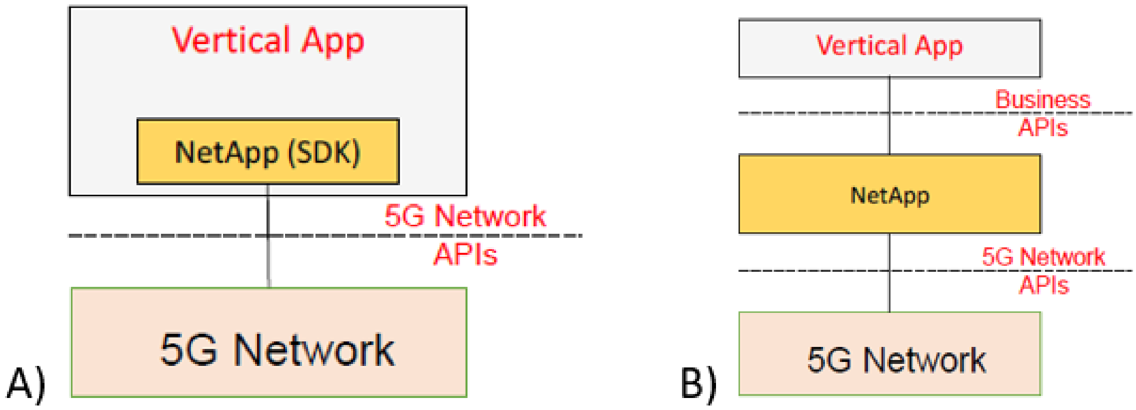

Figure 1: NetApp Types

As shown above in Figure 1, two types of NetApps have been identified, depending on the way the services are provided to the verticals. Those are:

- **Standalone NetApp (option A):** A standalone NetApp provides complete services to one or more vertical industries, either directly or through its integration to a vertical application. A NetApp that is integrated into a vertical application, enhances the functionality of the application by adding network management and monitoring capabilities exposed by the 5G network.
- **Non-Standalone NetApp (Option B):** NetApp that operates as a wrapper of Northbound APIs to expose services through Business APIs. It is an auxiliary non-standalone software piece (in the sense that it becomes functional when its business APIs are consumed by an app). A Non-Standalone NetApp allows vertical applications to be

developed/upgraded (and take advantage of the 5G exposure capabilities) without changing integral parts of their software, i.e., only by consuming the business APIs. Those interfaces will be consumed from the vAPP that will in turn translate into API calls to 3GPP APIs and other telco assets. When the necessary computations and data manipulation are completed, those business APIs will return the requested information to the vAPP.

In EVOLVED-5G project, we have chosen to support both types in order to provide flexibility and engage with vAPP developers. However, since in option A, the standalone NetApp is integrated with the vAPP, a common implementation pattern could not be reached. As a result, in this following section, we are going to focus on the implementation principles for the Non-Standalone NetApp that the project's tools will be able to support in a more complete way.

2.3. Implementation Principles

According to the current state of art of NetApps in the Industry 4.0 era - as described in section 2.3 of D2.1 - the expected workflow and intercommunication (assuming both already deployed) between vAPPs and NetApps would be as follows: It all begins with the vAPP making a request to the NetApp exposed interfaces. Consecutively, the NetApp interprets the request and in turn makes one or more requests to the 5G API Core. The NetApp then gets a reply with all the data that were requested and proceeds with the data modification and its designed functionality, while finally sending the reply to the vAPP.

It's important to note that in the above workflow, there could potentially be one extra flow, depending on the 5G API call needed. Some of the 5G APIs[6] could make a further Callback - POST call with updated information on a particular request. This aspect will be considered while developing a NetApp by making accommodations to the interfaces provided as well as in the vAPP.

Based on the above-mentioned workflow three main implementation principles for NetApps to be developed were evaluated[4]. These principles are cloud native approaches and have been proposed in order to facilitate the development of NetApps and the entire NetApp life cycle via an efficient and beneficial implementation:

A. Function as a Service (FaaS) Deployment
B. Container-based Deployment with a Message BUS
C. Container-based REST API DeploymentContainer-based REST API DeploymentFunction as a Service (FaaS) Deployment

In the following subsections, the three approaches are scrutinized individually and are arrived at the final project's selection and reasoning behind the decision.

2.3.1 Function as a Service (FaaS) Deployment

Since the NetApp acts as a micro-service, meaning that it exposes Southbound APIs to other services and applications, one idea is to utilize the Function as a Service (FaaS) ecosystem allowing its deployment in a serverless environment[3]. In Figure 2, the proposed architecture based on those technologies is depicted.

By adopting a serverless architecture, the NetApp no longer has the option of having its own built-in API backend and must instead communicate with the FaaS platform. However, by this approach, vertical scalability is enhanced as the platform orchestrator can handle the increased or decreased requests and scale accordingly. The developer would also only need to focus on the code and the functionality, whereas the creation of APIs is simplified.

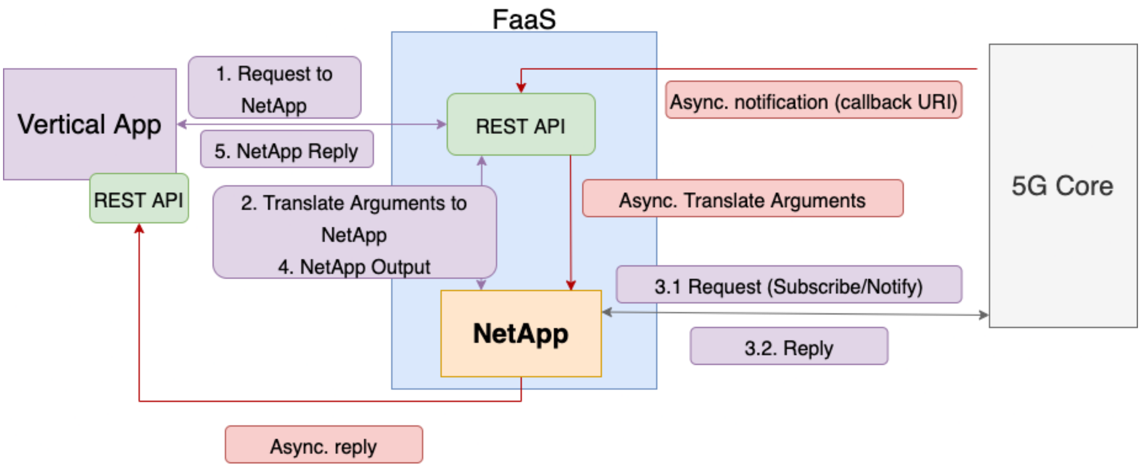

Figure 2: NetApp FaaS Deployment

After a thoughtful analysis, the implementation of a serverless approach was discarded as it adds further complexity and maintenance. To start with, NetApps shall be developed in a certain and strict way, conditional to be supported in a FaaS platform, and only there, which would make them much less flexible in terms of development. This way, not only the technology is not at a desired maturity, but it also includes the cost of maintaining such a platform. Additionally, the final users would have to install the particular platform in their premises in order to run the NetApps, which would in turn increase users' limitations and restrictions.

2.3.2 Container-based Deployment with a Message BUS

An alternative architecture to the NetApp implementation is the approach of a container-based deployment. The next two implementation considerations follow that design principle with some important distinctions. In this section a container-based deployment equipped with a Message BUS is analysed, and the overall architecture and workflow can be seen in the following Figure 3.

The Message BUS implementation aims to streamline the communication between the NetApp and the vAPP by using a Message Queue (MQ) communication protocol. This approach can result in a more effective consumption of the requests/replies by the vAPP, easier implementation towards the publish/subscribe functionalities. Moreover, the asynchronous communication enabled by the message queues optimizes the data flows between the components.

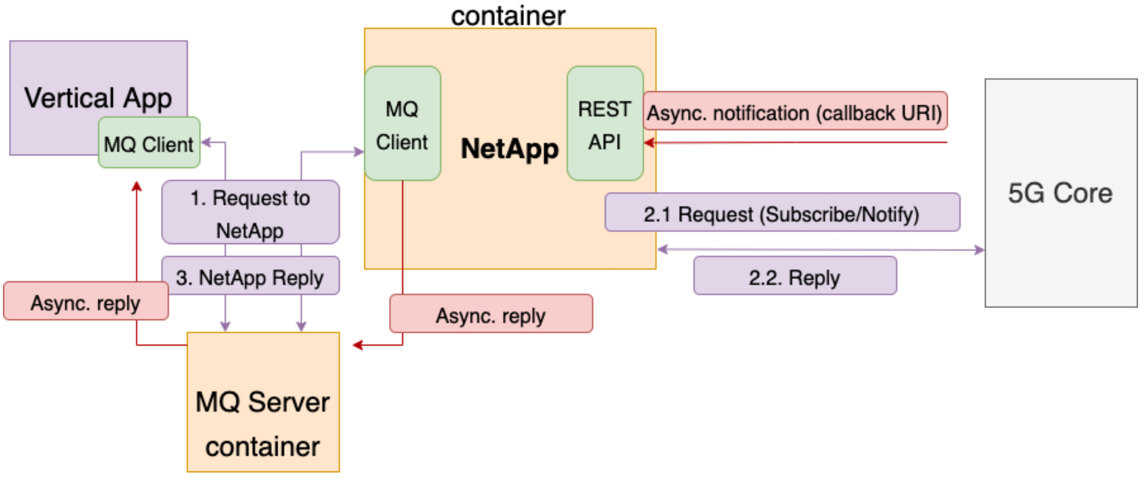

Figure 3: NetApp container-based Message BUS Deployment

While this approach offers several benefits on the overall design and the architecture, it was not without its drawbacks. A Message Queuing Telemetry Transport (MQTT) broker is needed to be deployed alongside the NetApp or the vAPP and act as an intermediate for the MQ. This approach however works effectively when there are several components that need to communicate and exchange information, which will be extremely rare case in the context of EVOLVED-5G.

2.3.3 Container-based REST API Deployment

Due to the fact that the NetApp communicates with the 5GC system, it is deemed necessary to implement a REST API endpoint even also by using MQ was for the rest of the interactions. Considering this, it was proposed and decided that a NetApp will extend the REST API endpoints with the aim to offer access to the vAPP and execute their designed functionalities. Those REST APIs endpoints can be also referred to as Business APIs since they provide the interfaces for all the execution functions. Those APIs are called summon functions initially consume the desired 5G API, and at a next stage they perform the required additional processes in order to return the data. to the VAPP.

An example of a prototype implementation architecture of a Non-Standalone NetApp as envisioned by the EVOLVED-5G project is presented in Figure 4:

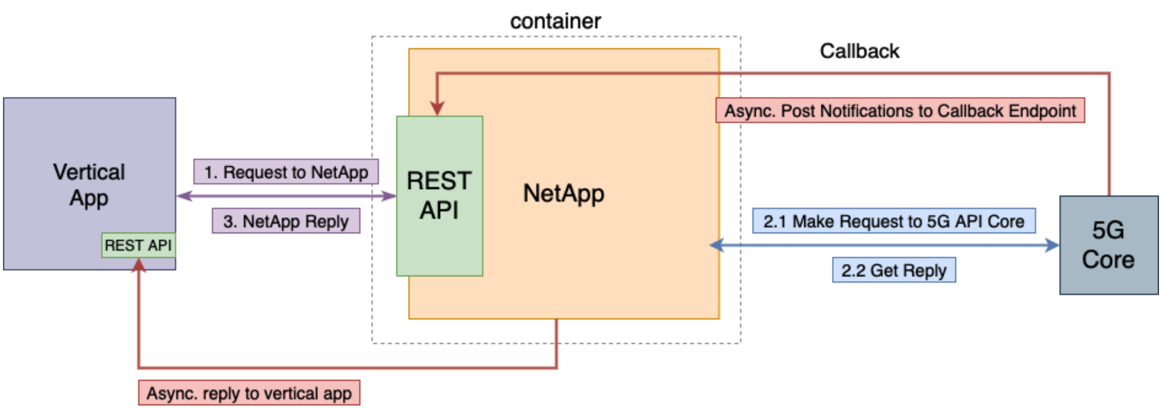

Figure 4: NetApp container-based REST API deployment

As in the previous section, the proposed implementation also involves a container-based deployment. The fact that all libraries for the NetApp implementation can be bundled within a selected container image, introduces a simpler yet more effective approach. The dependencies between the components of the system can be isolated, thus allowing for the inclusion of several secondary applications (i.e., database) towards the provision of more complex application and the support of advanced vertical services and applications.

Since most container engines nowadays can operate across several platforms, the process requires a smaller set of programming skills, significantly facilitating the development efforts, as well as the technical expertise needed to deal with the programming task. Furthermore, a container can be deployed easily and fast in a standalone mode can be also included in a complex orchestrator with several abilities (e.g., scaling, load-balancer).

Taking into account advantages and disadvantages, benefits and drawbacks, easiness of the implementation and potentially creating major issues down the road the container-based REST API Deployment approach seems to be the most appropriate one. To that end a typical NetApp within EVOLVED-5G will be based on a container image, offering REST API endpoints (a.k.a. Business APIs) to the vAPP as well as to the 5G system for subscription-based events when applicable.

3. NetApps Development Process

3.1. The EVOLVED-5G Facility

To understand the NetApp lifecycle, from their development to their eventual publication to the marketplace, it is important to examine the EVOLVED-5G proposed architecture in detail. Indeed, following the initial description of the EVOLVED-5G facility provided in D2.1, this section goes a step forward in the definition of all those core architectural components that support the realization of the facility. A more detailed vision of the reference architecture can be found below in Figure 5, before we delve deeper on each component in the following sections.

In order to design the reference architecture of the EVOLVED-5G facility two main design principles were considered and followed:

- Firstly, the **compositional and structural** logic of the architecture. Viewed this way, 3 main tiers are identified (from top -- most abstract -- to bottom -- most concrete):
  - Environments: Tier-1/Core architectural components. These environments drive the lifecycle of the NetApp within the whole ecosystem, from inception to its final release in the market.
  - Functional Blocks: Tier-2 architectural components whose integration defines the environment. The interaction and interconnection among these functional blocks will eventually provide the environments with the expected functionalities.
  - Tools: Tier-3 architectural components. For each one of the functional blocks there will be a set of tools that will support and materialize their implementation
- Secondly, **the logic of the process that is associated with the expected lifecycle of the NetApp** within the whole system, which is also divided into different phases. Indeed, each of the architectural components are designed to give support to each of the independent phases that a NetApp may reach.

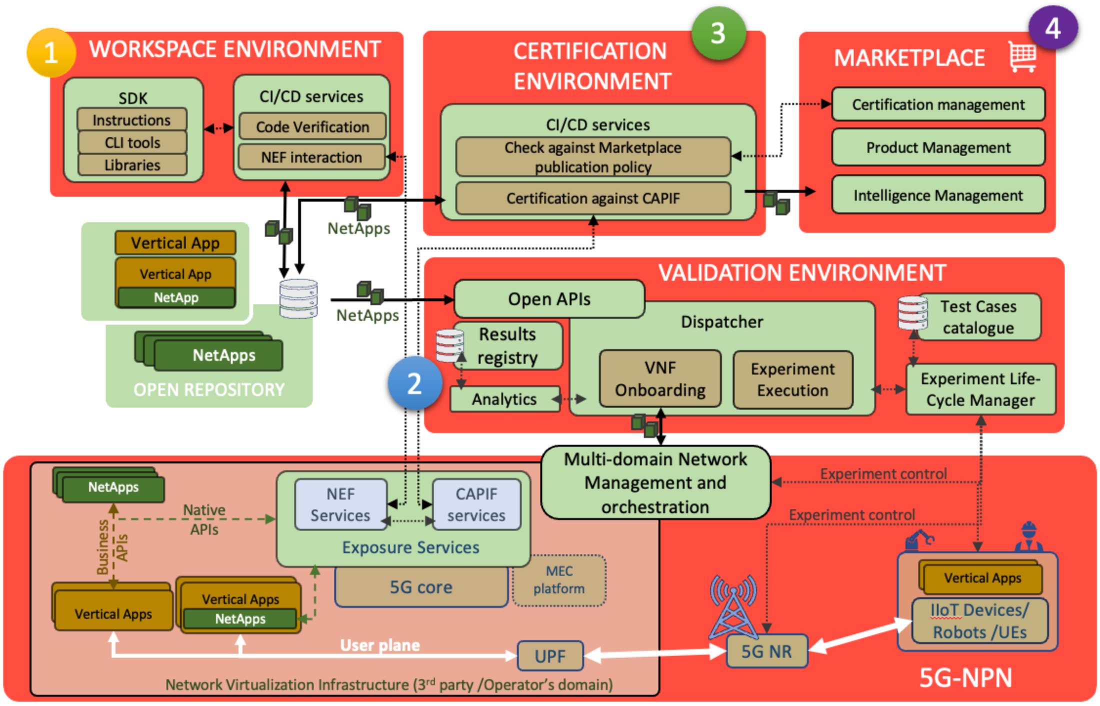

Figure 5: The EVOLVED-5G facility in greater detail

Uniting those principles, an overall architecture was built around 5 major environments. Each one of them acts as a foundation layer in support to the other environments whose role also correlates with the different NetApp Lifecycle phases.

The **Workspace** Environment includes the core NetApp development and code verification tools and services to be produced and used by Industry 4.0 NetApp developers. As an architectural environment, two of the lifecycle phases are identified and executed here: **Development and Verification**. They refer to the implementation of the NetApps and their basic functionalities and 5G core compatibility verification through a set of tests, respectively.

The Workspace also acts as the host for enablers that will be used in a variety of later phases of the NetApp lifecycle, as it will be later described in Section 3.2. For its implementation the following functional blocks will be made available:

- **The SDK (Software Development Kit)**: It will provide a set of SDK tools to support the NetApp development and integration, which will include documentation, instructions, Command Line Interface (CLI) tools, pre-defined templates, and libraries among others. Such SDK tools will be shared among the different Industry 4.0 NetApp developers to use it locally within their premises. Those tools are required for the development phase of the NetApp.
- **Repositories**: EVOLVED-5G project considers two different types that will be used during all the lifecycle phases:
    - GitHub: a code repository to store the code to which every NetApp Industry 4.0 developer will have access for developing the NetApp, storing it and also hosting the necessary files to connect to CI/CD pipeline. It will also be the home for all the other tools and enablers created inside the EVOLVED-5G ecosystem (e.g., SDK) in order to be available for all users.
    - The Open Repository: an artifact repository to store the builds and binaries coming from the CI/CD. It will be a central piece during the entire lifecycle as the NetApp binary will be stored there after each phase along with any required metadata and made available for the next one until its eventual publication to the Marketplace.
- **The CI/CD services:** Their first function is to verify the proper functionality of the NetApp by using a testing framework together with the 5G native APIs emulator as part of the Verification. However, it will also be responsible to connect all the different environments via automated pipelines, guiding the NetApp during the different phases of the lifecycle. It will be a centralized server managed by the project that will provide a series of pipelines, i.e., build the NetApp, deploy and testing, to verify the proper functionality of the NetApp etc.

The **Validation** Environment is the architectural component where the validation phase of the NetApps will be performed. The expected functionality is to test the correct operation of the NetApp along with the vAPP in a realistic environment that would make use of a real 5G infrastructure. Therefore, this phase aims to facilitate the coupling between the NetApp and the Vertical App in controlled scenarios that would eventually emulate real operating conditions as well as to carry out a set of tests agreed and coordinated with the vAPP provider (i.e., Industry 4.0 SME). It is based on the Open5Genesis Suite[5] built on and controlling parts of the 5G-NPN. In turn, the Open5Genesis Suite and its methodology is based on the definition of a Test Case, which describes among others, information such as the target measurements, scope and preconditions of an experiment. Once a Test Case has been defined, its execution is then implemented considering the interfaces and constraints of the platform where the testing procedure will be performed.

Given that details of the Validation phase will be different depending on the NetApp and vAPP tested, as well as due to additional requirements such as the use of specific devices, the Validation phase is envisioned as a collaborative activity between the Vertical and the Platform operators. During an initial consultation phase, the scope and details of the Validation will be agreed between both parties, which will result in a Test Case that is specifically tailored (though many of the used components and ideas are expected to be re-usable between different tests) to the needs of the Vertical. Following the Open5Genesis methodology, this Test Case will be then implemented and executed on top of the platform.

Moving on, there is the **Certification Environment** where Certification activities, such as conformance tests and quality assessments, for the validated NetApps will occur. More specifically, EVOLVED-5G plans to support existing audit bodies by defining the audit list that is suitable for the formal certification of the NetApps. It must be also noted that the certification environment's configuration setup, together with the tools developed by the project for the certification assessments, could be provided by the EVOLVED-5G project partners to the accredited labs that wish to instantiate a relevant environment. This environment is built with the aim to be transparent and automated, in order to effectively deploy the certification tools for performing the audit tests towards the certification process.

The **Marketplace** is the environment that hosts the last phase of the NetApp lifecycle. It is where certified NetApps are meant to be published and made them available to the end users. The main artefact of the Marketplace is built upon are NetApps. Therefore, an industry-oriented vertical type of Marketplace targeted to Telecom (5G) APIs and services will be the scope of the implementation. As single or multiple on-demand services can in principle be ordered by a user focusing on the design and orchestration of end-to-end services within an infrastructure, a Federated Marketplace is envisioned. The product bundle is composed of different services owned by different Providers.

The main characteristics of EVOLVED-5G Marketplace are as follows:

- Market the NetApps as SaaP (Service as a Product), in other words as a centrally hosted productized service sold by the seller/vendor to the buyer.
- Support of wizard type interfaces for onboarding and order Management of NetApps and services.
- Provision of dashboards for publishers and consumers for monitoring revenue/balance, API performance, consumption etc.
- Provision of CPQ (Configure, Price, Quote) functionality using Wizards. Bundles of NetApps and services shall be supported.
- Provision of the ability for user engagement through different channels. (E-shop, Mobile App, Bots etc).
- A public repository shall be available to store, search and download certified Apps and NetApps that are willingly uploaded (NetApp compiled version / artifact).

Finally, the **5G-NPN Infrastructure** provided by the Athens and Malaga platforms will act as an underlying layer that supports most of the EVOLVED-5G ecosystem functionalities. A 5G Non-Public Network (NPN) refers to a network that enables the deployment of a 5G system restricting its operability to organizations within its premises providing private network services.

All the necessary equipment, from cloud servers to 5G Network providers will be hosted on these promises to be used at different stages of the NetApp lifecycle. It will provide a dynamic environment for the deployment of NetApps within 5G connectivity spaces. Additionally, the platforms will contain all the equipment and functionality required for the execution of the NetApp Validation phase, and for the performance of any additional tests that are required for the Certification of the NetApp. 5GCore exposure services will be also provided, providing the developers interfaces to interact with the system and gather data.

3.2. NetApp Lifecycle

In this section, the NetApp Lifecycle in the context of EVOLVED-5G ecosystem is introduced together with all the different defined phases NetApps will pass through before we delve deeper on each phase at its correlated section. As it can be seen in the following Figure 6, 5 main phases have been identified. As mentioned in the previous section, those phases relate to the corresponding architectural blocks as designed from the project. Those phases are:

- **Development phase**: The NetApp development will take place during this step.
- **Verification phase**: Tests that verify the application compatibility with the 5GC APIs occur at this phase.
- **Validation phase**: Vertical App and NetApp are deployed together under real 5G infrastructure, and their combined functionality is tested.
- **Certification phase**: Execute certification audits.
- **Publication phase**: Publish and manage certified NetApps in the Marketplace to be sold to the end-users.

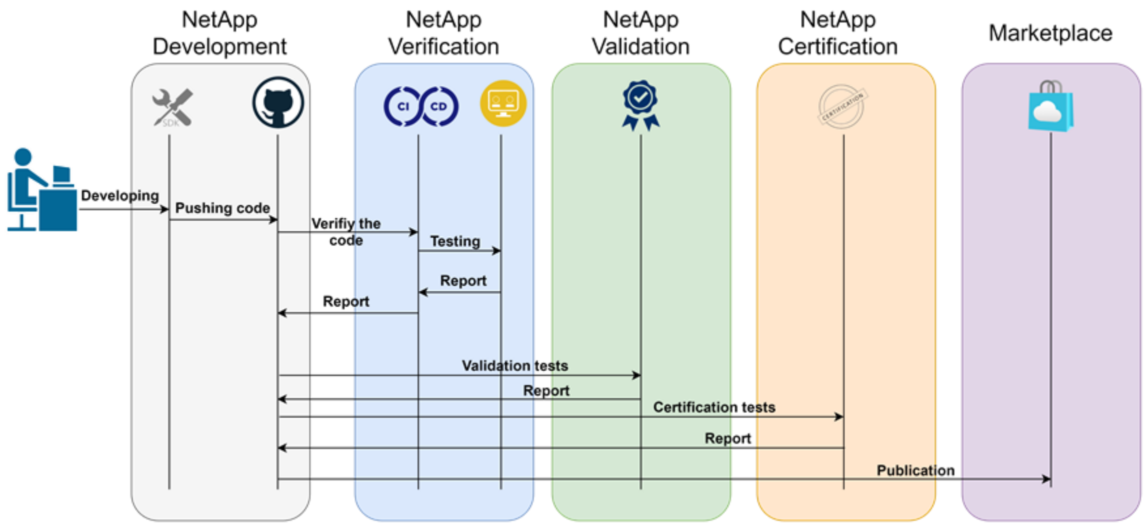

Figure 6: EVOLVED-5G Workflow Diagram

As shown in Figure 6, the first step within a NetApp's Lifecycle is the **Development** phase. It is closely interlinked with the Verification phase and in that regard they both take place in the Workspace Environment. The main process within the Development phase refers to the creation of the NetApp and the coding of the desirable functionalities. During this process the developer will use the enablers provided by the Workspace starting from the SDK tools and the Templates. A NetApp repository will be created in GitHub from the template while also providing the developer a starting code structure and CI/CD workflow connection. The SDK will act as a further assistance for the developers as consequently, the NetApp can be moved to the next phase.

The **Verification** phase, as already said, is also located in the Workspace Environment. It refers to the verification of the assorted functionalities the developer wishes to provide to their application. The phase will include a variety of tests, against the NEF Services to verify 5GC API compliance. During the Verification phase the CI/CD services will be introduced in order to help and guide the developers during the remaining steps of the NetApp's lifecycle.

The next step in the overall workflow is the **Validation** phase, where an extended evaluation of the NetApp alongside with the vertical application (vAPP) is performed. Also, functional, and non-functional tests are executed with the aim to examine synergies and compatibilities between vAPPs and NetApps as well as to evaluate the overall capabilities provided. The process takes place in a controlled environment, on top of a real 5G NPN infrastructure emulating the conditions where the NetApp would normally operate.

To perform the Validation process in the EVOLVED-5G context, the Open5Genesis framework running on the two available platforms, Athens, and Malaga, will be utilised. Test Cases per NetApp and per use case have to be defined with the cooperation between the developers and the Platform Operators. The goal will be to collect KPIs, both quantitative and qualitative in nature that will lead to the assessment of each NetApp in terms of functionality. When the validation process is completed, the NetApp will be then uploaded to the Open Repository for the next activity.

Indeed, the next step refers to the **Certification Environment** and the Certification of the NetApp. The process to be undergone is to assure certain supplementary software specifications in terms of conformance and quality. It will be done using certain automated tests that aim to cover specific certification aspects.

Finally, as soon as all the previous steps have been completed successfully, the NetApp will be released to the **Marketplace** for the Publication phase where it will be available for commercial use. The publisher will have several options at hand such as tracking revenue, view consumptions analytics etc.

4. 5G NPN INFRASTRUCTURE

The 5G NPN (Non-Public Network) infrastructure provides the functionality and equipment required for performing the NetApp validation phase, as well as any additional tests that may be required for the NetApp certification. In the case of EVOLVED-5G, the infrastructure located in Athens and Málaga provide radio access and exposure of the 5G APIs, a container orchestration system, measurement probes, and the possibility of integrating new devices as required for the Vertical, among others.

For the Validation and Certification of the NetApps, the EVOLVED-5G platforms provide access to the 5G APIs and connectivity by the use of a full 5G deployment that can simulate the perimeter of an industrial environment. Details about the equipment and capabilities of the two EVOLVED-5G Platforms can be seen in sections 4.2 and 4.3, while an overview of the general components of the NPN infrastructures can be found in the following section.

4.1. ARCHITECTURE

In the following Figure 7, an overview of the 5G-NPN main functional blocks that exists in both platforms is given.

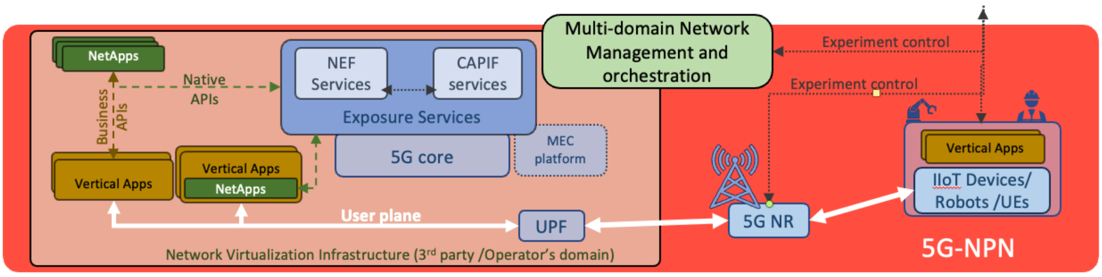

Figure 7: 5G-NPN Functional Blocks

This Network Management and Orchestration domain describes the overall functionality regarding virtualisation, management of network slices, management of virtualised resources, as well as the traditional Network Management System functionality, responsible for controlling the Network Functions (NFs) and other elements of the network.

Within the third-party/Operator's domain the NetApp resides either in standalone or Non standalone mode, as has been described in section 2.2 and interacts with the control plane of the core network. The core network in turn, exposes the required services in a trusted and standardized way through the Network Functions (NFs) and according to the 3GPP definitions [5]. The 5G core component also employs features, one of the most important being the separation of the user and control plane, which brings flexibility and agility towards the validation phase with the UPF being also the key core network component in MEC-based deployments.

4.1.1 NEF Services

The exposure of the NEF services by the 5G NPN Infrastructure will be realized by the NEF emulator tool. NEF emulator will be a software component that will implement some of the available APIs defined in 29.522[6]. The exposure of network services supports different capabilities such as Monitoring (i.e., monitoring of specific UEs regarding location, reachability, roaming status etc.), Policy and Charging for handling QoS and charging policies and network analytics that enable the consumption of analytics information generated by the 5GS. On the other hand, some NEF services enable third party applications (i.e., NetApps in EVOLVED-5G) to provide valuable information to the 5GS. In this way, NetApps can assist 5GS to make decisions based on the information provided through NEF. NEF services, that will be provided by the emulator are implemented as RESTful APIs, are described below:

- **Monitoring Event API**: This API allows a NetApp to access several events which may occur in the 5GC. Some preeminent examples include location reporting, loss of connectivity, and UE reachability.
- **AsSessionWithQoS API**: The AsSessionWithQoS API will allow a NetApp to choose a predefined QoS Profile from a list retrieved from the 5GC. Moreover, a NetApp can indicate the desired level of QoS (e.g., jitter, latency, and priority) for a given IP traffic flow.
- **AnalyticsExposure API**: For some use cases, data analytics can be useful for ensuring network availability or for providing predictive maintenance features. Therefore, Analytics exposure API will allow a NetApp to have access in data analytics information such as, QoS sustainability, network performance and UE mobility.
- **5GLANParameterProvision API**: 3GPP has extensively studied new use cases and potential requirements applicable to the 5G system[7] for a 3GPP network operator to support 5G LAN-type services over the 5G system (i.e., UE, RAN, Core Network, and potential application to manage the LAN-style service). 5G LAN is a promising solution providing services with similar functionalities to LANs and VPNs but improved with 5G capabilities. The goal of this API is to provide the required parameters to enable distributed LAN-based connectivity between two or more terminals/UEs connected to the 5G network.
- **LpiParameterProvision API**: This API will support NetApps with the capability of allowing/disallowing location sharing for specific UE(s).
- **AKMA API**: AKMA (Authentication and Key Agreement for Applications) is a mobile network service intended to support authentication and key management based on 3GPP credential in 5G system, for 3rd party applications. AKMA can provide authentication and session key negotiation services for third-party applications based on the access authentication system of the USIM card and carrier network and establish secure transmission channels from terminals to applications. This API will allow a NetApp to retrieve AKMA application key information.

4.1.2 CAPIF Services

CAPIF Tool will be a software component that emulates the CAPIF APIs of Rel. 17 (3GPP)[2]. At its core, it implements REST APIs in order to provide CAPIF services (CAPIF Core Functions) to NetApps (API Invokers function). Specifically, CAPIF Tool enables NetApps to consume CAPIF services to register NetApp as API Invokers and consume 5GS APIs exposed (e.g., NEF APIs from Emulator).

CAPIF Tool provides the following Core Functions for API Invokers:

- **API Invoker management**: CAPIF tool will implement CAPIF_API_Invoker_Management_API as defined in TS29.222. This API will enable NetApps to Register as API invokers to consume APIs from 5G environments.
- **Security API**: CAPIF Tool will implement CAPIF_Security_API as defined in TS29.222. This API let NetApps define the security preferences when interacting with CAPIF API endpoints.

- **Discover Service API**: CAPIF Tool will implement CAPIF_Discover_Service_API as defined in TS29.222. This API let NetApps discover what APIs are exposed in the 5G Network environment.
- **Event Service API**: CAPIF Tool will implement CAPIF_Events_API as defined in TS29.222. This API let NetApps receive notifications from CAPIF Core functions.

4.2. Athens Platform

The Athens 5G platform realises the 5GENESIS experimentation facility architecture and is composed of two sites in the Athens metropolitan area, forming an end-to-end (E2E) experimental 5G testbed. One is located in NCSR "Demokritos" campus and the other in COSMOTE/OTE Academy premises. Figure 8 provides an overall overview of the 5GENESIS Athens Platform topology spanning over the two sites, NCSRD and COSMOTE, which can support different 5G deployments, operating either as individual domains with multiple 5G-cores or as multi-domain deployment with a common 5G core.

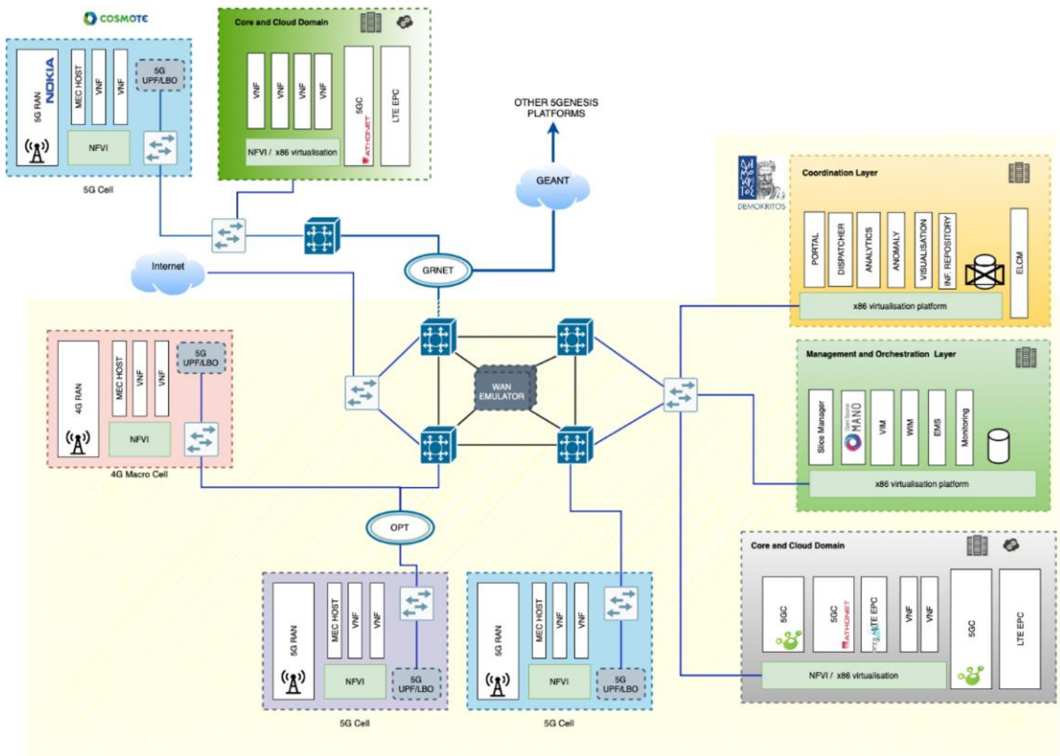

Figure 8: Athens Platform Topology

4.2.1 NCSR Demokritos

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)[8] which provides access to Internet and GÉANT (pan-European data network for the research and education community)[9]. This site is responsible for hosting most of the infrastructure required for the management, orchestration, and coordination of the Athens Platform.

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

The main identified components of the infrastructure platform at NCSRD are:

- 5G-Core
- 5G New Radio
- Slice Manager

The **5G-Core** is based in Amarisoft's 5G solution which has been integrated into the platform providing a stable mobile network system for testing and experimenting (Figure 9). 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 a 5GC cloud deployment.

Figure 9: Amarisoft's SA/NSA 5G System

Amarisoft's 5GC provides the fundamental network functions, such as the Access and Mobility Management Function (AMF), Session Management Function (SMF), Authentication Server Function (AUSF) for the control plane and User Plane Function (UPF) for the user plane. Additionally, at the NCSRD core are hosted the major management and orchestration components (NFV-MEC MANO, Monitoring tools, WIM NMS/EMS and slice management). For network programmability support, 5GENESIS Athens platform hosts the free5GC (Stage 2), which is an open-source project for 5th generation (5G) mobile core networks. The free5GC supports the Service-based interface, which will be used for supporting the NEF function. Other supported network functions are Network Repository Function (NRF), Network Slice Selection Function (NSSF), Unified Data Management (UDM), Unified Data Repository (UDR), and Additional features currently supported are: 5G Next Generation Application Protocol (NGAP), 5G Non-Access Stratum (NAS), and 5G authentication.

5G New Radio (NR) implementation is based on Amarisoft's 5G Callbox solution, which complies with Rel. 15/Rel. 16. Specifically, it supports both FDD and TDD transmission at FR1 and FR2 bands. Bandwidth configuration is applicable from 5 to 50 MHz with MIMO options for up to 4x43. The supported modulation schemes range up to 256QAM for downlink transmission and 64QAM for uplink. Finally, all the subcarrier spacing options (i.e., 15-120 kHz) are available.

The **Slice Manager** is the component that mediates between the Coordination layer components of the 5GENESIS architecture and the MANO layer. It is responsible for the lifecycle of network slices, i.e., it manages the creation and provision of network slices over the infrastructure and provides an API in order to communicate with the Coordination Layer and receive requests for network slices in the form of a Generic Slice Template (GST)[28]. 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, Katana Slice Manager v2.1.0[45] is deployed (Release B). 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.

4.2.2 COSMOTE

The COSMOTE building (OTE Academy), in the north of Athens, is a multi-functional complex, combining various indoor and outdoor usage scenarios; It is also directly connected to GRNET which provides access to GÉANT. Internet access is provided by OTE network. This site is hosting infrastructure components, radio access components and NFV/Edge Computing infrastructure.

At the COSMOTE site, the **5G NSA Core** deployed is based on commercial 5G equipment from NOKIA AirScale platform which is installed at OTE Academy premises. Figure 10 presents the 5G NR equipment currently installed at COSMOTE premises. The current installation includes notably the following modules and supports indoor/outdoor operation:

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

Figure 10: Nokia AirScale 5G BBU, Airscale Micro 4T4R, AirScale Outdoor Installation

A **Local Breakout Node** has been installed in the main data center of COSMOTE as it is an integral part of the interconnected testbed. The previously independent mobile networks operated by NCSRD and COSMOTE have been connected through the use of this LBO SGW node for the implementation of the 5Genesis mobile network.

4.3. Malaga Platform

The EVOLVED-5G Málaga platform is managed by the MORSE research group[10] (part of the University of Málaga) and is based on the infrastructure deployed on the Ada Byron research building as a result of multiple European projects. The latest instance of the platform is based on the 5GENESIS architecture, with many components of the deployment obtained within the context of this project[12]. Additionally, the platform integrates the original equipment of the TRIANGLE[11] testbed.

The Ada Byron building hosts the Core Network, Main Data Center and Edge infrastructure to support both the indoor and outdoor LTE and 5G deployments of the platform, as well as several radio emulators and additional measurement equipment. The indoor deployment integrates LTE and 5G NR equipment, 5G NSA and SA compatible EPC along with several compatible UEs. The radio access is provided by two pico RRH for 5G under 6GHz (Figure 11, right) as well as one pair of cells (LTE/5G NR) of the outdoor deployment, that point directly to the indoor premises of the lab.

Figure 11: Outdoor 5G mmW RRH (left) and indoor pico RRH for 5G under 6GHz

The indoor deployment also contains LTE and 5G radio emulators (Figure 12), power analyzers and other measurement equipment which is available for use by the experimenters.

Figure 12: Keysight UXM 5G radio emulator

The outdoor deployment covers the area around the Ada Byron building as presented in Figure 13. It is comprised by 4 small cells with the latest LTE radio release, 4 RRHs that provide 5G under 6GHz, and 2 more for 5G mmW Figure 11, left).

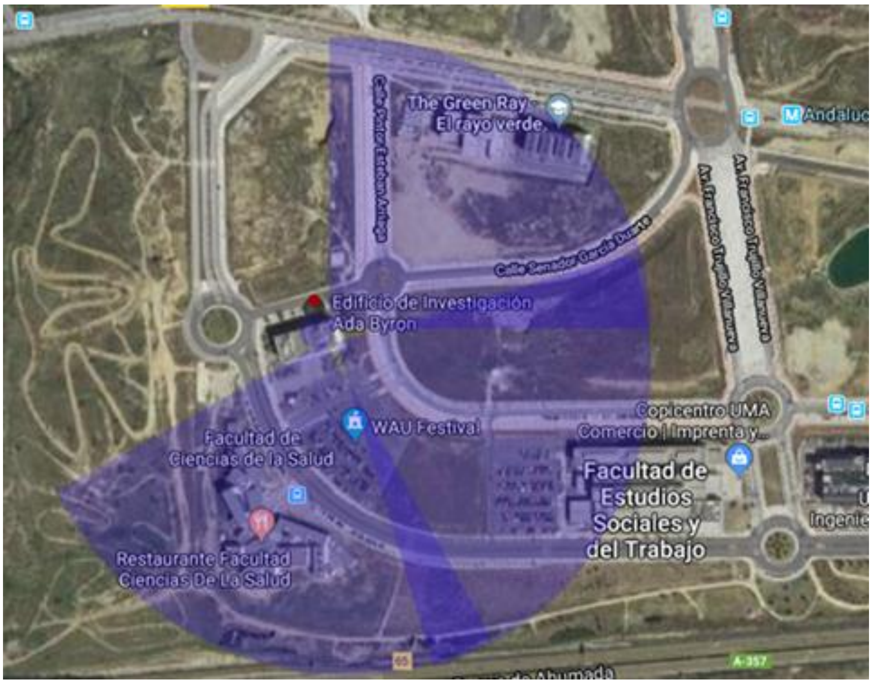

Figure 13: UMA outdoor deployment estimated coverage around Ada Byron building

The Málaga platform also provides capabilities for TSN (Time-Sensitive Networking). This functionality is based on the Relyum solution (Figure 14), which includes 1 TSN bridge (the element that acts as a switch, supporting the TSN features) and 2 TSN PCIe cards based on Intel I210. These cards provide IEEE 802.1 TSN features and are able to act as bridge or end station (sometimes called talker and listener, with regards to the direction of the TSN flow).

Figure 14: Relyum setup

With regards to the TSN translators, which are needed to enable the communication between the 5G and the TSN domains, these entities are based on the U-Blox EVK-R5 solution that provides the clock needed for the synchronization mechanisms. This solution can be seen in Figure 15.

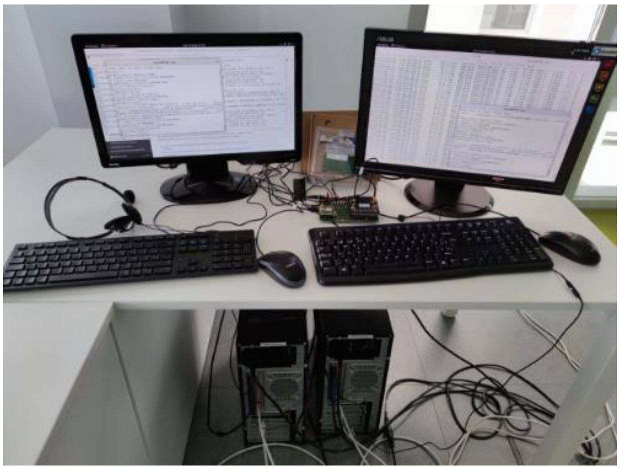

Figure 15: U-blox and Intel I210 cards

The orchestration of the equipment during the experiment execution is handled by the Open5Genesis framework[12], which is deployed as part of the platform. More information about the components and capabilities of the Málaga Platform can be seen in Deliverable D4.6 of the 5Genesis project[13].

5. The Workspace

5.1. Objectives

The objective of the Workspace is to provide means to developers as instructions, tools or libraries among others to develop a NetApp. The workspace will also take care of verifying the NetApp. It is worth mentioning that the Workspace will focus exclusively on the development and verification of the NetApp by hosting the code and all the files related to it in order to develop and verify it, and not on the development and verification of the vAPP.

The purpose of the workspace is to have a complete and verified NetApp ready to advance to the next step of the workflow process, namely the Validation phase.

5.2. Architecture

The architecture proposed for the Workspace environment is mainly composed by three core functional blocks: The SDK, repositories and CI/CD services. They will all be described more in-depth in the next sections. The architecture of the workspace environment provides the means for the developers to work towards the development of a NetApp from scratch, assisting them with tools and enablers during all the various steps. The architecture encompassed within the workspace environment can be split into two main modules, which, in turn, correspond and associate with the development and verification phases:

a) **Development**, composed by the SDK and repositories. It mainly carries out the NetApp development work.

b) **Verification**, composed by the CI/CD services and the 5G service interfaces described in section 4. The NetApp will mainly verify against the 5GC APIs implementations in the 5G service emulators, while previously verified by running some pipelines from the CI/CD.

The architecture of the Workspace can be seen in Figure 16.

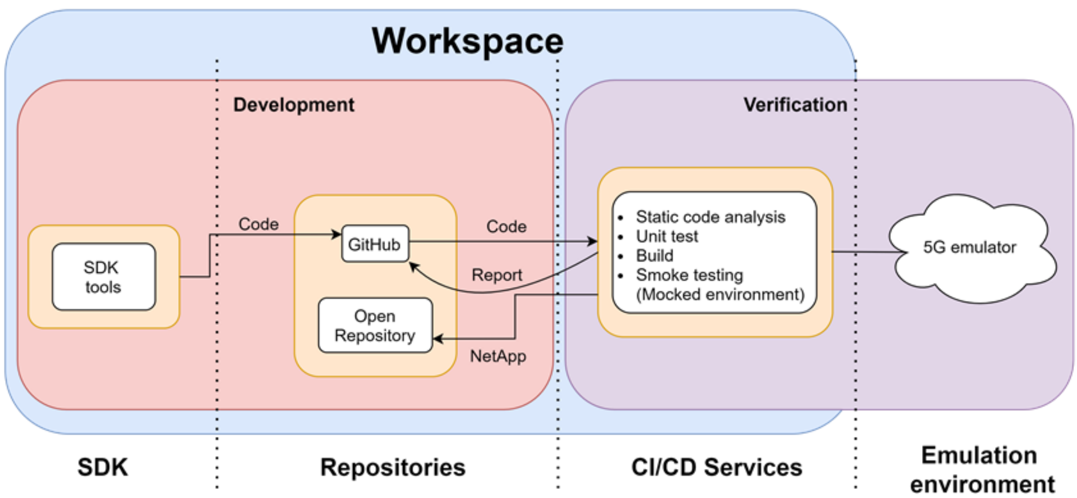

Figure 16: Workspace functional blocks

The overall architecture of the Workspace provides all the required resources in order to fully develop a NetApp and have it ready for the validation stage. A pre-requisite for validation is that the NetApp has to be previously verified.

For the sake of intelligibility, the architecture will not provide a mean for GUI editor, thus, the developer can use the GUI editor of their preference while interacting with the workspace environment. The workspace architecture enables the developer to work locally while developing the NetApp and later on interact with the architecture by using the SDK tools to create a repository in the EVOLVED-5G GitHub[14] and passing through all the verification steps, giving them meaningful information regarding why the NetApp has or has not passed the verification tests.

5.2.1 SDK

The software development kit (SDK) consists, as its name suggests, of a package of tools and data, which in this case will enable developers to develop NetApps using a GitHub repository. The SDK is one of the main functional blocks within the workspace, as it is where all the NetApp development phase will take place.

The SDK will also provide developers with all the necessary documentation towards the support of the NetApp development in the context of EVOLVED-5G:

- **Instructions**: It refers to the documentation that contains all the necessary steps for the developer to create a specific repository, in GitHub in which all the necessary files in order to create and develop the NetApp can be found. Such instructions will guide the developers during the process of a NetApp development, (for example, how to get access to GitHub, the steps to follow to create a repository or how to connect to the CI/CD and eventually deploy their newly developed NetApp for Verification.
- **Templates**: it refers to a repository where a well-defined structure composed by folders and files is stored in GitHub. Within these files the connection to the CI/CD pipelines (common between all developers) is defined as well as where to store the NetApp code. This template will be used along with the CLI tools to create the NetApp repository. This option will allow the developer to focus on the code and the overall functionality, rather than the setup of the project.
- **CLI tools**: such tools will be CLI tools with the purpose of helping the developer to create repositories for its NetApp. The tools will create the repository locally and push all the initial information to the remote repository in GitHub. Then the developer will be able to store all the required files and documentations for their NetApp. The process of creating the repository will be transparent for the developer, denoting that the developer will just need to download the tool and will be asked for some inputs. CLI tools will be open-source and will support multi-platform.
- **Libraries**: these libraries will help developers to better understand and simplify the interaction of their NetApps with the 5G APIs emulators, as well as with the real 5GC APIs. Essentially, they will offer an abstraction towards the APIs, handling the repetitive and default values of the requests, enabling them to pay only attention on those parts that are deemed of high significance to them.

5.2.2 Repository

The Repository is an additional component of the workspace, which is actually composed by two separate repositories. One of them is **GitHub**, which is a platform that allows collaborative code development and hosting in different repositories and projects. In GitHub, an organisation called EVOLVED-5G has been created, which includes a template to generate the NetApp file structure as part of the SDK toolchain. As soon as the developers will start developing their NetApps, individual applications' repositories in GitHub will be created, thus every developer with granted access can start sharing the generated NetApp code, as well as all the necessary files related to the proper functionality of the NetApp.

The second repository, namely the **Open Repository** (based on Artifactory[15]), is used to store and manage all the NetApp images (binaries) and is an extension to other repositories similar to source code repositories, i.e., GitHub. Artifactory usually stores individual application components that can be put together at a later stage, thus allowing to break bigger apps in smaller chunks, getting more efficient building processes and tracking building errors at ease. Therefore, after the NetApp has passed all the verification steps, the CI/CD services will create and store a binary of such NetApp in the open repository. Same steps will be followed for validation and certification environments.

The Repository will be connected to a third component of the workspace, namely the **CI/CD** for which more details will be given in the next section. This connection will be established when the NetApp is created from the "Template" repository in GitHub. Based on this connection, the developer will be able to create new projects for each NetApp, and as soon as the code is stored in the Repository, it will go through the CI/CD pipelines (build and deploy), where the NetApp is verified, through specific tests, whether is properly developed or not.

5.2.3 CI/CD Services

Evolved5G CI/CD Services are responsible for automating the main phases defined in Evolved5G:

- NetApp Development: CI/CD services allow the Developers to test their NetApps in the workplace. CI/CD Services include pipelines (automated tasks) to Build and Deploy the NetApp from the Code repository (GitHub).
- NetApp Verification: CI/CD services allow the Developers to Verify that their NetApps are compliant with Evolved5G execution environments and APIs (NEF and CAPIF Emulators). Validated NetApps are uploaded to the Open Repository (Artifactory) for certification.
- NetApp Certification: CI/CD services allow the developers to run the Certification pipeline to obtain the certification results. Certified NetApps are uploaded to the Certified area of the Open Repository (Artifactory) for releasing them to the Marketplace.
- Release to Marketplace: CI/CD services allow the Developers to promote their certified NetApps to the Marketplace for business and commercial exploitation.

5.2.3.1 Design Principles

Evolved5G CI/CD architecture design have been led by the following principles:

- **Declarative definitions**: A declarative approach must be chosen whenever possible. This makes easier to have versioned repositories with all CI/CD configurations, and significantly decreases dependencies with specific tools.
- **Infrastructure as Code**: Infrastructure must be managed and provisioned through declarative definition files, rather than physical hardware configuration or interactive configuration

tools. This allows faster provisioning times, and removes risks associated with human error. Infrastructure must be treated as other micro-service.

- **Cloud agnosti**c: Efforts must be made to avoid any particular cloud vendor lock-in. PaaS usage must be limited to well-known widely available services (e.g.: object storage, queues), which could be easily replaced in other environments (e.g.: on-premises, private clouds, etc.).
- **Ephemeral environment**: Each pipeline execution must create its own infrastructure environment and destroy it afterwards. Nothing has to keep running between executions, obtaining cost efficiency. Tests must be run in isolated containers, each of these doing their task and being removed later on.

5.2.3.2 High Level Component Design

The following Figure 17 shows the component stack used to compose the Evolved5G CI/CD chain:

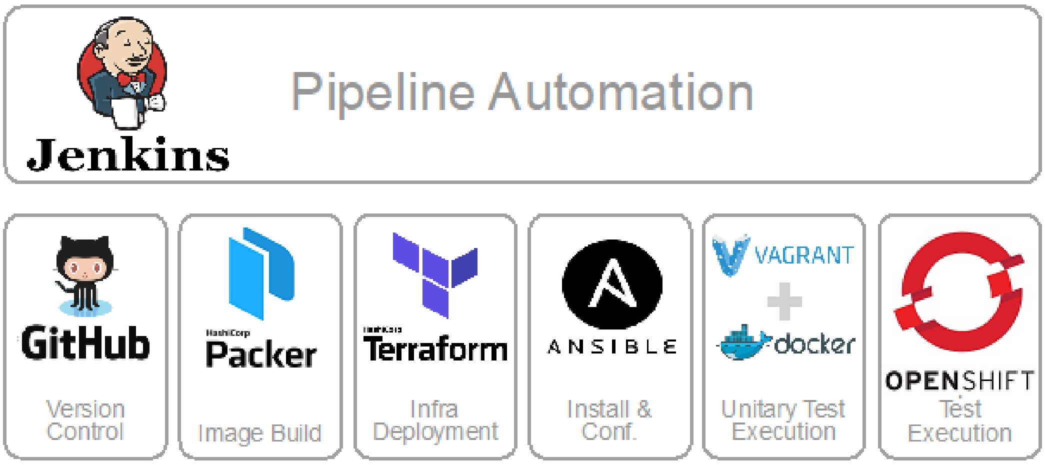

Figure 17: CI/CD component stack

Code Versioning: Evolved5G CI/CD uses GitHub as control version tool, along with git well-known best practices. GitHub is a cloud-managed code version control platform using Git. GitHub is widely used by programmers to publicize their work or for other programmers to contribute to projects, as well as to promote easy communication through features that report issues or merge remote repositories (issues, pull request, etc.).

Pipeline Automation: Jenkins[16] is a free and open-source automation server, which helps to automate continuous integration and facilitating continuous delivery. It supports version control tools, including Git. Builds can be triggered by various means, for example by committing in a version control system, by scheduling via a cron-like mechanism and by requesting a specific build URL. It can also be triggered after the other builds in the queue have completed. Jenkins's functionality can be extended with plugins. Pipeline configuration in Jenkins enables to define the whole application lifecycle. The pipeline plugin was built with requirements for a flexible, extensible, and script-based CD workflow capability in mind. Accordingly, pipeline functionality is:

- Durable: Pipelines can survive both planned and unplanned restarts of your Jenkins master.
- Pausable: Pipelines can optionally stop and wait for human input or approval before completing the jobs for which they were built.

- Versatile: Pipelines support complex real-world CD requirements, including the ability to fork or join, loop, and work in parallel with each other.
- Efficient: Pipelines can restart from any of several saved checkpoints.
- Extensible: The Pipeline plugin supports custom extensions to its DSL (domain scripting language) and multiple options for integration with other plugins.

Pipelines are Jenkins jobs, typically built with simple text scripts that use a Pipeline DSL (domain-specific language) based on the Groovy programming language. Pipelines leverage the power of multiple steps to execute both simple and complex tasks according to parameters that you establish. Once created, pipelines can build code and orchestrate the work required to drive applications from commit to delivery.

Image Build Automation: Packer[17] is an open-source tool for creating identical machine images for multiple platforms from a single source configuration. Packer is lightweight, runs on every major operating system, and is highly performant, creating machine images for multiple platforms in parallel. Packer does not replace configuration management like Chef or Ansible. In fact, when building images, Packer is able to use tools like Chef or Ansible to install software onto the image.

Infrastructure Deployment Automation: Terraform[18] is a tool for building, changing, and versioning infrastructure safely and efficiently. Terraform can manage existing and popular service providers as well as custom in-house solutions.

Configuration files describe the components needed to run a single application or an entire datacenter. Terraform generates an execution plan describing what it is needed to reach the desired state, and then executes it to build the described infrastructure. As the configuration changes, Terraform is able to determine what changed and creates incremental execution plans which can be applied.

The infrastructure Terraform can manage includes low-level components such as compute instances, storage, and networking, as well as high-level components such as DNS entries, SaaS features, etc.

Automatic Software Installation and Configuration: Ansible[19] is an open-source software provisioning, configuration management, and application-deployment tool. It includes its own declarative language to describe system configuration.

Unlike most configuration-management software, Ansible does not require a single controlling machine where orchestration begins. Any machine with Ansible utilities installed can leverage a set of files/directories to orchestrate other nodes, the absence of a central-server requirement greatly simplifies disaster-recovery planning. Nodes are managed by this controlling machine - typically over SSH. The controlling machine describes the location of nodes through its inventory.

Ansible uses an agentless architecture, with Ansible software not normally running or even installed on the controlled node. Instead, Ansible orchestrates a node by installing and running modules on the node temporarily via SSH. For the duration of an orchestration task, a process running the module communicates with the controlling machine with a JSON-based protocol via its standard input and output. When Ansible is not managing a node, it does not consume resources on the node because no daemons are executing of software installed.

Containerization of NetApps: Evolved5G CI/CD uses Docker[20] as its containerization tool, to run tests in a portable way. Docker is the world's leading software container platform today. When using containerization, it is possible to run processes within an isolated environment (sandbox) called "container" by providing specific instructions on which host resources can be allocated. Technically, the difference between a regular process and a process that runs inside a container is that the latter can only "see" the resources let by cgroups, a Linux kernel feature that limits accounts, and isolates the resource usage (CPU, memory, disk I/O, network, etc.). Several containers can be created on each operating system, each of which runs using its own namespace and is controlled by cgroups and in the case that are configured properly, they can all share portions of the host resources.

NetApp Building Process: Traditionally, Docker images are built based on the instructions provided by a Dockerfile. A Dockerfile is a text document that contains all the commands a user could call on the command line to assemble an image. Using docker build users can create an automated build that executes several command-line instructions in succession.

However, Evolved5G CI/CD uses Packer as an alternative approach for Docker image building. Packer builds Docker containers without the use of Dockerfiles. By not using Dockerfiles, Packer is able to provision containers with portable scripts or configuration management systems (like Ansible) that are not tied to Docker in any way. It also has a simple mental model: container provisioning and normal virtualized or dedicated server provisioning happen much the same way.

Deployment and Execution Environment: Evolved5G CI/CD uses OpenShift[21] as the environment to deploy Containers (NetApps) and test them. OpenShift is based in Kubernetes[22], and we will be using Kubernetes services and APIs natively, instead of using proprietary OpenShift tools and APIs.

Code Quality Analysis: SonarQube[23] is an open-source platform developed by SonarSource for continuous inspection of code quality to perform automatic reviews with static analysis of code to detect bugs, code smells, and security vulnerabilities on 20+ programming languages. Evolved5G CI/CD will use this tool to assess the quality of the code for NetApps.

5.3. Process Design

Figure 18 displays the process undergone by a NetApp during the development and verification, presenting the different steps to be executed during each phase.

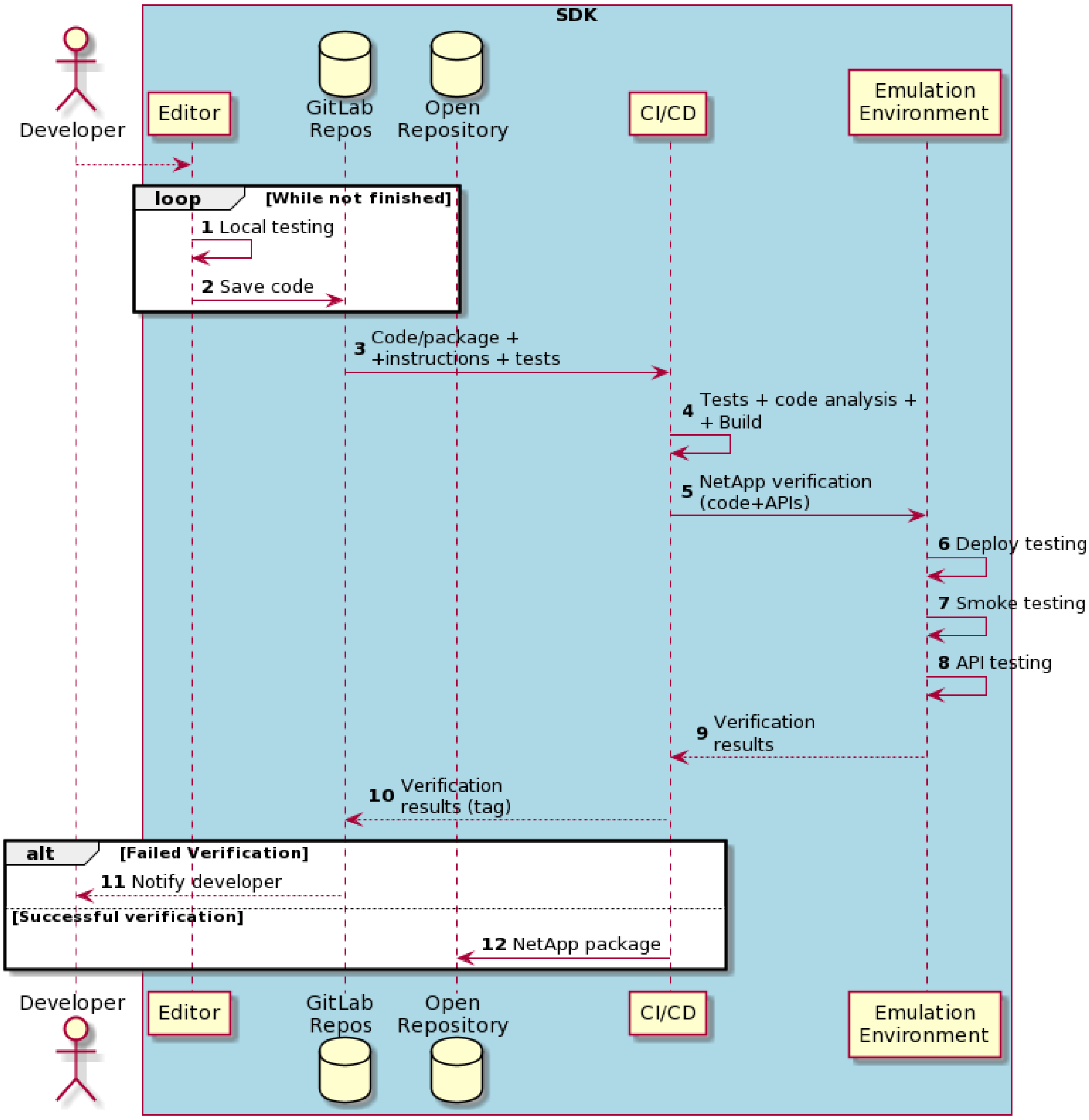

Figure 18:NetApp Workspace sequence diagram

As it can be seen in the figure, a developer role has been defined which will work locally writing the code and functionalities for the NetApp. As a first step however, the developer can use a well-defined template provided by the CLI tool in order to create a personal NetApp repository in Github which includes a suggested file structure. More importantly, creating the repository in this way will allow for the connection to the Verification module as well, through the CI/CD services, as all the necessary files for the pipeline attachment and configuration will be included. Further on, the developer can use the IDE or a code editor of their preference and as soon as they have prepared the NetApp and successfully performed their own local tests, the code will be uploaded to the GitHub repository that has been created.

From this step on, the developer will start testing the NetApp within the Verification environment. This can be achieved by executing different CI/CD pipelines (such as build, deploy) and initialize the verification tests against the NEF API emulator and/or the CAPIF tool, which were analyzed in the previous section.

Whether the NetApp passes or not all the stages from the verification module, the developer will receive a report including details and justification whether the NetApp has passed or failed. After the successful completion of the verification steps, the CI/CD will automatically trigger an action to create a binary for the NetApp to be uploaded to the Open Repository. The NetApp will be then procced to the next step which is the Validation phase.

6. VALIDATION ENVIRONMENT

6.1. OBJECTIVES

The objective of the Validation is the evaluation of the correct functionality of the NetApp when it is being used in conjunction with a vAPP in a controlled environment that emulates the conditions of the real operating environment. This assessment includes both the correct operation of the NetApp as well as the performance obtained based on several KPIs of prime interest for the Vertical.

In order to achieve these objectives, a series of Test Cases targeting the main KPIs for each NetApp will have to be defined along with corresponding deployment Scenario which includes configuration parameters for the underlying 5G Infrastructure. More information on the methodology used in this phase can be found later in this section.

6.2. ARCHITECTURE

For the implementation and execution of the Test Cases, the Open5Genesis framework will be used both in Athens and Málaga platform, given that it is tailored for the execution of Test Cases based on the 5GENESIS Experimentation Methodology. This framework will be extended and adapted for the particular needs of the NetApp Validation process as part of the EVOLVED-5G project. The general architecture of the framework can be seen in Figure 19, and it is briefly described below.

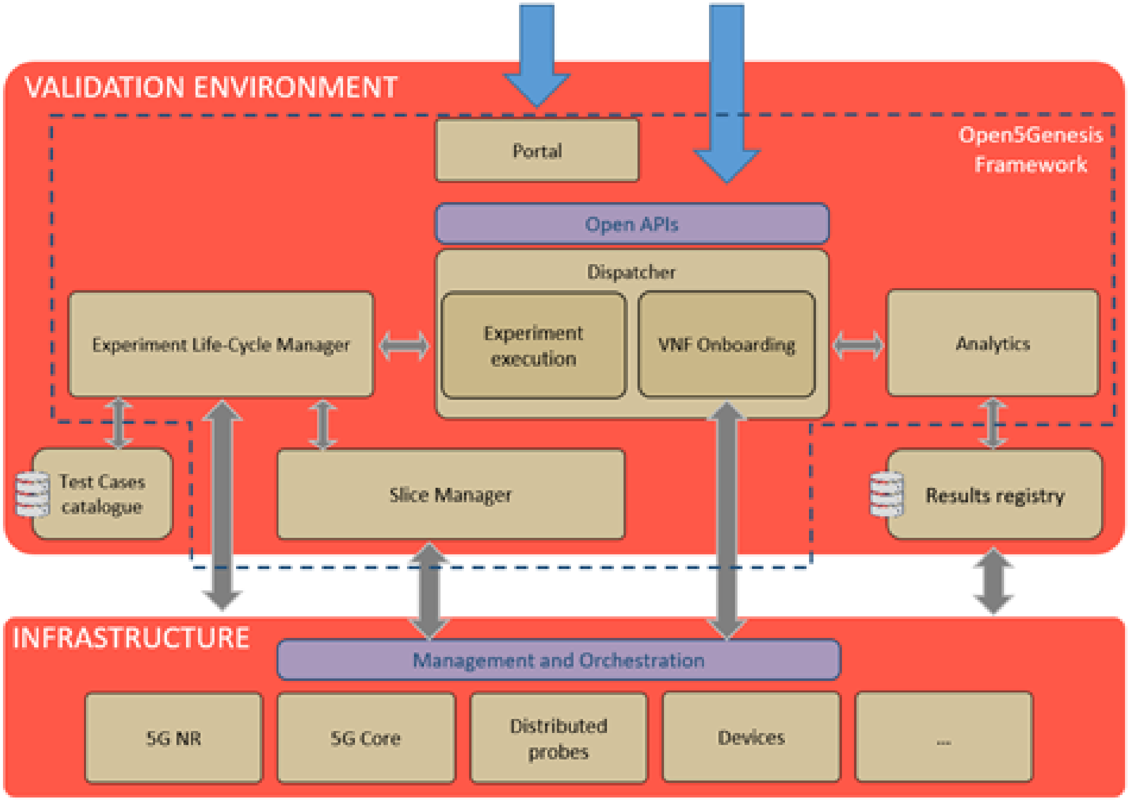

Figure 19: Validation Environment Architecture

The entry point to the Open5Genesis framework is the **Dispatcher**, which is the entity that performs the authentication of users, the validation of the experiment execution requests (known as the Experiment Descriptors), and the onboarding of the different Network Service artifacts, in order to make them available for deployment during the execution of the experiments.

On top of this component, two ways for accessing the platform are supported: The Open APIs, which are implemented directly in the Dispatcher and provide access via a REST API, and the Portal, which leverages the use of the Open APIs with additional functionality to provide a graphical user interface for experimenters. More details about the Dispatcher, Portal and Open APIs are available in Deliverable D3.8 of the 5GENESIS project[24].

At this point, we can find two adaptations that are expected to be performed as part of the EVOLVED-5G project:

1 The 5GENESIS Portal is not adapted to the specific details of the NetApp Validation. For this reason, a different interface will be developed for the Vertical, either as a command line interface, a dedicated Web portal or as a separate pipeline in the CI/CD services.
2 The MANO infrastructure used in 5GENESIS is based on the use of VNFs, while the NetApps will be deployed using containerized applications. For this reason, a container orchestration system will be made available to the Platforms for use during the Validation. Nevertheless, the existing VM based functionality will remain available if needed, for example for the deployment of the Vertical App.

Specific details about the implementation of a particular Test Case are recorded in the Test Cases Catalogue (also known as the “Platform Registry”). This entity contains the specific actions and configurations to be used in each step of the Test Case sequence.

The execution of the experiment is coordinated by the Experiment Life-Cycle Manager (ELCM). This entity is able to coordinate the concurrent execution of experiments, making use of multiple kinds of scripts and plugins that control the different applications and specific components of the testbed. More information about this component can be seen in Deliverable D3.16 of the 5GENESIS project[25].

All the results obtained by the distributed probes within the testbed as well as potentially by those generated from the NetApp or the Vertical App are stored in the Result Registry. These raw results can be analyzed and processed for obtaining the KPIs required for the NetApp Validation. These results will be used for the creation of a Validation Report that will be made available to the Vertical.

More information about the methodology and the architecture of the Open5GENESIS framework can be seen in Deliverable 2.4 of the 5GENESIS project[26].

6.3. Process Design

The Validation process consists of several processes along with their expected inputs and outputs which can be seen in Figure 20, along with their expected inputs and outputs. A brief l description of the different phases can also be found. below.

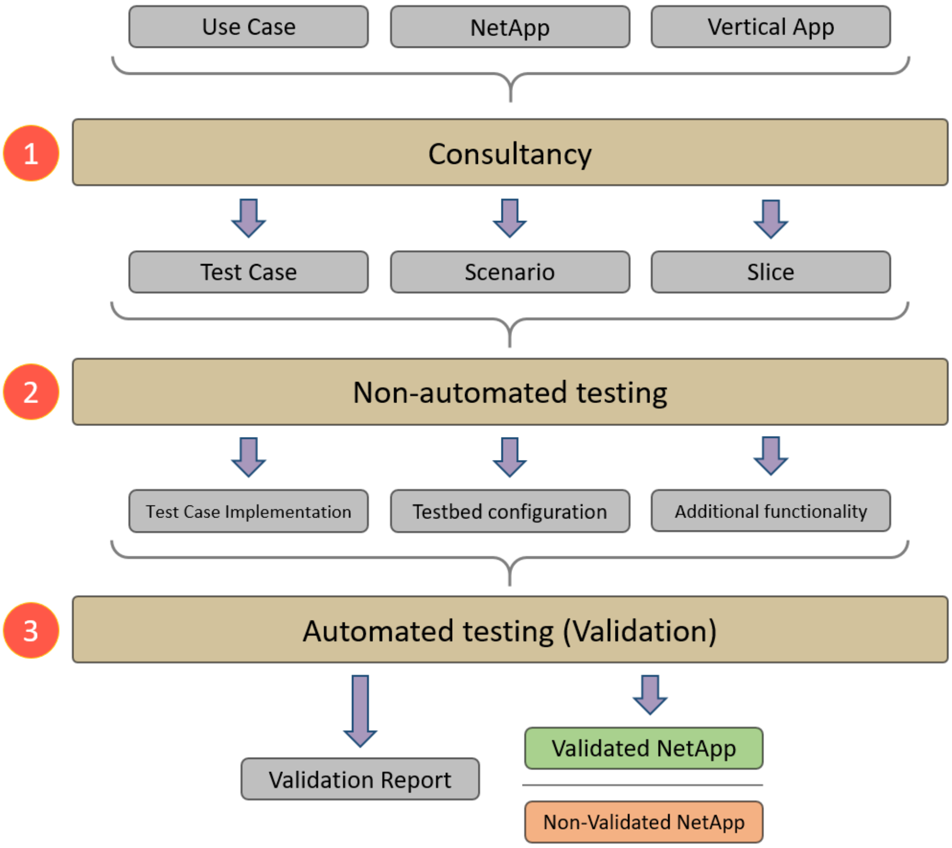

Figure 20: Validation Process

1. **Consultancy process**: Initially a consultation process takes place, involving the Vertical and the operators of the platform where the Validation process will take place (the Platform Operators). During this process, the scope and the details of the Validation are discussed between both parties, in order to reach an agreement regarding, among others:

- The set of NetApp and vAPP functionality that will be tested, and the KPIs that will be measured as part of the experiment(s).
- The deployment of any additional devices or equipment within the premises of the Platform and the deployment or access to the Vertical App during the experiment.
- The control and measurement interfaces to be used, for any of the devices and applications that are part of the experiment.
- The methods for retrieving and/or calculating the required KPIs.
- The sequence of actions that are part of the experiment (the Test Case), the radio conditions to use (the Scenario) and the end-to-end resources reserved for the system under test (the Slice).
- Any other business or security details.

2. **Non-Automated Testing process:** Once the details of the Validation process are defined, both parties work on the implementation of the Test Case, possibly implementing any additional functionality that may be required or re-using existing features of the Platforms. During this process:
   - The Required devices and applications are deployed in the Platform.

- If necessary, new scripts or plugins are developed for controlling, or existing functionality is configured for working with any of the required components.
- Initial (manual) tests, in order to confirm the correct functionality of each of the components involved in the Validation, are performed.
- The different steps of the experiment are automated or, if not possible, added to the set of pre-conditions that must be prepared before the execution of the Validation.

3. **Automated Testing process**: Finally, once all the required functionality is confirmed to work, the Vertical and the Platform Operators agree on a timeline where the experiments will be performed. During this period:
    - The Platform Operators prepare the environment for the execution of the tests (the pre-conditions). This includes the activation and setup of any device or application required, in order to ensure that it is available, and the configuration of the 5G infrastructure with the parameters agreed for the experiment (the Scenario and the Slice).
    - The Vertical initiates the automated experiment execution, which can then be repeated as many times as needed during the allocated period and receives a Validation Report that includes details about the performance of the NetApp and the agreed set of KPIs.

6.4. Methodology

The methodology used for the Validation phase in EVOLVED-5G project will be primarily based on the Experimentation Methodology that has been defined by the 5GENESIS project[5], which states a modular approach that includes at least the following interlinked fields:

- Experiment description
- Test case description
- Scenario identification
- Slice template

Experiment description. Information required to uniquely identify an experiment. Each experiment shall include combinations of at least the following mandatory fields for the experiment, namely, the test cases, the scenarios, and the slice.

Test case description. The test case includes information which is related to the configurations of the experimentation infrastructure needed for receiving the measurement(s). The KPI definition, the measurements methodology and the information for the equipment preparation are added in this field. More precisely, a test case provides the following info:

- *Target KPI*. Each test case targets a single KPI. Secondary/complementary KPIs could also be defined as complementary measurements (see below). The definition of the main KPI declares at least the reference points from which the measurement(s) will be performed, the underlay system, and the reference protocol stack level. The physical formula, the unit, and the type of the KPI as defined in 3GPP TS 28.554[27] are included here.
- *Complementary measurements*. A secondary list of KPIs useful to interpret the values of the target KPI. Getting these measurements is not mandatory for the test case. However, allows for test cases that, besides the target measurement, provide an

additional set of results useful for analysis and interpretation of the relation between different KPIs

- *Pre-conditions*. A list of test-specific information about equipment configuration and traffic description. Also, precise description of the initial state of the system under test, required to start executing a test case sequence.
- *Test case sequence*. It specializes the set of processes needed for executing the experiment in the selected underlay system.
- *Methodology, calculation process and expected output*. The experimenter shall provide the acceptable values for variables that affect the testing procedure, as the monitoring time, the iterations required, the monitoring frequency, etc. In addition, the units that shall be used in the measurements and, potentially, a request for first order statistics (Min, Max, etc.) of the target KPI measurement.
- *Applicability*. A list of features and capabilities which are required by the system in order to guarantee the feasibility of the test.

Scenario identification. The scenario includes information which is related to network, service and environment configurations and it is specific to the selected technologies and the target system. From the performance perspective the scenario quantifies the parameters that affect the values of the KPIs to be measured. More precisely, a test case that targets a specific measurement can be set for different scenarios that declare parameters such as the network slice characteristics, network configuration parameters (e.g., the level of the transmission power in a base station), mobility aspects (e.g., the mobility of the end devices), the network status (e.g., the traffic load in the system), etc.

Slice template. A slice defines the set of end-to-end resources that are reserved in the 5G infrastructure for a particular system under test. A specific slice template hasn't been defined but instead the Slice Manager uses a Generic Slice Template (GST)[28] which has been defined by the GSMA[29]. The Generic Slice Template (GST) is a set of attributes that can characterise a type of network slice/service and is not tied to any specific network deployment. The attributes and their values are assigned to fulfil a given set of requirements derived from a network slice customer use case.

7. Certification Environment

7.1. State of the Art in Mobile Telecommunications

A broad set of certification schemes exist for products, systems, solutions, services, and organizations. Certification is the means to promote excellence through adherence to the identified best practices per case, as well as, to ensure the appropriate security and transparency in alignment to regulations set by the market and governmental administrations.

For the equipment industry, apart from the vendors' internal conformance testing practices, specific regulations apply per target market. In Europe, with DECISION No 768/2008/EC of the European Parliament[32] and the aspiration for the 'EU single market for goods', the European Commission's main goal is to ensure the free movement of goods within the market, and to set high safety standards for consumers and the protection of the environment. To achieve this the Blue Guide[38] sets the framework focusing on non-food and non-agricultural products, referred to as industrial products or products whether for use by consumers or professionals, and serves as a guide for the member states on harmonizing obligations of product manufacturers, distributors, importers and authorized representatives. Especially in Sections 4, 5 of the Blue Guide, the product requirements and conformity assessment are set, with special care on the CE sign, mandatory for the products in the EU market.

In the mobile telecommunications domain, certification for the radio equipment and user terminals has been a fundamental practice driven not only by the practical interoperability and compliance mandates of the operators, but also by strict regulation obligations with main concern on the public health and environmental protection. The RED 2014/53/EU (RED[39] establishes a regulatory framework for placing radio equipment (including airborne, marine and other radio applications) on the market by setting essential requirements for safety and health, electromagnetic compatibility, and the efficient use of the radio spectrum, including technical features for the protection of privacy, personal data and against fraud. Furthermore, additional aspects cover interoperability, access to emergency services, and compliance regarding the combination of radio equipment and software. The conformity assessment procedures are defined in the Annexes III and IV of the European RE Directive 2014/53/EU (RED) and typically involve an accredited third-party test laboratory and third-party certification body, such as Telefication[40]. Furthermore, PTCRB is a certification program established in 1997 by leading wireless operators to define test specifications and processes to ensure device interoperability on global wireless networks. Especially for the mobile User Equipment (UE), the appropriate conformance testing is specified by 3GPP WG RAN5[35] and the certification process is performed by the Global Certification Forum (GCF)[37].

In the Information Communication Technologies (ICT) domain, conformity with international standards such as ITU Recommendations is one of the core principles underlying the global interoperability of ICT networks, devices and services. ITU has taken action to achieve the interoperability of ICTs globally (according to international ISO/IEC standards) through the Conformity and Interoperability (C&I) Programme[41] that organizes in four pillars the basic concepts, practices and relevant standards and incorporates the ITU Product Conformity Database.

It is therefore evident, that the components of the EVOLVED-5G blueprint that relate to equipment (either end-user or network products) have a set background on the proper compliance with standards and regulations as already referenced. As the technology evolution moves functions to the software layer through virtualization and allows for open and dynamic composition of network services, extending capabilities to the business through the NetApps concept, the established certification practice in the mobile network business needs to extend beyond the current practice and include supplementary software specification conformance and quality assessments.

7.2. EVOLVED-5G CERTIFICATION PROCESS DESIGN

In the following paragraphs, it is set the perceived certification framework to accomplish the above objectives, aligned with the existing best practices and in accordance with the identified stakeholders and processes.

7.2.1 Key Stakeholders

EVOLVED-5G has explored the best practices for the certification process in order to devise the recommended approach. As NetApps certification is corresponding to software product quality, SQuaRE (System and Software Quality Requirements and Evaluation) that is part of the ISO/IEC 25000 series[31] with the goal of creating a framework for the evaluation of software product quality, is considered a valid methodology to follow. Even more, SQuaRE involves a stakeholder ecosystem aligned with the current equipment-oriented certification framework, in this respect facilitating the adaptation with minimum interventions. In an overview, the following actors are involved:

- **Organizations interested** in the evaluation, for improvement and certification of their software products. They can be the product's developers or companies interested to acquire a software product.
- **Certification/Audit/Accreditation Body**, responsible for awarding certificates for software product quality. The Accreditation Body has an established internal regulation for software product certification, so that by reviewing an evaluation report issued by an accredited laboratory and auditing the company that develops the product at their premises, to be in the position to issue a certificate specifying the quality level of the product. Accreditation bodies operate in accordance with ISO/IEC 17011 that specifies the general requirements for the assessment and accreditation of conformity assessment bodies and for the peer assessment of accreditation bodies for mutual recognition arrangements.
- **Accredited software product quality evaluation laboratory**, an external entity capable of providing an independent evaluation. The independent laboratory provides to the certification body the evaluation reports made, as an input to the certification process. The technical competence of the laboratory must be confirmed through relevant accreditation (according to ISO/IEC 17025) so that to guarantee the reliability of the evaluation results. ISO/IEC 17025 is useful for any organization that performs testing, sampling or calibration including all types of laboratories, whether they be owned and operated by government, industry or, in fact, any other organization[33].
- **Expert consultants in software quality**, either internal or external experts, employed by the organisations interested, to assure the quality of their software products before the execution of the certification process.
- **Companies developing tools for software product measurement:** Measuring tools are an important mechanism for the expert consultants and the accredited laboratory to evaluate, improve and certify the quality of software products. The companies

developing such tools must follow the specifications and be in alignment with the measurements and thresholds set by the evaluation laboratory and the certification body.

7.2.2 Certification Life Cycle

The Certification Life Cycle involves primarily a Certification-Creation life cycle where the proper definitions and certification artefacts are set in place, including the preparation of the audit list and execution environment, and the certification execution cycle that shall be activated upon each request for certification. A high-level sequence diagram for the perceived steps is presented in Figure 21 below.

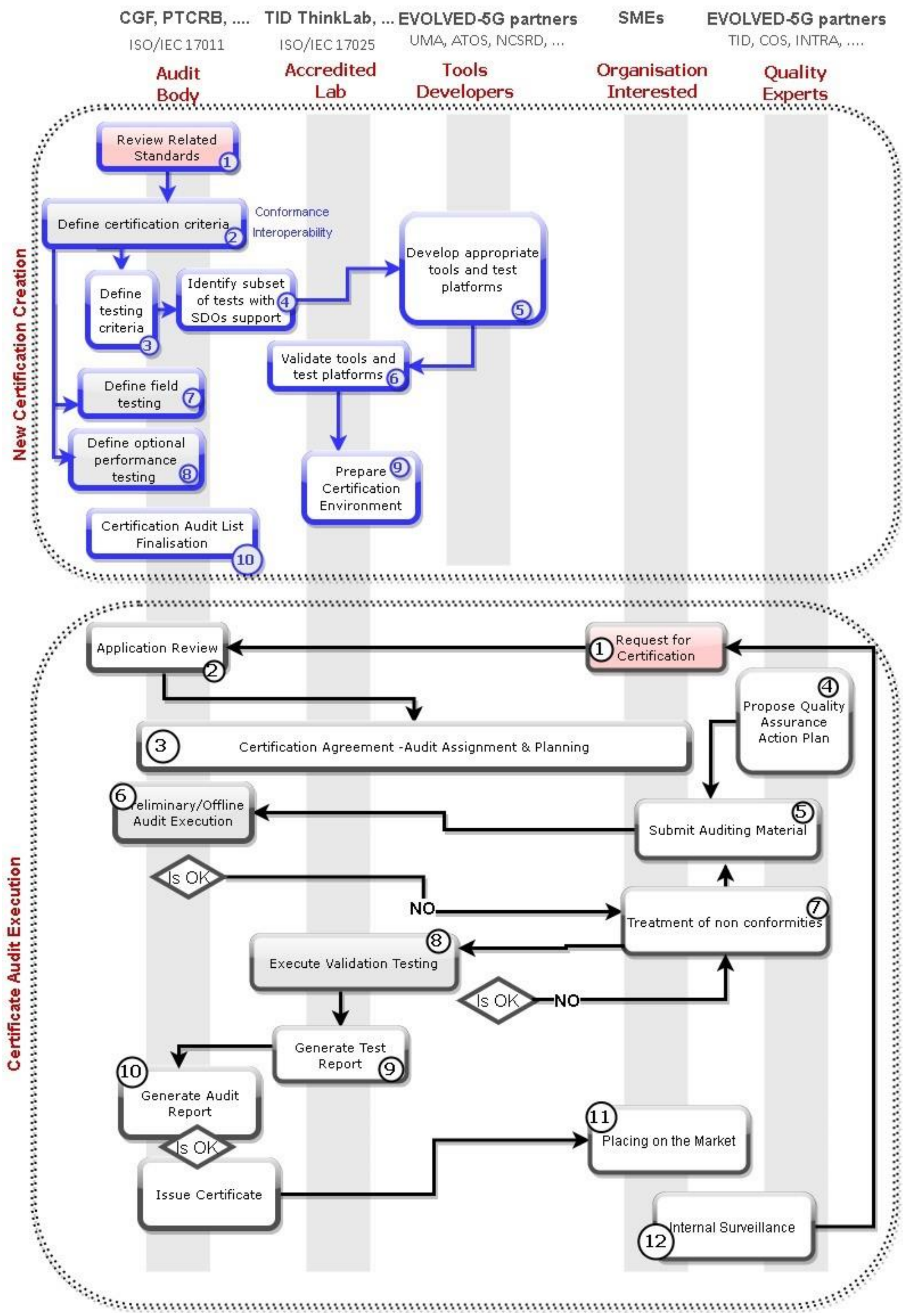

Figure 21: Certification Process Sequence Diagram

7.2.3 Certification Creation Process

The NetApps' certification creation process encompasses all preparatory actions that need to be put in place to ensure the validity of the certification execution and is considered a key delivery of Task 2.4. As part of the creation process the fundamental considerations are to:

- Deliver a concrete audit checklist so that to support interested partners to ensure that the objectives set for the NetApps certification are met. During this process, the certification objectives must become more specific and the technical evaluation criteria must be specified. On this issue, the resulting analysis is provided in Section 7.3.
- Propose the appropriate testing methodology, framing the certification execution environment for field testing where necessary. This is discussed extensively in Section 7.4.
- Design and implement tools to execute the defined testing methodology in a transparent and repeatable manner, as presented in Section 7.4.1.

7.2.4 Certification Execution Process

Following the appropriate definition of the certification process and the preparation of the execution tools and environment, the certification audit can be executed for each requested NetApp. The execution process, apart from setting the initial contractual agreements to formalise the responsibilities per party, and the submission of supporting material, primarily refers to the audit list evaluation, performed as an automated testing process. In this process, it is possible that several testing iterations shall be necessary to achieve conformance, and findings of the certification process can trigger the software development process, providing concrete feedback on missing capabilities and issues to be treated. In this sense, there is a clear association of the certification evaluation with the verification and validation steps, and even though different they operate with different life cycle and iterations, they can share methodology and tools.

7.3 EVOLVED-5G CERTIFICATION OBJECTIVES & REQUIREMENT ANALYSIS

The purpose of the EVOLVED-5G certification process becomes to build upon the existing status quo in the telecommunications and ICT domain, as introduced above, and increment the certification process with the capabilities seen necessary for the incorporation and interoperability of the NetApps in a 5G SA network. Reflecting on the certification objectives as set for the device and ICT interoperability, as well as the EU Directives regulating market and security considerations, the certification objectives can be classified around the following pillars:

- Software product quality (functional suitability)
- Security, with primary focus on fraud protection and data privacy
- Conformance to market mandates

Decomposing these pillar objectives further, and in accordance with the requirements already set in Section 3 of D2.1[1], we can identify the specific certification criteria, the respective validation criteria and -where applicable- the technical means to evaluate them transparently (i.e. test cases). In the following paragraph the first analysis is presented, that in the course of the project shall be further detailed and fine-tuned based on the project developments.

7.3.1 Software product quality certification & validation criteria

The certification objectives around software quality primarily relate to the NetApps conformance with 3GPPP standards that would allow tight integration and effortless interworking with the 5G SA mobile core networks. Table 1 below analyses the core objectives, key validation criteria and means for verification

Table 1: NetApps Software Certification Objectives and Validation Approach

OBJECTIVE	VALIDATION CRITERIA/Test Cases	VALIDATION MEANS
Compliance with CAPIF	NetApp API Invoker Management Onboard/Offboard	Automatic (Tool-based) tests
	NetApp Security Context setup	Automatic (Tool-based) tests
	API Discover Service	Automatic (Tool-based) tests
	NetApp Event Subscription	Automatic (Tool-based) tests
	Netapp Event Notifications	Automatic (Tool-based) tests
5G Integration	NEF Emulator - APIs Exposure: • MonitoringEvent API (TS 29.522 - TS 29.122) • MoLcsNotify API (TS 29.522) • AsSessionWithQoS API (TS 29.522 - TS 29.122) • AnalyticsExposure API (TS 29.522) • 5GLANParameterProvision API (TS 29.522) • ServiceParameter API (TS 29.522) • LpiParameterProvision API • AKMA API (TS 29.522)	Automatic (Tool-based) tests
Documentation quality	The NetApp software package needs to be properly accompanied by: • Design & Specification Document • Installation Manual • Operational Manual	Manual

In order to provide higher level of transparency the project plans to develop a tool that can evaluate the CAPIF compliance by implementing the 3GPP test cases that can be used to evaluate the validation criteria. This tool shall be hereby called “**CAPIF Core Function**”.

7.3.2 Security certification & validation criteria

The certification objectives around security focus in fraud prevention, considering that the NetApps are hosted, and therefore foreign to the execution environment, software components. In this respect data privacy becomes key, as the NetApps through the interface with the NEF core function can have access to sensitive user data (such as location and user identification).

Table 2: Security Certification Objectives and Validation Approach

OBJECTIVE	VALIDATION CRITERIA/Test Cases	VALIDATION MEANS
Fraud protection	Test data streams to and from NetApp	Manual Tests
	Detailed Logging required	Automatic tools
	Automatic Fraud Detection Tools	Automatic tools
	Continuous Monitoring	Automatic tools
	False Positive Management	Automatic tools + statement form

	End User License Agreement, Accountability	Manual- Statement form
GDPR	Ensure Data Remains Private	Tool-based test + manual test
	Inquire about Data Collection	Manual- Questionnaire
	User must agree to Data Collection	Manual- Statement form
Connection	Ensure Privacy of Connection	Automatic tools

There are two key aspects pertaining to security that the certification process must address. The first aspect relates to fraudulent development and usage of a NetApp. In order to safeguard users against malicious NetApps, as well as provide a degree of reliability in the usage of a NetApp, validation must address data streaming to and from the NetApp. To this end, manual testing of data collected and generated from the NetApp must be tested and explained why they are necessary for the operation of the NetApp. Furthermore, automatic tools ensuring accurate logging of operation events must be developed, as well as monitoring of NetApp activity. Automatic Fraud Detection tools that exist in the literature are a good candidate to incorporate in the certification process of a NetApp. Finally, the validation process must address false positives in fraud detection, providing an agreed-upon degree of "acceptable false-positive rate", as well as ensure the existence of a fair EULA for proper NetApp usage and accountability in case the NetApp proves malicious.

The second aspect relates to complying to GDPR. NetApp developers need to provide detailed, accurate records of data collected by the NetApps, inform potential users and require user consent to the aforementioned data collection. Succeeding in this, the NetApp must be thoroughly tested through automatic tools, as well as manual tests for more irregular cases, to ensure that the collected data, as stated by the developer, remains private knowledge to the NetApp and is not shared to any unauthorized third party.

Another concern for the security of a NetApp pertains to the safety of communication between the NetApp and its connected entities. On the transport layer, standard tests validating adherence to the SSL protocol must be included in the certification process, as well as tests on other layers where communication takes place involving the NetApp.

7.3.3 Marketplace certification & validation criteria

Since the Marketplace inherently is a platform that acts as the final stage of commercializing the NetApps and the relevant Telecommunication services, needs to act as an aggregator of all the available certification results provided by the NetApp developers and some additional items that are needed to certify that the services published comply with the Marketplace policy.

The certification objectives around the marketplace compliance are related to the NetApps conformance with Legal requirements and Terms as well as to the content and the metadata validity that the NetApp developers are uploading to the platform.

Table 3: Marketplace Certification Objectives and Validation Approach

OBJECTIVE	VALIDATION CRITERIA/Test Cases	VALIDATION MEANS
Use Policy/Terms of service/ License files	End User Use Policy and Terms of Service	• Manual - Statement form • License file
Open Source Scan Report	Identifies and catalogs all third-party software components, associated licenses	• Automatic tools

Valid Container Image and/or Endpoint details	Ensure binary Container file is valid/Ensure endpoints are working properly	• Automatic tools

In order to achieve the certification objectives of the Marketplace specific actions are needed during the registration and sign up of the Marketplace user and at a later stage during the procedure of on-boarding NetApps and services.

For that purpose, a specific module will be implemented which will handle all the procedures and actions needed for the certification. The Certification/Validation Management module should also interact with the Certification Environment to collect all the necessary information. This information should be either stored in the Marketplace or provided as links to relevant data.

7.4 Certification Environment Reference Architecture

Evolved5G Certification Environment is assisting the execution of the Certification Phase. This phase will be ignited by NetApp developers once they have validated their NetApps. In terms of Architecture, the Certification Environment is based on CI/CD tools complemented with specific certification tools developed for this purpose, such as the NEF Services for NEF compliance and CAPIF Core Services for CAPIF compliance.

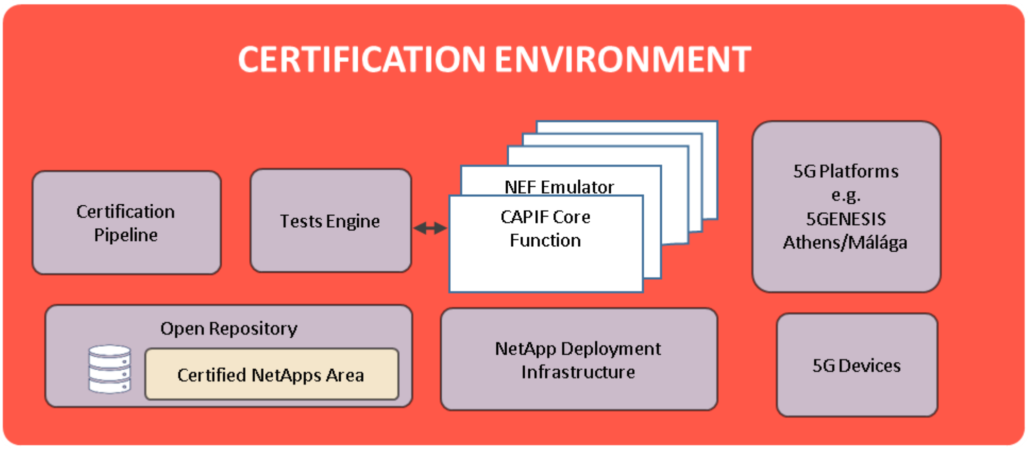

Figure 22: Certification Environment Architecture

From the architectural point of view, The Certification environment, displayed in Figure 22, includes the following elements:

- Certification Pipeline: This pipeline orchestrates the whole certification phase and automates all steps towards the completion of the tasks. The certification pipeline considers the automation to be integral for the execution of the tests and therefore leverages CI/CD capabilities. Evidently, some of the tools introduced as part of the Workspace, will be included to assist the certification pipeline. Technically the pipeline refers to the:
    - Infrastructure Deployment Automation: Certification pipeline will automatically build the required container infrastructure to deploy the NetApp over the container enabled infrastructure.
    - Automatic Software Installation and Configuration: Certification pipeline will configure the NetApp automatically and the rest of the elements involved in the certification tests.

  - Image Builder as the final step of the certification pipeline will be to build the Containerized image of the NetApp for deployment over a Container enabled infrastructure.
- **Open Repository**: this repository serves two purposes; as input, the open repository is the source of validated NetApps that can go through the certification process. As output, once the Certification is complete, the certification pipeline will upload the certified NetApp to the certified area of the open repository.
- **Test Engine**: Certification phase comprises a set of tests to be performed over the NetApp. These tests will be triggered by the certification pipeline and will use a test engine that will execute the tests and report the results. Tests will cover several aspects in regard to the functionality of the NetApp such as API Compliance (NEF and CAPIF), Security Tests, Licensing test etc., discussed in 7.4.1
- **NetApp Deployment Infrastructure**: during certification process, the NetApp will be deployed and instantiated in container infrastructure. This infrastructure will be connected with the elements that are deployed remotely, namely the NEF Services, Málaga and Athens 5G platforms.
- **5G Devices**: Devices connected using 5G will be required so as to interact with the NetApp depending on the use case, the vAPP and the overall functionality of the NetApp.

All test reports will be consolidated and reported as part of the Certification phase. If a NetApp successfully complete this phase, it will then be uploaded to the Certified area of the Open Repository.

7.4.1 Certification Tools

The tools involved in Certification refer to the evaluation tests that can be executed systemically and in an automated manner. These are the following

- **NEF Services**: This services, which are described in section 4.1.1, that will be used as a core validation tool, are also relevant for the evaluation purposes of the certification and will be used to certify the proper interaction of the NetApps with the exposed yet emulated NEF services.
- **CAPIF Services**: These services will be developed in Evolved5G specifically to enable compliant use of CAPIF APIs by NetApps. CAPIF Services Endpoint will implement the set of 3GPP APIs described in Section 4.1.2 and will verify that NetApps consume these APIs properly. CAPIF Services will audit the proper usage of CAPIF APIs and provide audited information of APIs, methods, headers, Information Elements, and error codes used between the interaction of the NetApp and CAPIF.
- **Security Tools:** These tools will be used to help protect sensitive information and overall performance. They are designed to protect data from intruders by analysing network traffic and identify potential problems. These are the following:
  - **Wireshark:** Wireshark is a network packet analyser, used for network traffic analysis. It has many uses, including troubleshooting networks, trace connections and view the contents of any package.
  - **Metasploit:** Metasploit is a tool that provides information about systematic vulnerabilities on networks and servers. It includes modules that can perform scanning, fuzzing, sniffing etc.
  - **Nessus:** Nessus is a remote scanning tool, that raises alert if discovers any vulnerabilities. Examples of vulnerabilities Nessus can scan include

vulnerabilities that could allow unauthorized access, misconfigurations, default or common passwords, denial of service vulnerabilities, etc.

- **Licence Compliance Tool:** This tool will be used to automate the license compliance processes. The Debricked tool[42] will be used for this purpose as it makes open-source management an easy task. This tool can be integrated in the CI/CD process of the development, export a license report to share with relevant stakeholders and keep track of the compliance progress over time.
- **Container Image Validator:** Chef InSpec[43] is an open-source testing framework for infrastructure with a human-readable language for specifying compliance, security and other policy requirements. While InSpec is used primarily to test security configurations it is well suited for acceptance testing as well. Integrating InSpec with Packer you can verify that the configurations applied (builders) by Packer are getting applied, and that you can guarantee an image built with a process meets a base level of acceptance.
- **Container endpoint Health check:** This tool will be used to provide a validation of the health status of the Docker container. This tool will be developed using custom command scripts through the HEALTHCHECK command in the Dockerfile.

7.4.2 Certification Execution within EVOLVED-5G

As already highlighted in Figure 22, there is a clear association of the EVOLVED-5G project and partners' role in respect to the underlying certification stakeholders' ecosystem. More specifically, EVOLVED-5G plans to support existing audit bodies with the audit list suitable for the formal certification of the NetApps, but can't undertake this role, due to lack of the appropriate accreditation.

Similarly, EVOLVED-5G can prototype the target execution environment for the certification validation based on the existing 5GENESIS infrastructure, but it can't offer accreditation lab services as necessary accreditation is not available in the 5GENESIS platforms. Note that the certification's environment configuration and setup, together with the tools developed by the project for the certification and validation tests, can be provided by the EVOLVED-5G project partners to the accredited labs that wish to instantiate a relevant environment during the New Certification Creation process cycle.

Finally, it is noteworthy that the certification execution environment for EVOLVED-5G is treated as an isolated environment from the EVOLVED-5G validation environment, that can be nevertheless share infrastructure and utilities, if need be, but under different configuration and provisioning setups. The main reason is that while the validation process is a rigorous process that follows each minor NetApp software update, the certification process shall need to be executed rarely, upon very specific recommendations and mandates (for example periodically so that to be re-enforced, or upon major software releases as documented during the certification execution process). Potentially loose integration between the validation and certification environments and optimizations through the utilization of same automation tools (like a CI/CD framework) can be considered, as long as the lifecycle of each process is not intervening with the other.

8 The Marketplace

8.1 Status and Evolution in Telecommunications Market

The Telecommunication services industry is under continuous stress to react to changes driven by a new reality of open ecosystems and the evolution of 5G towards next generation[46]. On the other hand, this new reality introduces some opportunities that will enable the Communication Service Providers (CSPs)[47] to introduce new revenue streams and monetize their existing assets and services easily and effectively.

Hyperscale Cloud Native[48] services and technologies are available and widely adopted as some basic operations of a CSP, like network virtualization and orchestration software, can now be built on a container-based micro-services architecture. In addition, open-source initiatives[49][50] are moving towards microservices and containers using open APIs.

In order to achieve that the CSPs need to adapt a Software Defined Architecture and create platforms exploiting all these available technologies. CSPs are not eager to provide competitors with physical networks without finding a new way to protect and expose their value. They can do this as providers of not only connectivity, but also networking and operations assets, management capabilities and perhaps most importantly data.

Verticals play a key role in 5G ecosystems as innovation enablers and most of them[51][52] want to reach their customers digitally, either through their own web portals, a partner's platform or a broader marketplace. In all cases, connectivity is required to link end users with developers (I.e., buyers/consumers and sellers/publishers respectively, if we use a classic term in marketplaces methodology) and the supply chain in between. These are some of the reasons for operators to strongly consider new business models including marketplaces.

8.2 Objectives

The EVOLVED-5G Marketplace will provide the means for enabling the digital market around the NetApps i.e., maintain an active marketplace/App store that will store NetApps that are certified by operator-driven certification tools. In order to achieve that, the EVOLVED-5G Marketplace will be driven by the following main principles, implementing the requirements discussed in D2.1[1]:

1. Implement a Vertical Marketplace targeted to Telecom (5G) APIs and Services and more specifically:
    - NetApps.
    - Pre-configured slices.
    - Other services (To Be Defined).
2. Adapt a Service as a Product (SaaP) model where a Productized Software Service is sold by the seller/vendor to the buyer and is centrally hosted.
3. Initiate Dynamic service execution in the Open Repository upon settlement completion.
4. Support the interface for deploying Smart contracts on a Blockchain platform.
5. Exploit the knowledge by supporting a community/forum of NetApp developers.

8.3 ARCHITECTURE

The architecture of EVOLVED-5G Marketplace will be using parts of the TM Forum Open Digital Architecture (ODA)[44] framework architectural blocks and custom blocks in order to fit the EVOLVED-5G architecture. Having review similar marketplace implementations, such as the one provided by MARKET 4.0[53] project, EVOLVED-5G marketplace architecture borrows some common design decisions, which reassure the compliance of it with compensated initiatives, like DOME 4.0[54], which augment the operations and effectiveness by adding value to each individual marketplace, data repository and platform. Moreover, EVOLVED-5G marketplace will incorporate Business use cases and scenarios as well as integrate additional functionality defined by the project scope.

Therefore, the architecture EVOLVED-5G has proposed for the Marketplace implementation is depicted in the following Figure 23:

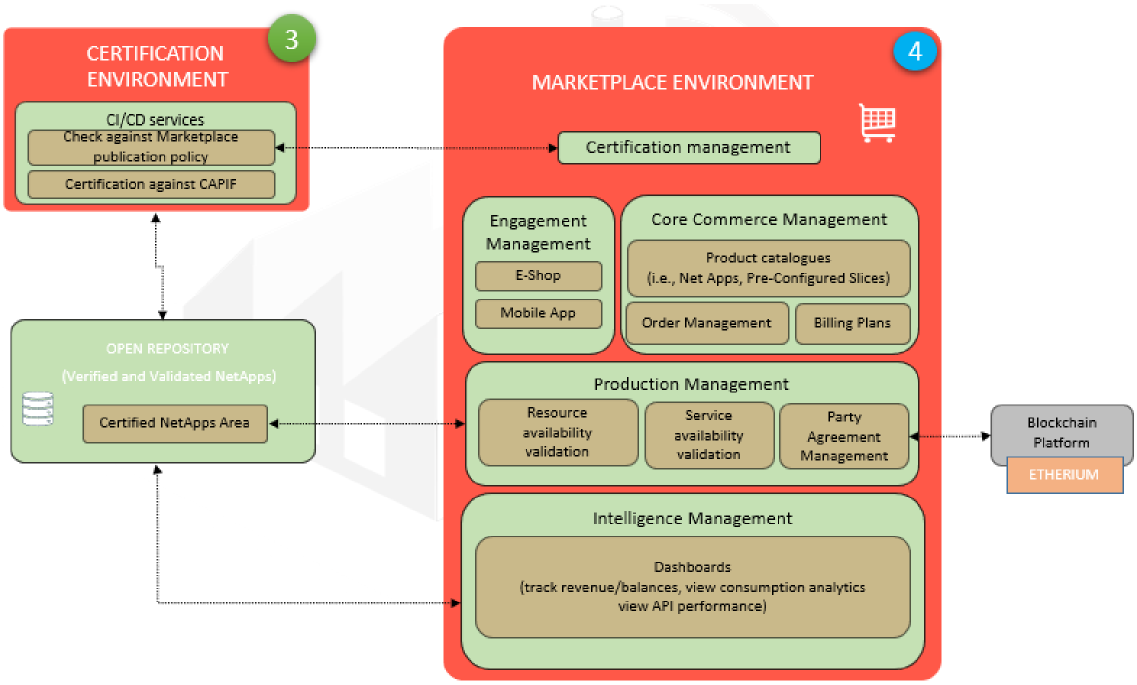

Figure 23: EVOLVED-5G Marketplace Architecture

The following blocks are implementing the functionality of the Marketplace itself and the interoperability of the Marketplace with the other EVOLVED-5G components (Certification environment, Open repository):

- **Engagement management:** This functional block implements all the user interfaces to enable the users of the Marketplace through different channels (E-shop, Mobile App, bots, etc.). In the context of the project only the Web interfaces will be implemented.
- **Certification Management:** This block implements the procedure to certify the service published against the rules of the Marketplace. These rules may include the following parts:

- Results of the validation/certification phase.
- Conformance with GDPR.
- Privacy Statement
- License documentation and Legal conformance
- User Documentation of NetApp.
- NetApp metadata.

- **Core Commerce Management:** This block implements the core functionality of the Marketplace. The main functionality may include:
  - Product catalogues
  - Onboarding and Order Management
  - Billing plans templates
- **Production Management:** This block enables the final stage of Commerce in order to productize the available services, APIs and NetApps including:
  - Party Agreement Management through a blockchain platform
- **Intelligence Management:** This block implements Dashboards for developers and end users of the Marketplace to track (virtual) revenue/balances and view consumption analytics.

All the above functional blocks are loosely coupled and integrated in order to enable scalability.

8.4 Marketplace Process Design

Following the Architecture block diagram of the Marketplace two basic user workflows are defined as follows:

- **Service provider Workflow:** This flow describes the steps that a developer will follow in order to distribute a NetApp through the Marketplace, it can be seen in Figure 24.
- **Service consumer Workflow:** This flow describes the steps that an end-user will follow to *purchase* a NetApp through the Marketplace, it can be seen in Figure 25.

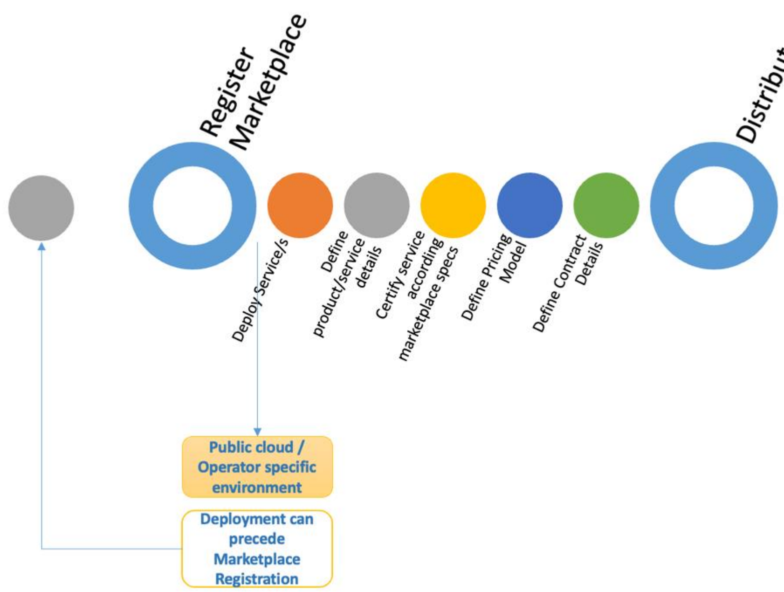

Figure 24: Service provider Workflow

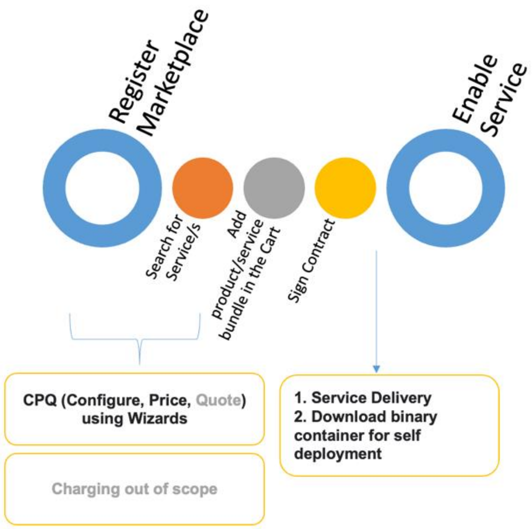

Figure 25: Service consumer workflow

Some key features that are essential for the Marketplace and will be incorporated in the process are the following:

- **Detailed Product Description:** EVOLVED-5G marketplace will host many NetApps from different pillars, so the "products" themselves vary. Having detailed descriptions will help end users navigate and make decisions easier with more information about every NetApp provided.
- **Advanced Filtering:** A search functionality is vital for digital marketplaces for end users to find the NetApps they want. Narrowing the scope of what they are searching for will make the process of *shopping and buying* much easier.
- **Product Catalogues:** A detailed and well-maintained product catalog can help the potential end user understand, correctly choose a NetApp according to their needs and bundle it with other NetApps and services.

The workflow depicted in Figure 26, depicts a user (either a developer/publisher/seller or end user/consumer/buyer) visiting the EVOLVED-5G Marketplace portal and before registering or logging in they can browse through the contents of the portal and get some information about the EVOLVED-5G project Vision and goal, read the Technical Documentation and How to' s and even take a look in the product catalog to get some idea of the NetApps already published in the Marketplace. Only a high-level description of the NetApps is visible for the not-registered users.

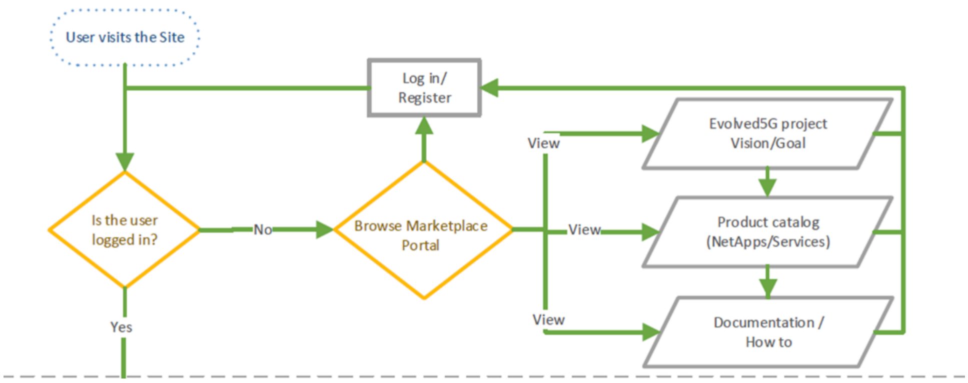

Figure 26: EVOLVED-5G Marketplace portal workflow

After a user register to the Marketplace and logs-in, they can selectively buy or sell a NetApp. For the end-user, the following process will be implemented, as also shown in Figure 27:

The end user can browse the product catalog and find the NetApp he is interested in by applying the search filters. After selecting the NetApp, he can check the details of the service, be informed about the availability and the *pricing*. The *purchase* has been completed after finalizing a theoretical process of payment (ideally implemented virtually, this functionality is out of the scope), signs the blockchain contract and gets the Service Availability Confirmation from the Open Repository. The NetApp is automatically initiated in the Open Repository, and it is ready for use.

Upon completion of the procedure the user can exit the Marketplace or visit the dashboard to get an overview of the already accessed NetApps, where they can view its status, track balances, etc.

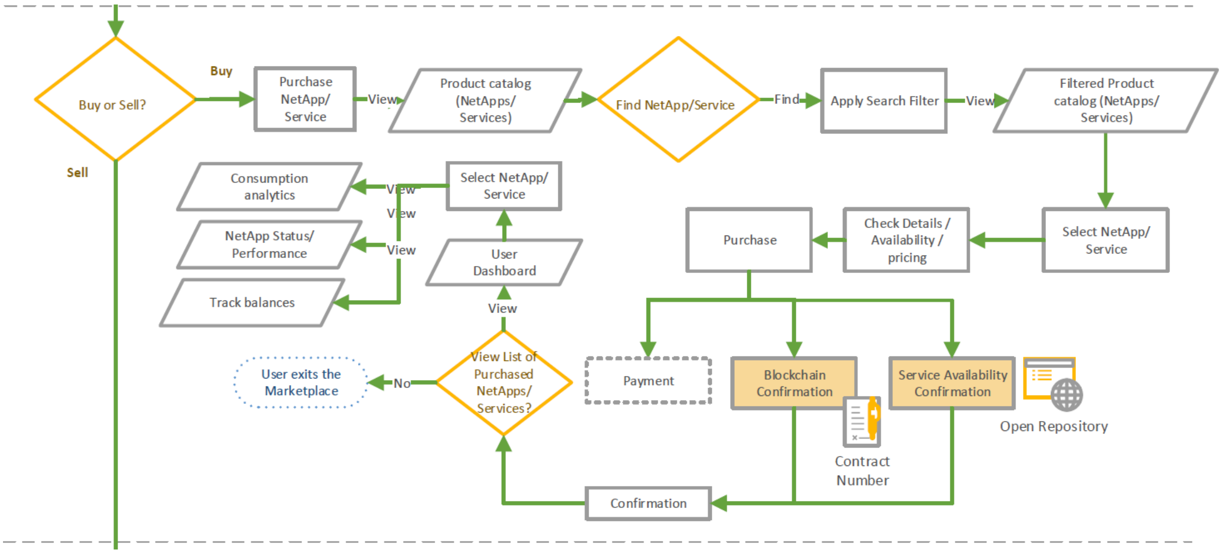

Figure 27: Buyer workflow

For the developer according to their familiarity with the process depicted in Figure 27 will be implemented. A new developer can choose to either go through the documentation or even visit the users' Forum in order to get some insights and follow the publishing process. If they are familiar, then they will be directed to the users' Dashboard where they will be able to complete the publishing of their NetApp.

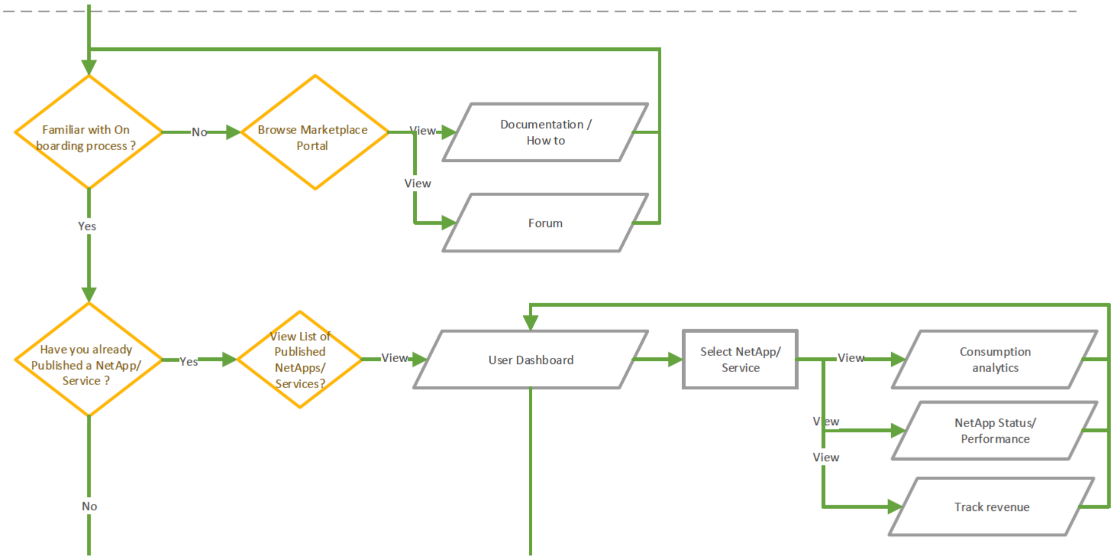

Figure 28: User publishing experience

In order to complete the onboarding of the NetApp, as shown in Figure 29 the developer shall:

- Submit NetApp/Service basic information and metadata
- Check NetApp/Service compliance with Marketplace policy
- Submit NetApp/Service Certification Number
- Submit NetApp/Service link to Certification registry report

If the NetApp is already deployed in the Open Repository the developer shall:

- Submit NetApp/Service Endpoint information
- Submit NetApp/Service Swagger files
- Validate NetApp/Service binary container
- Upload NetApp/Service binary container
- Submit NetApp/Service documentation/tutorials
- Submit NetApp/Service Pricing Scheme

If the NetApp is only provided as a binary container the developer shall:

- Validate NetApp/Service binary container
- Upload NetApp/Service binary container
- Submit NetApp/Service documentation/tutorials
- Submit NetApp/Service Pricing Scheme

After the publication process is finalized successfully the developer gets a confirmation message. Upon completion of the procedure the developer can exit the Marketplace or visit the dashboard to get an overview of the published NetApps. Through the dashboard and after selecting one of the NetApps the developer can view the NetApp Status and performance, the consumption Analytics and track the revenue.

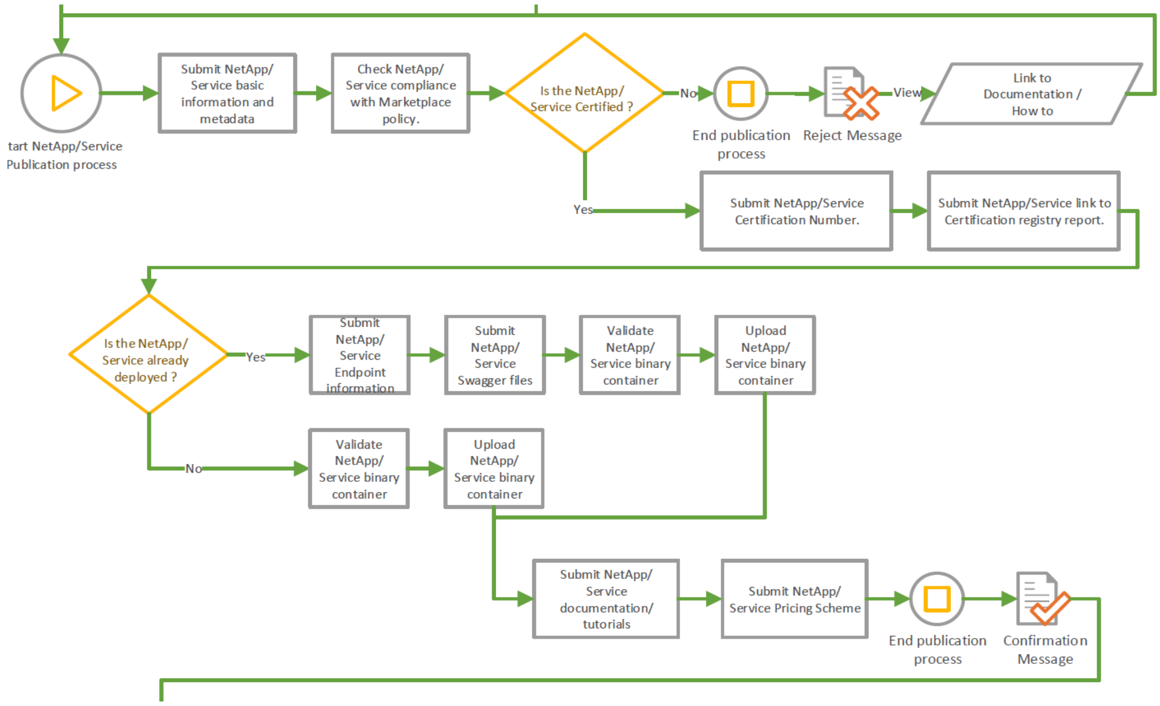

Figure 29: NetApp Service Publication process

9 Conclusion

In this deliverable, we presented a detailed description of the components within the workspace of EVOLVED5G and the validation and certification phase, which constitutes a reference point for the overall technical design, development, and lifecycle of the NetApps. Tasks 2.3 and 2.4 are driving the current deliverable and one of the primary purposes of the specific tasks, during the lifetime of the project, is to tightly interact with WP3, WP4 and WP5 in order to consistently facilitate the development of the NetApps by providing specific tools, as well as to incorporate automation in the experimentation process so as to enable reliable and accurate validation results for the NetApp performance.

To that end, the structuring of the deliverable has been built on basis of the aforementioned aspects. During the first part of the deliverable, the NetApp principles were presented in Section 2. Section 3 provided insights into the NetApp development phase, while in Section 4 a representation of the overall 5GNPN architecture, notably giving a breakdown of this architecture into its major components and their role in the system, has been provided.

Following, in the second part, a dedicated description of the Workspace was given, in Section 5, by a dedicated presentation and analysis of the SDK tools and the components that the project will utilise. The Validation environment was presented in Section 6 illuminating on the various processes to be executed during that phase. In Section 7, the Certification environment was illuminated, from its definition in the context of the EVOLVED-5G to the specific process to be followed during the certification phase. Lastly, Section 8 embraces the final part of the NetApps service chain, namely the Marketplace and its functional requirements and characteristics.

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