



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

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Deliverable D2.1

Overall Framework Design and Industry 4.0 Requirements

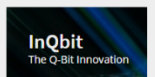
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GLOSSARY

Abbreviations/Acronym	Description
CICD	<i>Continuous Integration/Continuous Development</i>
SDK	<i>Software Development Kit</i>
NEF	<i>Network Exposure Function</i>
FoF	<i>Factory of the Future</i>
AAA	<i>Authentication Authorization Accounting</i>
ROS	<i>Robot Operating System</i>
SaaS	<i>Service As a Product</i>
NetApps	<i>Network Application</i>
SME	<i>Small Medium Companies</i>
vAPP	<i>Vertical Application</i>
NSaaS	<i>Network Slice as a Service</i>
UE	<i>User Equipment</i>
NF	<i>Network Functions</i>
5GC	<i>5G core</i>
SBA	<i>Service Based Architecture</i>
SBI	<i>Service Based Interface</i>
NRF	<i>Network Repository Function</i>
VAE	<i>Vertical Application Enabler</i>
3GPP	<i>3rd Generation Partnership Project</i>
CAPIF	<i>Common API Framework</i>
CCF	<i>CAPIF Core Function</i>
SEAL	<i>Service Enabler Architecture Layer</i>
AEF	<i>API Exposing Function</i>
APF	<i>API Publishing Function</i>
AMF	<i>API Management Function</i>
PLMN	<i>Public Land Mobile Network</i>
VoD	<i>Video on Demand</i>
VAS	<i>Vertical Application Server</i>
CPS	<i>Cyber-Physical Systems</i>
IEM	<i>Interaction of Employees and Machines</i>
eMBB	<i>Enhanced Mobile Broadband</i>
UHD	<i>Ultra-High Definition</i>
URLLC	<i>Ultra-Reliable and Low-Latency Communications</i>
mMTC	<i>Massive Machine Type Communications</i>
5G PPP	<i>5G Public Private Partnership</i>
NR	<i>New Radio</i>
SC	<i>Service Customer</i>
SP	<i>Service Provider</i>
NOP	<i>Network Operator</i>
VISP	<i>Virtualization Infrastructure Service Provider</i>
DCSP	<i>Data Centre Service Provider</i>



D2.1 Overall Framework Design and Industry 4.0 Requirements

GA Number 101016608

MNO	<i>Mobile Network Operator</i>
NPN	<i>Non-Public networks</i>
OS	<i>Operating System</i>
5GS	<i>5G System</i>
PNI	<i>Public Network Integrated</i>
IaaS	<i>Infrastructure as a Service</i>
SEC	<i>Security guarantees and risk analysis</i>
PLI	<i>Production line infrastructure</i>
AMS	<i>Adaptive Management and Security System</i>
LF	<i>Learning Factories</i>
HCI	<i>Human-Computer Interaction</i>
PPE	<i>Personal Protective Equipment</i>
NWDAF	<i>Network data analytics function</i>
DoS	<i>Denial-of-Service</i>

EXECUTIVE SUMMARY

The intense ongoing work towards 5G readiness has reached the point where the performance gains provided by 5G infrastructures should be exploited by third party innovators and SMEs, to create a new, open, and dynamic ecosystem from both technology and marketing perspectives. Towards the materialization of the 5G performance gains at application and market level, key contributions are expected by the domain of design and development of Network Application (NetApp).

EVOLVED-5G endorses this vision through the definition of a NetApp ecosystem and proposes a functional architecture relevant to the implementation of an experimental facility blueprint (The EVOLVED-5G facility), that will provide the tools and the processes for the development and validation of NetApps, as well as any supporting network infrastructure (e.g., a 5G-NPN) and mechanisms for market releasing and collaboration (e.g., a Marketplace).

Based on the facility blueprint, a requirements analysis work is depicted, maintaining a clear separation among:

- Requirements that are fundamental for Industry 4.0 businesses, as expected by the vertical Apps (vApps) and NetApps.
- Requirements that relate to the 5G network infrastructure, relating to both the network equipment, access and core network components as well as the orchestration and monitoring capabilities.
- Physical infrastructure requirements that involve the data center capabilities.
- Requirements related to the NetApps development, validation and testing.

Furthermore, EVOLVED-5G brings innovate Industry 4.0-related use cases that are also defined in this deliverable so as to help understand and visualize the importance of the proposed NetApp ecosystem and the value it will bring.

The designated approach in this deliverable will guide the project towards the realization of the EVOLVED-5G Facility. The definition and identification of core requirements from both the Facility and use cases perspective will also become a common reference for the project and will serve as a fundamental guide for the subsequent specification and implementation activities.

TABLE OF CONTENTS

1	Introduction.....	1
1.1	Purpose of the document.....	1
1.2	Structure of the document.....	1
1.3	Target Audience.....	2
2	The NetApp Ecosystem.....	3
2.1	Background on 5G Openness.....	3
2.1.1	5G Core Programmability and APIs Exposure	3
2.1.2	Common API Framework - CAPIF.....	4
2.1.3	Service Enabler Architecture Layer - SEAL	7
2.2	The NetApp concept.....	8
2.3	NetApps in the Industry 4.0 era.....	10
3	NetApp Deployment and Validation Facility	11
3.1	The EVOLVED-5G Facility	11
3.1.1	The Workspace Environment	13
3.1.2	The Validation Environment	13
3.1.3	The Certification Environment.....	14
3.1.4	The Marketplace Environment	16
3.1.5	The 5G-NPN Environment	18
4	Stakeholders and Roles in the NetApp ecosystem	22
4.1	Stakeholders and Roles in the 5G ecosystem	22
4.2	Stakeholders and Roles in the EVOLVED-5G ecosystem	25
4.2.1	EVOLVED-5G Ecosystem Stakeholders.....	25
4.2.2	EVOLVED-5G Ecosystem Roles.....	26
5	EVOLVED-5G NetApp Ecosystem Requirements.....	29
5.1	The Requirements Gathering Methodology	29
5.2	Business-related Requirements	30
5.3	5G Network Infrastructure Requirements	38
5.4	Compute and Data Infrastructure Requirements	42
5.5	NetApp Lifecycle Requirements	45
6	EVOLVED-5G Use Cases	48
6.1	Industry 4.0 Pillars	48
6.1.1	Interaction of Employees and Machines (IEM) pillar (IMM, INF, GMI-Aero).	50
6.1.2	Efficiency in FoF Operations (FoF) pillar (CAF, ININ, QUCOMM).....	50
6.1.3	Security Guarantees and Risk Analysis (SEC) pillar (8BELLS, IQB, FOGUS).	51
6.1.4	Production Line Infrastructure (PLI) pillar (PAL, UML).	51

6.2	Interaction of Employees and Machines (IEM) Pillar	51
6.2.1	State-of-the-Art and Current challenges	51
6.2.2	The NetApp Opportunity	56
6.2.3	Target Use Cases.....	56
6.3	Efficiency in FoF Operations (FoF) Pillar	61
6.3.1	State-of-the-Art and Current challenges	61
6.3.2	The NetApp Opportunity	63
6.3.3	Target Use Cases.....	63
6.4	Security Guarantees And Risk Analysis (SEC) Pillar	67
6.4.1	State-of-the-Art and Current challenges	67
6.4.2	The NetApp Opportunity	68
6.4.3	Target Use Cases.....	69
6.5	Production Line Infrastructure (PLI) Pillar	71
6.5.1	State-of-the-Art and Current challenges	71
6.5.2	The NetApp Opportunity	73
6.5.3	Target Use Cases.....	73
7	Summary and Conclusions.....	81
8	References.....	83

LIST OF FIGURES

Figure 1. RESTful APIs for the Service Based Interfaces and Northbound communication.....	4
Figure 2. Simplified CAPIF Architecture	5
Figure 3. Third-party Standalone (A) and Non-standalone (B) NetApp representation	9
Figure 4. NetApp's interaction with the data and control plane when a Vertical application is provided	10
Figure 5. The EVOLVED-5G Facility.....	13
Figure 6. Certification's main functional blocks	15
Figure 7. Workflow for the service provider	16
Figure 8. Workflow for the service consumer.....	17
Figure 9. Marketplace framework Interactions	18
Figure 10. Athens platform sites overview	19
Figure 11. OTE Academy Site	20
Figure 12. UMA outdoor deployment estimated coverage around Ada Byron building	21
Figure 13. 5GPPP Target Stakeholder Groups and Stakeholders, April 2020 [10]	23
Figure 14. Stakeholder roles in the 5G ecosystem, February August 2021 [11].....	24
Figure 15. Mapping between stakeholders and roles in the EVOLVED-5G ecosystem	26
Figure 16. Demo Chatbot Interface and Feasibilities	53
Figure 17. Demo remote collaboration from industry employees	54
Figure 18. INF Use Case Schema	56
Figure 19. Demo secure communications IMM use case 1	58
Figure 20. FoF IoT System Architecture	64
Figure 21. FoF IoT System Deployment in 5G-EVOLVED Environment	64
Figure 22. Common workforce Teleoperation	76

LIST OF TABLES

Table 1. Summary table of Roles and Stakeholders	27
Table 2. Requirements Description Template.....	29
Table 3. EVOLVED-5G Industry 4.0 NetApp Common Requirements	30
Table 4: Industry 4.0 Pillar Specific Requirements.....	33
Table 5. NetApps Certification & Marketplace Requirements.....	34
Table 6. 5G Network infrastructure Requirements.....	38
Table 7. Compute and Data Infrastructure requirements	42
Table 8. NetApp Lifecycle Requirements	45

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The goal of this deliverable entitled “*Overall Framework Design and Industry 4.0 Requirements*” is to define the NetApp ecosystem (also referred to as EVOLVED-5G ecosystem) envisioned in the EVOLVED-5G project and to provide both the requirements and a reference architecture (the EVOLVED-5G facility) for the realization of such ecosystem. An analysis on the functional blocks and tools that can be adopted for the realization of the architectural components are also provided, together with the methodology for requirements gathering and monitoring for NetApps development. Since the EVOLVED-5G ecosystem will be used for NetApps development to the overall validation and publication in a marketplace, Industry 4.0-related use cases are defined in this document as well, highlighting the importance of the proposed ecosystem.

This deliverable report work conducted in tasks T2.1 (*Overall Framework and Reference Architecture Design*) and T2.2 (*Definition of Technical Requirements for Industry 4.0. NetApps*) of the project and provides fundamental input to all the subsequent technical WPs (namely, WP3, WP4 and WP5), especially to Tasks 3.3 and T3.2 in WP3 and WP4 tasks overall, where major development work is being conducted.

1.2 STRUCTURE OF THE DOCUMENT

The document follows a top-down descriptive approach organized around four main sections:

- **Section 2. The NetApp Ecosystem:** Where the definition and description of the vision, objectives and key innovations of the NetApp ecosystem are provided. A definition of the NetApp is also given along with the 5G Core Programmability and API’s exposure.
- **Section 3. NetApp Deployment and Validation Facility:** The EVOLVED-5G facility encompasses all the architectural components that are necessary for the realization of the NetApp ecosystem. This section includes a high-level description of said EVOLVED-5G facility and continues with a description of main environments (namely, the NetApp Workspace, Validation, the 5G–NPN Infrastructure, Certification and Marketplace). As part of the 5G-NPN Infrastructure environment, a short description of both Malaga and Athens platforms is provided. Both platforms will serve as the experimental test benches of the facility.
- **Section 4. Stakeholders and Roles in the NetApp ecosystem:** In this section, main stakeholders and roles of the EVOLVED-5G ecosystem are described in great detail. Said description is presented on the basis of the 5G-PPP background for stakeholders and roles in the 5G ecosystem.
- **Section 5. EVOLVED-5G NetApp Ecosystem Requirements:** This section presents a formalized project-wide gathering methodology for the collection of NetApp ecosystem requirements. Following the overall EVOLVED-5G architectural design provided in Section 3, four main groups of technical requirements are identified and grouped-by as follows: Business-related, 5G network infrastructure, Compute & Data infrastructure and NetApp lifecycle.
- **Section 6. EVOLVED-5G Use Cases:** The description of the four Industry 4.0 Pillars EVOLVED-5G brings, the thorough case-study per pillar analysis (including use cases per

SME) as well as the NetApp Opportunity and the State-of-the-Art (and current) challenges are core topics for this particular section.

1.3 TARGET AUDIENCE

The release of the deliverable is public, intending to expose the overall EVOLVED-5G framework design and key Industry 4.0 requirements to a wide variety of research individuals and communities.

From specific to broader, different target audiences for D2.1 are identified as detailed below:

- **Project Consortium:** To validate that all objectives and proposed technological advancements have been analyzed and to ensure that, through the identified requirements and the proposed architecture, further work can be concretely derived. Furthermore, the deliverable sets to establish a common understanding among the consortium with regards to:
 - The NetApp Ecosystem in the context of latest 5G technology advancements and main groups of technical requirements that are fundamental for the realization of said ecosystem.
 - The blueprint architecture to be set for future reference and evolution, including tools and technologies to be utilized.
 - Industry 4.0-related use cases that will show the added value of the NetApp ecosystem in real industry 4.0 scenarios.
- **Industry 4.0 and FoF (factories of the future) vertical groups:** To crystallize a common understanding of standards, technologies, and design principles that underline the architectural design of EVOLVED-5G, and to understand main technical requirements that should be considered beforehand and essential for later implementations of the EVOLVED-5G facility. 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-focused RTOs and institutes, marketers of exploitable results, potential users of exploitable results
 - Industry 4.0 Investors and business angels.
- **Other vertical industries and groups:** This deliverable seeks 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 general public:** including citizens students, and non-governmental organizations (NGOs) to get a better understanding of the underlying components and design approach behind the EVOLVED-5G facility.

2 THE NETAPP ECOSYSTEM

2.1 BACKGROUND ON 5G OPENNESS

The enormous growth in connectivity, the high volume of traffic data and the broad range of business models nowadays, impose the need to move towards highly flexible infrastructures that are characterized by consistency in terms of capabilities and Quality of Service (QoS) provision. In this regard, 5G network needs to be able to support a wide range of new business solutions with different performance requirements and at the same to allow existing service offerings in an enhanced and optimized manner compared to the previous generations of mobile networks. Therefore, openness comes in different shapes and forms and undeniable requires coordinated efforts between the industry and standardization bodies.

Indeed, 5G specifications from the 3rd Generation Partnership Project (3GPP) materializes this openness vision through the Service Based Architecture (SBA), adopted by the 5G Core (5GC) network. This shifted approach allows for resource allocation, service orchestration, lifecycle management as well as service slicing in a more efficient manner, thus in turn enables an increased flexibility, availability, and reliability within the network, allowing the exploitation of the new business opportunities.

In this section main 3GPP 5G specifications adopted by the EVOLVED-5G project are presented in detail, as well as key disruptive enablers and standard APIs that would eventually make the realization of this openness vision a reality. A definition for NetApps is also provided as it constitutes the very basic element that links the development of the EVOLVED-5G ecosystem with the above-mentioned opportunities in 5G openness capabilities.

2.1.1 5G Core Programmability and APIs Exposure

The 3GPP 5G specification introduces a core network model that looks very different from the traditional architecture. With the aim to support fragmentation within the network and promote more dynamic 5G services, it defines an “open” core, in which all core network functions have been virtualized. This approach allows for the elimination of resource inefficiency and performance degradation associated with virtual machines and hypervisors, thereby improving the network in terms of flexibility, speed, and automation. Key enabler for this openness is the realization network programmability through standard APIs, so that higher-level service orchestrators can handle configurations for a variety of services and slices. This endeavor shapes a new and dynamic ecosystem in mobile networks from both the technology and marketing perspectives. External third parties with permission, such as industries, platform developers, and designers, may use those standard APIs for building network-aware (5G-enabled) applications, which establish a bi-directional communication with the 5GC, retrieving network statistics, but also triggering specific policies and commands to the network.

The above-mentioned exposure capability is materialized through the Service Based Architecture (SBA), adopted by the 5GC network. Indeed, the 5GC control plane NFs communicate through API-calls that define the related Service Based Interfaces (SBIs). In this context, the Network Repository Function (NRF) allows other NFs to register their services, which may subsequently be discovered by other NFs. This allows for a versatile implementation, in which each NF allows other approved NFs to access resources.

In addition, the Network Exposure Function (NEF), provides a set of northbound APIs for exposing network data and receiving management commands. More precisely, NEF provides adaptors for connecting the southbound interfaces with the SBA to an exposure layer with northbound interfaces offered to third-party developers. The overall approach is illustrated in Figure 1. In this way, NEF facilitates the secure disclosure of network resources to 3rd parties, such as network slicing, edge computing, and machine learning utilizing the 5G system, fully compliant with the innovative paradigms that underpin a wide range of services.

The functionality provided by NRF and NEF to 3rd parties, enables programmability and adaptability of the 5G connectivity services, and creates a new ecosystem where 3rd parties' developments bridge 5G exposed capabilities and service requirements/potentials from the vertical industries. This is the feature of 5G core that on top of which the EVOLVED-5G project builds its innovation.

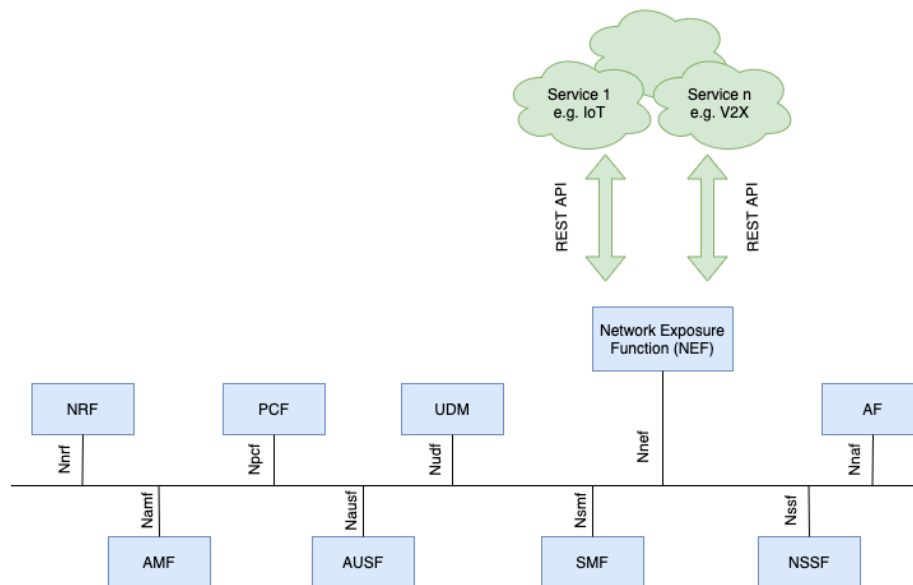


Figure 1. RESTful APIs for the Service Based Interfaces and Northbound communication

In this framework, 3GPP introduced the concept of Vertical Application Enablers (VAEs) in Rel. 16, enabling the efficient use and deployment of vertical apps over 3GPP systems. The specifications and the architecture are based on the notion of the VAE layer that interfaces with one or more Vertical apps. VAEs communicate via network-based interfaces that are well-defined and version-controlled. The focus of VAEs is to provide key capabilities, such as message distribution, service continuity, application resource management, dynamic group management and vertical app server APIs over the 5G system capabilities [1].

3GPP has already established the foundations to provide 5GC Network capabilities to vertical industries. The key concepts that have emerged are the Common API Framework (CAPIF) and the Service Enabler Architecture Layer (SEAL) together with NEF. Following paragraphs shall provide a brief synopsis of these core concepts, that are the considered the fundamental basis for EVOLVED-5G.

2.1.2 Common API Framework - CAPIF

CAPIF was introduced in 3GPP Rel.17 [2] for enabling a unified approach for the interaction between 5GC's northbound APIs framework and vertical apps. The key concept of CAPIF is to

specify a set of common supporting capabilities (e.g., authentication, service discovery, charging policies) that are applicable to northbound APIs and facilitate a secure the interaction with 3rd party vertical apps. CAPIF consists of the CAPIF Core Function (CCF), API Invokers and API provider domain which comprises API Exposing Function (AEF), API Publishing Function (APF), and API Management Function (AMF). The architectural model adapted form is presented in Figure 2 and the functional entities are briefly described as follows:

- CCF, acts as an orchestrator that manages the interaction between service consumers (vertical apps) and service providers (e.g., NEF, SEAL). The main responsibilities of CCF are authentication of the API invoker, authorization of the API invoker to access the available service APIs and monitoring the service API invocations.
- API Invoker, represents the vertical app which consumes the service APIs utilizing CAPIF. API Invoker provides to the CCF the required information for authentication, discovers and then invokes the available service APIs.
- AEF, is responsible for the exposure of the service APIs. Assuming that API Invokers are authorized by the CCF, AEF validates the authorization and subsequently provides the direct communication entry points to the service APIs. AEF may also authorize API invokers and record the invocations in log files.
- APF, is responsible for the publication of the service APIs to CCF in order to enable the discovery capability to the API Invokers.
- AMF, supplies the API provider domain with administrative capabilities. Some of these capabilities include, auditing the service API invocation logs received from the CCF, on-boarding/off-boarding new API invokers and monitoring the status of the service APIs.

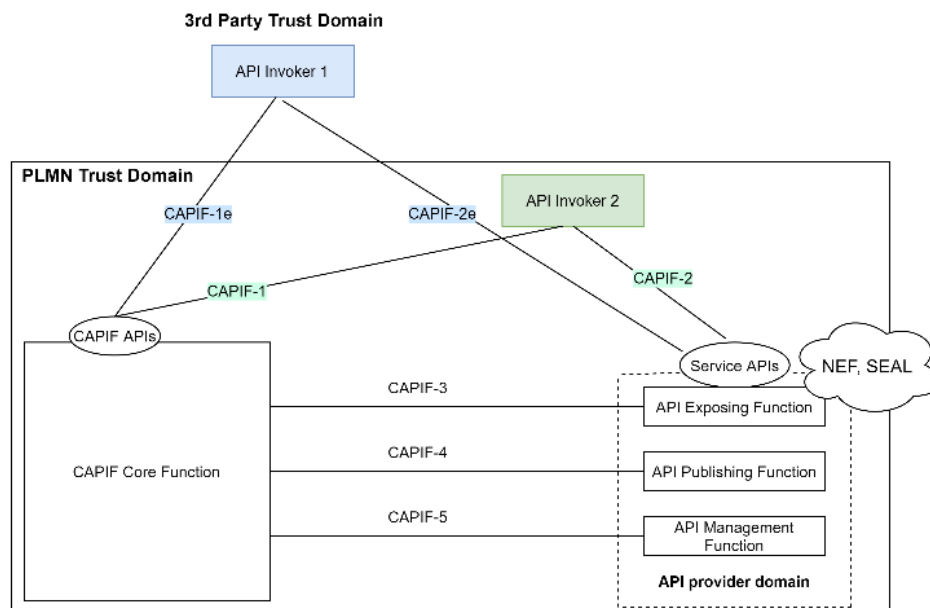


Figure 2. Simplified CAPIF Architecture

3GPP considers two main architectural deployment models (see Figure 2), centralized, when the CCF and API Provider domain functions are co-located and distributed, when CCF and API Provider domain functions are not co-located and they are interacting through CAPIF-3/4/5 interfaces. Therefore, multiple CCFs can be deployed in the same PLMN trust domain.

CAPIF is located within the PLMN operator network. Thus, there are two functional options for API Invokers; usually 3rd party applications, which have service agreement with PLMN operator,

represent API invokers (i.e., API Invoker 1), but they may also be co-located within the same PLMN trust domain (i.e., API Invoker 2). Whether third parties have business relationship with PLMN, they can provide their own service APIs to CCF through CAPIF-3e/4e/5e interfaces, but they need to act in accordance with the functionalities of API provider domain. In order to be compliant with the overall architecture (see Figure 2), NEF and SEAL (i.e., SEAL server) support the CAPIF's API provider domain capabilities.

The available CAPIF services and their respective functionalities are listed hereby. Services are divided into four categories: common, security, management, and internal connectivity services:

Common Services

- Discover (CAPIF Discover Service API): This service enables API Invokers to retrieve the available services that have been registered in CCF.
- Publish/Unpublish/Update (CAPIF Publish Service API): APF consumes this service to publish/unpublish a service API to the CCF. The publication includes details about the specific service API. APF can also update already published services.
- Retrieve (CAPIF Publish Service API): APF requests from CCF information related with previous published services. When a publication occurs CAPIF registers all the related information in a repository (i.e., API registry).

Management Services

- Logging (CAPIF Logging API Invocation): Upon invocations (i.e., from API Invokers), CCF may store valuable information such as API invoker's ID, IP address, service API name etc. AEF utilizes this service to access the potential log files that have been stored in CCF.
- Auditing (CAPIF Auditing): This service can be used to control CAPIF interactions with API Invokers (e.g., invocation events, onboarding events, authentication), which are stored in CCF. AMF initiates a request to fetch the respective log files.
- Charging: AEF can use this service to retrieve charging related information flows from the CCF.
- Monitoring events (CAPIF Monitoring): Monitoring event service is used by AMF in order to get notified whether an event occurs in the CCF. Some of the events are the availability of service APIs (e.g., active, inactive), changes in service APIs (e.g., after an update), service API invocations, API invoker status (e.g., onboarded, offboarded) and performance related events (e.g., load conditions).

Security services

- Authentication (CAPIF Security / AEF Security API): An API Invoker can be authenticated from the CCF or the AEF. The former service enables invoker to initiate a direct request to the CCF. Otherwise, AEF authenticates an invoker with assistance from CCF. The authentication occurs prior or upon an invocation.
- Authorization (CAPIF Security / AEF Security API): After authentication occurs, API Invokers initiate requests to retrieve service APIs. AEF checks whether the invoker is authorized to do so. If the AEF does not have the required information for authorization, AEF inquires CCF. Thus, AEF and CCF can invalidate invoker's configured authorization at any moment.
- Access control policy (CAPIF Access Control Policy): This service enables AEF to obtain the configured policies to perform access control on the service API invocations.
- Registration of provider domain: This service enables AMF to register the API provider domain functions to CCF in order to be authorized and use CAPIF's functionalities.
- On/off boarding (CAPIF API invoker management): This service enables API Invokers as recognized users of the CAPIF. Invokers initiate the on-boarding process by sending a request to the CCF. If the enrolment information provided is valid, CCF on boards

invokers and creates a new profile, which is sent back upon the response. API Invokers can also cancel their on-board status.

Internal connectivity

- CCF interconnection (CAPIF Discover Service API / CAPIF Publish Service API): This service enables the interconnection between multiple CAPIF providers. Each CAPIF provider has a CCF which utilizes publish and discover services in order to interchange its APIs.
- Topology hiding (CAPIF Routing Info): This service enables hiding the topology in the functional scenario where CAPIF includes PLMN trust domains, third party domains and API invokers access the service APIs from outside both the PLMN and third-party trust domains. In this case, API invokers access an AEF which acts as an entry point. Thus, the information for the entry AEF is shared with API Invoker in the discovery service. Then, subsequently, AEF resolves the actual destination address of the requested service API and forwards the initial request.

2.1.3 Service Enabler Architecture Layer - SEAL

SEAL was introduced in Rel. 16 to support easier and faster development and deployment of vertical apps [3]. While the demand to develop vertical app standards for different types of industries was continuously increasing, it became obvious that many auxiliary services, such as location management, are needed across multiple vertical apps. As a result, capturing these commonly used auxiliary services and offering them to verticals as a common service layer, will both benefit verticals, allowing them to focus only on the core features and functionality of the vertical app, and operators, saving them from enormous efforts and time to develop the corresponding services for each vertical. The above concept became reality with the standardization of SEAL architecture. SEAL architecture enables these common services to be consumed by vertical apps over 3GPP, CAPIF compliant, northbound APIs. SEAL architecture supports two functional models: on-network (i.e., SEAL-Uu), when the UE connects to the 3GPP network system to consume the service, and off-network (i.e., SEAL-PC5), when UEs connect to each other directly. The main functional entities of SEAL architecture are the following:

- Vertical Application Layer Client (VAL client): This entity provides the client-side functionalities of the corresponding vertical app (e.g., Vehicle to Everything (V2X) client).
- Vertical Application Layer Server (VAL server): This entity provides the server-side functionalities of the corresponding vertical app (e.g., V2X application server). If CAPIF is supported, VAL server acts as an AEF to provide the service APIs to the Vertical Application Server (VAS) or another VAE server. It can also act like an API Invoker to consume the service APIs, whether they are provided by another VAL server.
- SEAL Client: This entity provides the client-side functionalities corresponding to a specific SEAL service (e.g., Location Management client).
- SEAL Server: This entity provides the server-side functionalities corresponding to a specific SEAL service (e.g., Location Management server). It can act as CAPIF's API exposing function.

Various deployment scenarios have been proposed in SEAL architecture, concerning the domain in which SEAL servers are deployed. The SEAL servers can be deployed: a) in a single PLMN operator domain (centralized deployment), b) in multiple PLMN operator domains, as distributed function, with or without interconnection between the SEAL servers, c) in the VAL

service provider domain or d) in a separate SEAL provider. The common set of SEAL services designed to be used by vertical apps can be described as follows:

- Location Management: Enables the vertical app to have access to network location information of its corresponding UEs. More specifically, this service can send reports on-demand to a VAS about the location of its UEs, subscribe the VAS so as to receive notification when location information of UEs changes, share UE location information etc.
- Group Management: Allows vertical apps to group UEs, thus enabling group management operations, such as enforce group policies, edit group configurations etc. The service also allows the vertical app to subscribe for and receive notifications when group information or status is modified.
- Configuration Management: Enables the vertical app to create and manage configuration on its UEs (provide initial configuration, edit configuration, notify server when configuration changes etc.)
- Identity Management: This service is responsible for the authentication and authorization procedures of a vertical app user.
- Key Management: Enables a vertical app to support secure transfer of data by providing and storing encryption keys.
- Network Resource Management: Allows a vertical app to manage network resources by managing (create, modify, delete) unicast and/or multicast bearers.

2.2 THE NETAPP CONCEPT

Considering the 5G openness capabilities, materialized through APIs, as described above, in this section the concept of the **Network Application (NetApp)** is defined. More precisely, in the context of EVOLVED-5G as NetApp is defined a software piece that interacts with the control plane of a mobile network by consuming exposed APIs (e.g., Northbound APIs of 5G core and/or MEC APIs) in a standardized and trusted way (i.e., for a 5G network a NetApp should be CAPIF compliant [2]) to compose services for the vertical industries.

A NetApp shall provide services to vertical applications either as an integral part of the vertical application or by exposing APIs, which are referred to as **business APIs**. In this context, vertical industries will be able to develop NetApps that compose new services by consuming 3GPP APIs as well as other telco assets (referring to business support system – BSS APIs, e.g., service orchestration APIs).

For example, authors in [4], proposed a framework that leverages NEF APIs (i.e., *TrafficInfluence* API to influence data-path configurations and *MonitoringEvent* API to retrieve location information) to plan where to place Video on Demand (VoD) content. The framework distributes segments of the full video to MEC caches, but only a portion will effectively be consumed while the user traverses MEC's coverage area, minimizing access time (i.e., low latency) and optimizing traffic load on the core network. The components that carry out this activity in the proposed framework, could be considered as NetApps. Note that, this potential NetApp not only receives information from the 5G Core but utilizes these data to perform a more intelligent task. Machine learning algorithms can be applied on the framework to predict where to place the segments. Therefore, considering the way that the services are provided to verticals, the NetApps can be classified to:

- **Standalone NetApp.** 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.** 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.

The two types of NetApps are presented in Figure 3:

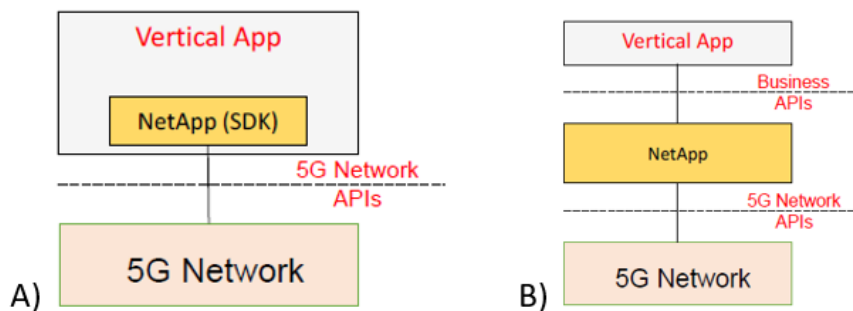


Figure 3. Third-party Standalone (A) and Non-standalone (B) NetApp representation

The NetApp ecosystem is something more than the introduction of new vertical applications that have 5G-interaction capabilities; it responds to the request for a separated middleware layer that will simplify the implementation and deployment of vertical systems at large scale (considering also the adaptation needed for Non-Public 5G Network – 5G NPN deployments). This is the same request that triggered the development of Vertical Application Enablers (VAE) by 3GPP SA6. NetApps can also be categorized by the level of interaction and trust with the Mobile Network Operator (MNO):

- **Third-party NetApp.** NetApp that resides at a trusted third-party domain. A third-party NetApp consumes Northbound APIs and, also, supports trust mechanisms and security policies defined by the network for the verticals.
- **Operator NetApp.** NetApps that reside at the operator domain, considering mainly Non-Public Network (NPN) deployments, and, potentially, can have further access to 5G network capabilities, beyond those provided through the Northbound APIs (e.g., vertical specific functionality at the OSS for slice management) and those available in a third-party NetApp. In that case, the NetApp may interact directly with the 5G network functions.

Considering the 5G SBA, a NetApp can be an Application Function (AF) that assists the vertical server client to communicate with the 5G network (i.e., control plane) and utilize its capabilities to enable network-aware applications. Note that, a NetApp is part of the VAS as defined by 3GPP SA6, thus a NetApp is instantiated during the development time of a VAS.

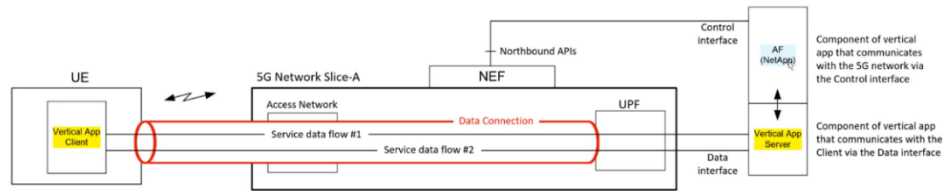


Figure 4. NetApp's interaction with the data and control plane when a Vertical application is provided

2.3 NETAPPS IN THE INDUSTRY 4.0 ERA

Industry 4.0 refers to the fourth era of change of manufacturing with the emergence of Smart Factories. All manufacturing processes, from supply chain to production and services, are called to evolve by the introduction of intelligent autonomous systems based on the Internet of Things (IoT) and Cyber-Physical Systems (CPS).

Thus, there is a strong need for industrial network infrastructures that can support the high volumes of communication and connecting needs as well as to have the flexibility to support the various heterogeneous processes inside a Smart Factory. The major candidate for this is the 5G Non-Public-Network (5G NPN). In addition, a 5G-NPN can also provide low-latency communications with high data rates and reliability; major requirements of Industry 4.0.

Considering the 5G-enabled factories of the future, the openness of 5G (as described in Section 2.1) provides a fertile field for the NetApp ecosystem. Motivated by this, the main vision of EVOLVED-5G is to provide a set of NetApps for the smart manufacturing sector.

The vision proposed by EVOLVED-5G with NetApps addresses a major gap: the lack of deep expertise about the internal operating mode from the industrial service providers. By making available an intermediate layer between the 5G core and the existing industrial vertical applications, EVOLVED-5G facilitates the development of 5G-enabled industrial applications that take full advantage of the 5G capabilities.

To respond to the potential of providing NetApps for the industrial sector, four pillars/groups of industrial services are targeted in EVOLVED-5G:

- Interaction of Employees and Machines (IEM).
- Efficiency in FoF Operations (FoF).
- Security Guarantees and Risk Analysis (SEC).
- Production Line Infrastructure (PLI).

To enable the above-mentioned NetApp ecosystem, where industrial NetApps are targeted for the defined pillars, a related facility is designed in EVOLVED-5G, as explained in the following section.

3 NETAPP DEPLOYMENT AND VALIDATION FACILITY

3.1 THE EVOLVED-5G FACILITY

The creation of the NetApp ecosystem described in section 2 requires the realization of a supporting facility, that provides the tools and the processes for the development and validation of NetApps, as well as any supporting network infrastructure (e.g., a 5G-NPN) and mechanisms for market releasing and collaboration (e.g., a Marketplace).

This section aims to provide an overall description of a reference architecture – together with its core architectural components – that refers to the EVOLVED-5G response to the need for a NetApp deployment and validation facility.

For the design of the reference architecture (Figure 5) of the EVOLVED-5G facility two logics have been considered:

- Firstly, **the purely compositional and structural logic** of the architecture itself. Viewed this way, 3 main tiers are identified (from top -- most abstract -- to bottom -- most concrete):
 - Environments: Tier-1/Core architectural components of the NetApp Ecosystem. 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 of the NetApp Ecosystem. Indeed, for each one of the functional blocks there will be a set of tools that will support and materialize the implementation of the functional block(s).
- 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.

Uniting both logics, we can find an overall architecture that is built around 5 major environments (they will all be detailed in depth in D2.2) that are also designed to follow the expected lifecycle of the NetApp within the whole ecosystem as described below:

1. **The Workspace Environment**: This environment serves as space and collaborative area for the implementation of the NetApps, and thus provides all the tools and functionalities for NetApp development and verification for functional testing. In this environment two phases in the lifecycle of the NetApp are therefore identified: Development and Verification. For its implementation the following functional blocks are made available (see chapter 3.2 for additional details):
 - a. **The SDK (Software Development Kit)**: It includes any of the tools (libraries, scripts, pre-defined templates, documentation, etc.) required for the development phase of the NetApp.
 - b. **Repositories**: EVOLVED-5G considers two types of repositories. One repository (GitHub) will serve to store the code, documentation and every file related to

the NetApp. The second repository (Open Repository) will serve to store the NetApps artifacts (files).

- c. **CI/CD services:** CI/CD services are managed by the EVOLVED-5G consortium and function as a service. CI/CD services provide the necessary functionality required for the verification phase, which is the process that assures the compatibility and checks compliance of the NetApp with 5G APIs.
2. The **Validation Environment:** This environment aims to facilitate the coupling between the NetApp and the Vertical App in controlled scenarios that would eventually emulate real NetApp operating conditions. This is called Validation phase of the NetApp lifecycle and it is based on the Open5Genesis suite [5]. This phase consists of a set of tests agreed and coordinated with the Vertical Application provider (i.e., Industry 4.0 SME). The expected functionality is to test the correct operation of the NetApp along with the Vertical App in a more realistic environment that would make use of a real 5G infrastructure. It is worth mentioning that the validation phase involves the entire service provisioning chain, meaning that not only the NetApp functionality is verified but also the entire infrastructure is evaluated and performance KPIs are extracted.
3. The **Certification Environment:** Conformance tests and quality assessments are undeniably essential in today's virtualized network domains, and this is exactly what this environment is designed for. It is composed by a series of functional blocks (see chapter 3.5) that will make a validated NetApp eventually certified (i.e., NetApp interoperability with a 5G SA network is guaranteed).
4. The **Marketplace Environment:** In this environment the last phase of the NetApp lifecycle takes place: The release of certified NetApps to the market, making them available to end users.
5. **The 5G-NPN environment:** The main objective of this environment is to provide NetApps with the necessary 5G native or northbound APIs (as presented in Section 2) as well as with the connectivity infrastructure so that the Validation and Certification environments can meet their respective goals (see chapter 3.1.5). It includes both equipment and software components required for the execution of the validation and certification phases (such as the NetApp interoperability with the 5G network, devices and the management and orchestration, etc.).

These five environments can be found in Figure 5 as depicted below. As it can be noticed, the Open Repository as functional block plays a central role in the whole architecture. Indeed, it is worth highlighting the use of an Open Repository as a central piece of the architecture where the NetApp, along with any required metadata that details its current status, is saved and made accessible to other components in the architecture.

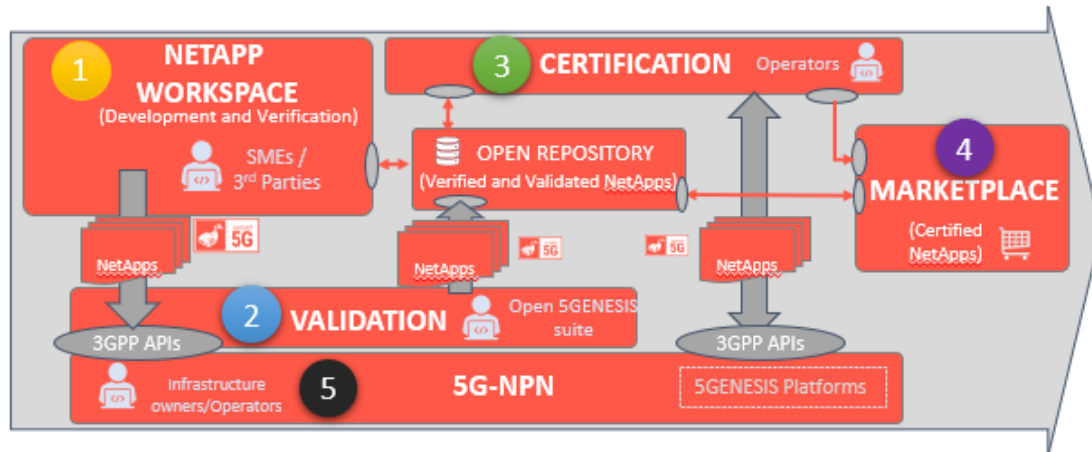


Figure 5. The EVOLVED-5G Facility

3.1.1 The Workspace Environment

A workspace can be defined as a place to carry out the work, i.e., in computing can refer to a file or system of files where related software and data can be developed isolated from others, also in an Operating System (OS) can be referred as a grouping of windows on your desktop.

In EVOLVED-5G the NetApp Workspace will refer to the following functional blocks:

- **The SDK:** It will provide a set of SDK tools to support the NetApp development and integration which will include documentation, instructions, scripts, and libraries among others. Such SDK tools will be shared among the different Industry 4.0 NetApp developers as a complete package to use it locally within their premises. To develop the NetApp, the Industry 4.0 NetApp developers will make use of some repositories managed by the project.
- **Repositories:** EVOLVED-5G project considers two different types:
 - GitHub: a code repository to store the code to which every NetApp SME developer will have access for developing the NetApp.
 - The Open Repository: a centralized artifact repository to store the builds and binaries coming from the CI/CD.
- **The CI/CD services:** They will verify the proper functionality of the NetApp by using a testing framework together with the 5G native APIs emulator as part of the Verification phase. The CI/CD is the component in charge to do such verification. It will be a centralized server managed by the project, it will also provide a series of pipelines, i.e., build the NetApp, deploy and testing, to verify the proper functionality of the NetApp.

3.1.2 The Validation Environment

The Validation environment is based on the Open5Genesis framework and methodology. This methodology is detailed on Deliverable D2.4 of the 5GENESIS Project [6], however, a small description of this methodology is detailed below.

The Open5Genesis methodology is based on the definition of a Test Case, which describes information such as the target measurements, scope and pre-conditions of an experiment, among others. 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. The repeatability of the experiment and the possibility of comparing results

obtained in different platforms are guaranteed, if the requirements of the Test Case have been taken into account during the implementation phase.

Additionally, in order to define the network conditions that are used during the experiment, one or more sets of Scenarios and Slices can be defined. The Scenario defines the configuration of the network, the location and mobility conditions of the user equipment, and is meant as a guide to reproduce realistic conditions during the experiments. The Slice, on the other hand, defines the end-to-end resources allocated in the network specifically for the system under test.

By following this approach, it is possible to de-couple the testing methodology described in the Test Case from the conditions of the experiment, which can then be re-used on multiple Scenarios and Slices.

The Open5Genesis framework a set of tools tailored for supporting this methodology. In the context of EVOLVED-5G the Open5Genesis framework will be applied on top of Industrial network platforms, and more specifically to 5G-NPN platforms (as described in section 3.1.5). It is expected, however, that as part of the EVOLVED-5G project some existing functionality of the Open5Genesis framework will need to be adapted and/or extended in order to support the specific needs of the NetApp Validation and Certification.

Given that the details of the Validation phase will be different depending on the NetApp and Vertical Application tested, as well as due to additional requirements such as the use of specific devices, the Validation 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 Validations) to the needs of the Vertical. Following the 5Genesis methodology, this Test Case is then implemented and executed in the platform.

3.1.3 The Certification Environment

Certification is the means to promote excellence through adherence to the identified best practices and ensures alignment with the regulations set by the market and governmental administrations. 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. As the telecommunications services move towards software and virtualization, 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, which is the purpose of the EVOLVED-5G NetApps Certification Initiative.

More specifically, EVOLVED-5G plans to support existing audit bodies with the audit list that can be suitable for the formal certification of the NetApps. Note that the certification environment's configuration setup, together with the tools developed by the project for the certification validation tests, can be provided by the EVOLVED-5G project partners to the accredited labs that wish to instantiate a relevant environment.

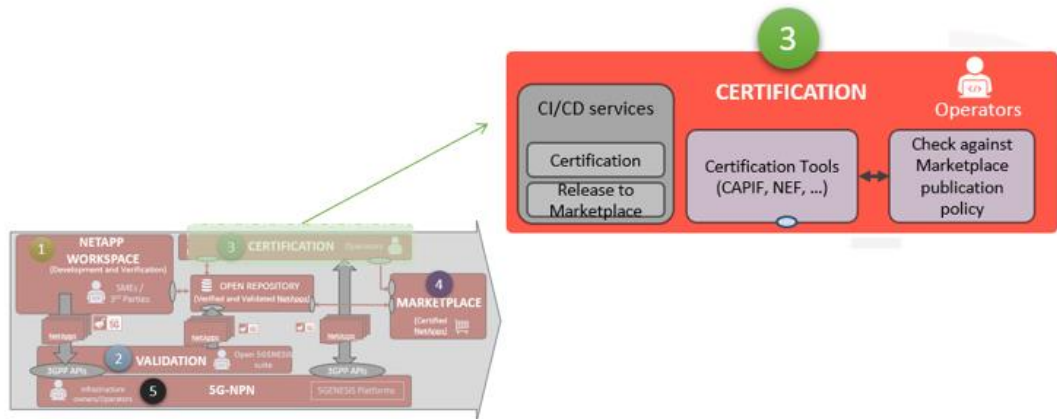


Figure 6. Certification's main functional blocks

Therefore, the Certification Environment assists the execution of the Certification phase, that sets the assessment objectives, and will be detailed in D2.2. It will include the following functional blocks:

- The **Open Repository** contains the NetApps artifacts (files) required to build the NetApp binaries and run it through the Certification phase. This is the fundamental source for starting the certification process.
- The **CI/CD Services** will be the trigger of the Certification phase. It will consist of a set of tests and verifications that can include some that were already performed in the Validation and Verification phases, augmented with specific certification tests to cover specific purposes. Indeed, as part of the certification phase NetApps will be CAPIF and NEF APIs compliant. These tests will be executed using the NetApp against 5Genesis platforms with specific Certification Configuration. This process shall be repeatable, and the certification results will be tagged for specific NetApp fingerprint (version, binary MD5 checksum, etc). so that it can also be easily traceable. After any change of the NetApp code, Certification process will need to be executed again to update the NetApp fingerprint.

In addition to the above-mentioned functional blocks, there will be Certification Tools as specific software components that enable the testing and assurance of certain certification purposes such as CAPIF and NEF. These tools will be deployed along with Athens and Malaga platforms with limited integration. These tools will enable the testing and assurance of proper usage of standard APIs from the NetApps running through the certification phase. These tools will provide conformance test reports that will be attached to Certification results for NetApp developers.

- Upon the NetApp being successfully certified, it will be **uploaded to the Certified area of the Open Repository**. Only certified NetApps will be uploaded in this area.
- Developers can decide to **Release to Marketplace** their certified NetApps. This operation will be ignited also from the CI/CD toolset. The CI/CD system will upload the certified NetApp from the Certified area of the Open Repository to the Marketplace, including the required information from the Marketplace to publish the NetApp for usage.

3.1.4 The Marketplace Environment

In order to complete the lifecycle of a NetApp an agile, on-demand-based sourcing is needed to ensure increased trust, reduced settlement time and a simple mechanism for monetization where the users collaborate, federate, and share their services.

As the main item of the Marketplace will be the NetApps, a vertical type of Marketplace targeted to Telecom (5G) APIs and services, will be implemented.

Single or multiple services can be ordered by a user who needs to design and orchestrate end-to-end services within an infrastructure. To achieve this, the user needs to request services on-demand within this Federated Marketplace. The product bundle is composed of different services owned by different Providers. A high-level description of the main supported marketplace workflows for the service providers and users is described below.

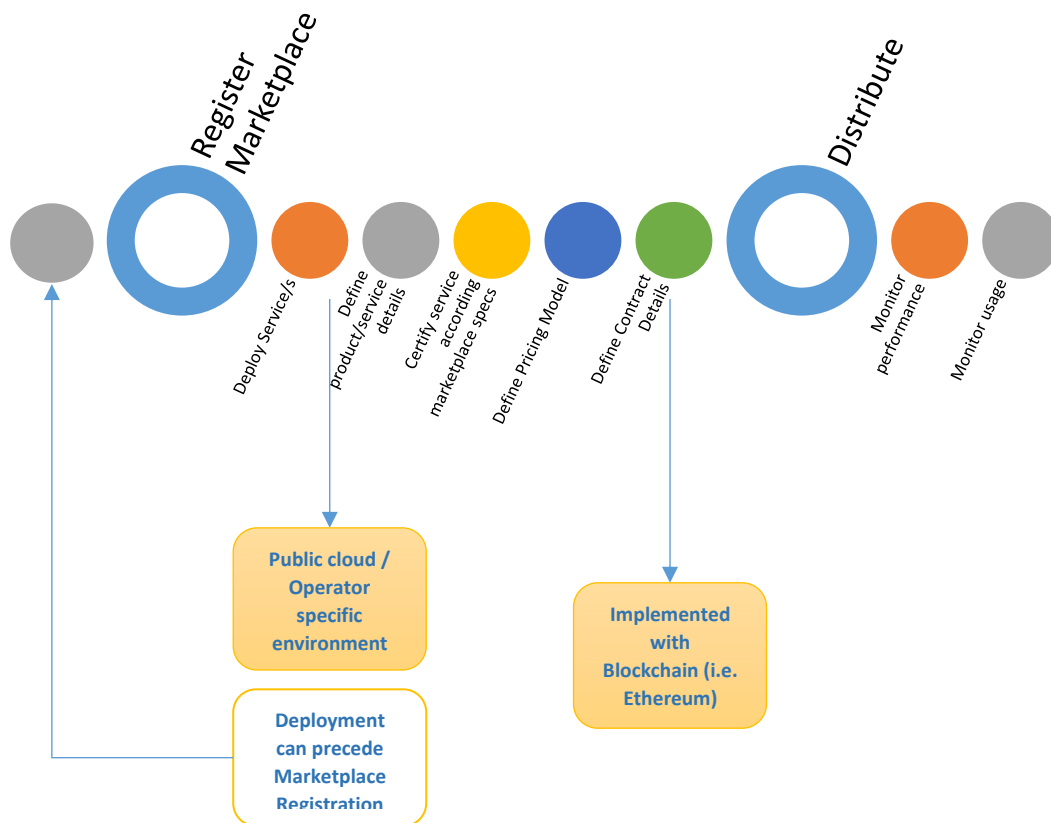


Figure 7. Workflow for the service provider

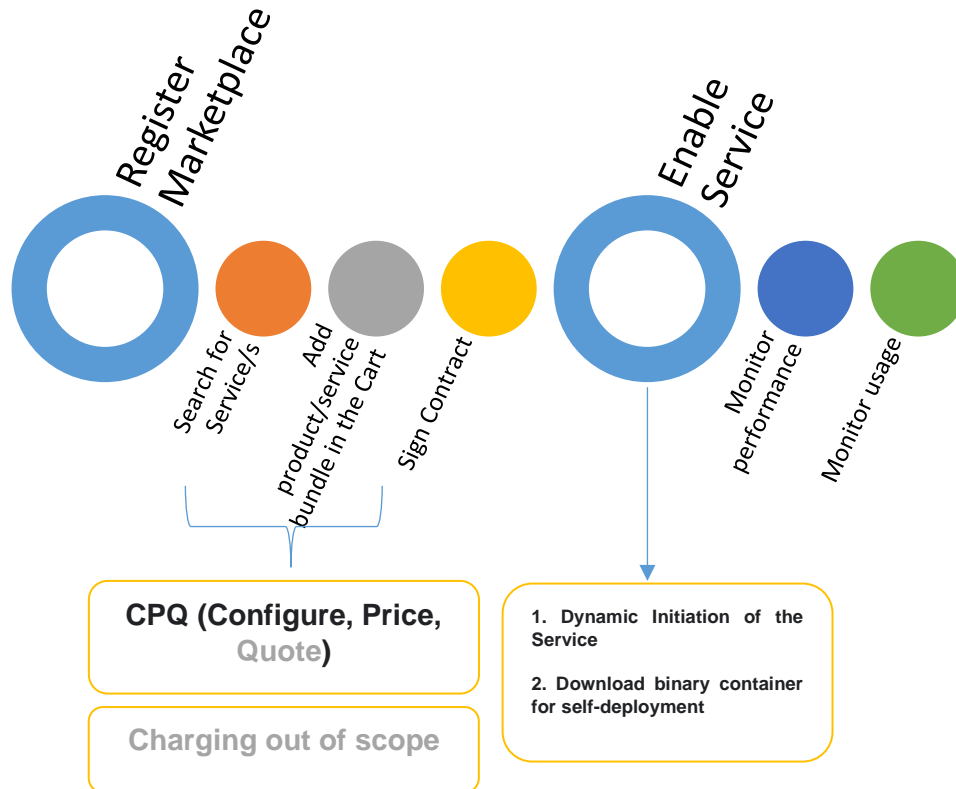


Figure 8. Workflow for the service consumer

The EVOLVED-5G Marketplace should support the following characteristics and functionality:

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

Payment Settlement will take place outside the Marketplace using certified external payment gateways (ex. 3D-Secure platforms).

A high-level overview of the architecture interactions and main functional blocks are described below:

- Certification/Validation Manager: This functional block interacts with the Certification and Validation environments to complete the certification phase with the Marketplace audit publication policy list for final release of NetApps.

- Production Manager: This functional block connects with the Open Repository to check whether new NetApps are certified and hence being made available.
- Intelligence Manager: This functional block interacts with the Open Repository to get data for consumption analytics and API performance.

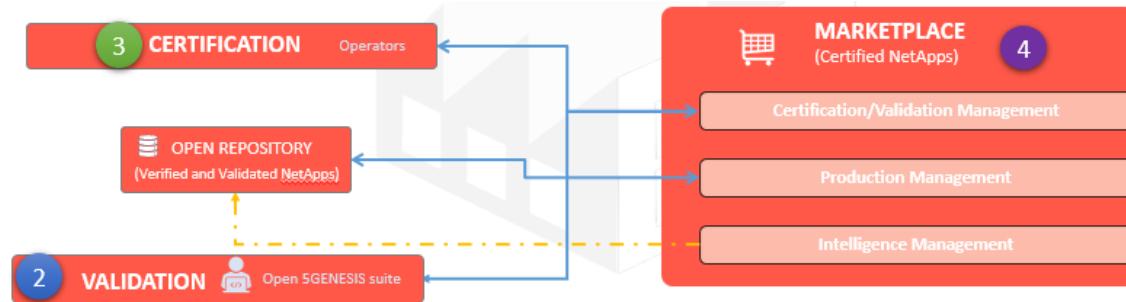


Figure 9. Marketplace framework Interactions

3.1.5 The 5G-NPN Environment

At first glance, next generation mobile networks can be classified into public and Non Public Networks (NPN). According to 3GPP the former refers to Public Land Mobile Networks (PLMN) which are typically led by Mobile Network Operators (MNOs) that provide their services publicly and they primarily operate in national scope. On the other hand, a NPN enables the deployment of a 5G System (5GS) that restricts its operability to private organizations, typically an industry vertical and offers private network services to end users acting within organization's premises.

NPNs can be divided into two main categories [7], Stand alone and Public Network Integrated (PNI). A stand-alone NPN is an isolated private network that has zero interaction with PLMN. PNI-NPNs rely on PLMN, meaning that a part or the whole of the functionality is provided by the MNO.

The autonomy of a NPN in relation to a PLMN can be described based on the following characteristics:

- The use of a unique identifier for the NPN.
- The assignment of private spectrum to the NPN.
- The full deployment of a 5GS (Radio Access Network and Core Network) within the perimeter of an industrial environment.

In the light of the above, the 5G NPN environment of the EVOLVED-5G facility is composed of two NPN platforms, namely the Malaga and the Athens platforms, which provide a dynamic environment for the deployment of NetApps as well as 5G connectivity industrial spaces.

In addition, the NPN platforms 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. This includes (but not limited to) the NetApp interoperability with the 5G network, a container orchestration system and the addition of any devices that may be required for the development of both the validation and certification.

As the 5G NPN platforms will be used during the Validation and Certification phases, it would expose the required 5G APIs through Malaga and Athens platforms which are eventually to be used by the NetApp.

A container orchestration system is also required for the instantiation of the NetApp during the Validation and Certification phases. In order to reduce complexity, and to be able to re-use part of the functionality developed for the support of the Verification, the same orchestration solution (Kubernetes) would be deployed in Málaga and Athens platforms.

The following sections shortly describe the equipment already available in the two platforms that are part of the EVOLVED-5G project (both platforms will be described with further details in D2.2).

3.1.5.1 The Athens platform

The Athens 5G platform comprises 2 dispersed sites, namely NCSR and OTE Academy, in the Athens metropolitan area forming an end-to-end (E2E) experimental 5G testbed as depicted in Figure 10. It features 5G and 4G radio access technologies (RATs) deployed in both indoor and outdoor environments, combining software network technologies (i.e., NFV and SDN) and cloud/edge computing deployments.



Figure 10. Athens platform sites overview

3.1.5.1.1 NCSR Site

NCSR provides a reliable operation of the network to the Athens Platform computing and RAT deployments within its premises. Core and RAN networks provide the option to be hosted separately, providing the capability of a 5GC cloud deployment. 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.

3.1.5.1.2 OTE Academy site

In the context of 5GENESIS Facility and the Athens Platform, COSMOTE is hosting edge network capabilities empowered by the lab's cloud infrastructure, as well as 5G outdoor and indoor deployments based on commercial equipment. COSMOTE's OpenStack implementation provides a private cloud service model, as Infrastructure as a Service (IaaS), where required use case VNFs are deployed.

Figure 11 illustrates the current deployment. It can be observed that the MANO and coordination components are installed in separate cloud infrastructure (IaaS cloud), and the

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

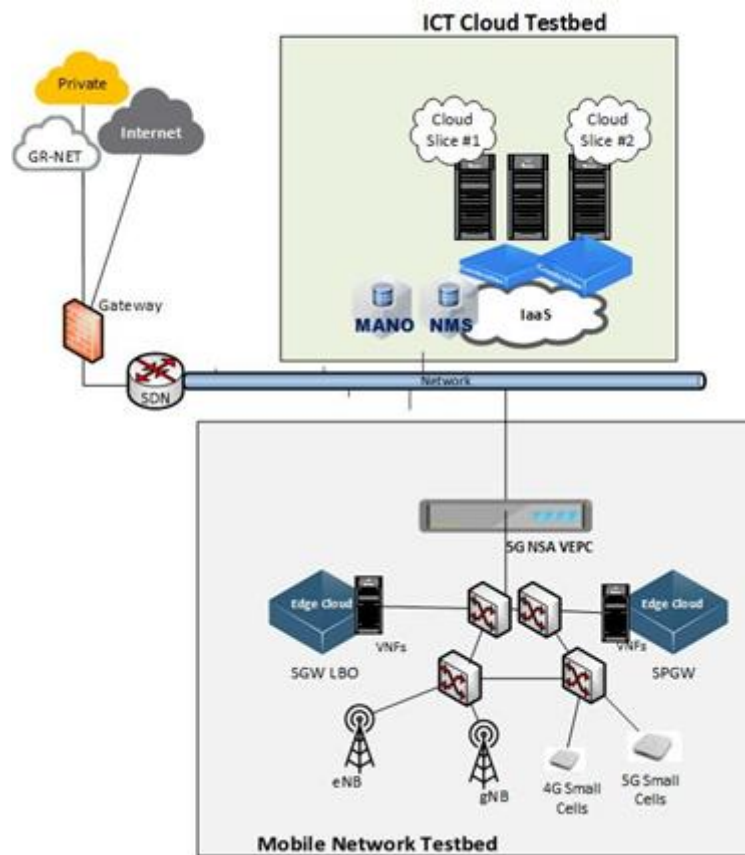


Figure 11. OTE Academy Site

3.1.5.2 The Málaga platform

The EVOLVED-5G Málaga platform is based on the infrastructure deployed in the Ada Byron research building. This platform integrates two LTE and 5G NR deployments: An outdoor deployment around the area of the building (Figure 12) that makes use of commercial Nokia equipment to provide coverage, and an indoor deployment where the radio access is provided by several pico RRHs. Both 5G deployments can work in standalone and non-standalone mode and sub-6GHz, while the outdoor deployment also makes use of two antennas for 5G mmW.



Figure 12. UMA outdoor deployment estimated coverage around Ada Byron building

The Ada Byron building also hosts several radio emulators and other measurement equipment, as well as the Core Network, Main Data Center and Edge Infrastructure used by both 5G deployments.

4 STAKEHOLDERS AND ROLES IN THE NETAPP ECOSYSTEM

4.1 STAKEHOLDERS AND ROLES IN THE 5G ECOSYSTEM

Through 5G and its innovative technological advancements, the performance requirements of a diverse set of service categories can be satisfied, delivering high data rates (referring to both aggregate and peak values from both the network and user experienced levels), low latency, enhanced mobility support and spectrum efficiency. At the same time, 5G capabilities incorporate automatic connectivity establishment for a vast range of smart appliances, machines and other objects without human intervention. The 5G technology promises to offer a specific set of premium service classes in a dedicated, guaranteed and extremely reliable manner, identified as follows:

- **Enhanced Mobile Broadband (eMBB)** addressing bandwidth intensive services and applications, including Augmented Reality (AR)/Virtual Reality (VR), Ultra-High Definition (UHD) Video sharing in heavily crowded hotspots, TV programs broadcasting, etc. The bandwidth requirements for this type of services are expected to be on average about 100 Mbps per user and can reach up to 10 Gbps (for broadcast services).
- **Ultra-Reliable and Low-Latency Communications (URLLC)** focusing on latency sensitive, wireless applications and services, some of which are impossible to be supported by existing network deployments. These services refer to “mission-critical” communications and include public safety lifeline and situational awareness, industrial automation, drone control, new medical applications, autonomous vehicles, etc. The latency requirements for this type of services range between 1ms-2ms for the radio interface and less than 10ms for the end-to-end data plane.
- **Massive Machine Type Communications (mMTC)** referring to massive Internet of Things (IoT) services extending the Long-Term Evolution (LTE) IoT (Narrow Band-IoT) to support huge numbers of devices with lower costs, enhanced coverage, and long battery life. With regard to ITU objectives, 5G will support ten times as many devices per area as LTE. This category includes eHealth, wearables, industrial control and factory automation, and sensor networks.

In the first quarter of 2021, 5G was already commercially available in 62 markets worldwide from 157 operators, and the forecast for 2025 considers 1.8 billion connections, with an adoption rate of 21% [8]. While 5G has appeared on the mass market with consumer facing offers, such as eMBB for Cloud Gaming not possible with 4G, it is the industrial applications that target to reveal the true potentials of the technology by exploring URLLC and mMTC capabilities. A recent study [9] forecasts that by 2030 the industries economic potential from leveraging 5G capabilities shall contribute US\$1.3tn to global GDP, with the majority attributed to healthcare applications (US\$530bn) and smart utilities management (US\$330bn), the latter closely associated with Industry 4.0 applications.

The 5G Public Private Partnership (5G PPP), the European initiative that is actively promoting 5G innovative solutions per industry (a.k.a. ‘Vertical’), has revealed the extended map of involved stakeholder categories, graphically depicted in Figure 13. As shown, the 5G adopters primarily considered are the business verticals that benefit significantly from the global digital transformation that is accelerated by 5G. In vertical sectors such as factories of the future, innovative use cases are identified and realized through the advanced features of 5G and are expected to become the revenue source to justify the significant investments necessary [9]. It is

noteworthy that among the advanced 5G features, the 5G New Radio (NR) interface and the network slicing functionality are considered the prevailing technology enablers across the majority of vertical categories.

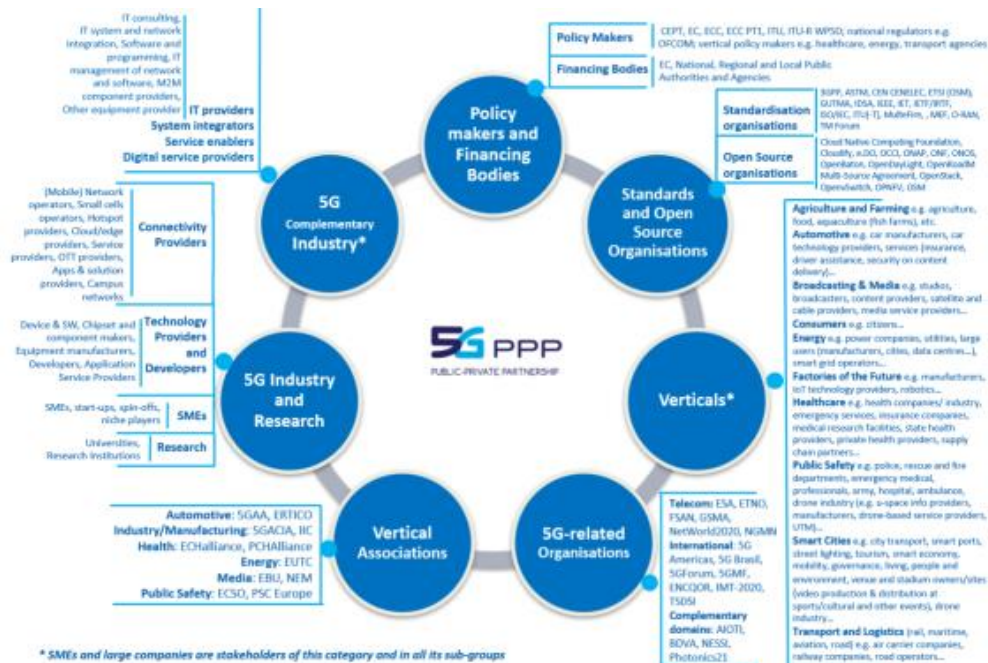


Figure 13. 5GPPP Target Stakeholder Groups and Stakeholders, April 2020 [10]

In such an ecosystem, various business models are expected to arise, and 5G PPP assesses through its trials the viability of 5G infrastructure investments, in either global or localized opportunities, and the foreseen role of private, public stakeholders, 3rd parties and SMEs. The 5GPPP’s “Business Validation, Models, and Ecosystems” Sub-Group (BVME-SG) is working to establish guidelines on best practice and approaches for business validation across all 5GPPP projects so that to facilitate a sustainable evolution of the 5G market. As part of this work [10], it is clarified that a **stakeholder**, equivalent to the term *actor* used in 3GPP TR 28.801, is a **party that holds a business interest or concern in the ecosystem**, while **role** (also business role) is the **expected function performed by a stakeholder in the ecosystem**. In this sense, a **business role can be mapped onto a stakeholder**, whereas a **stakeholder can perform one or more business roles**. EVOLVED-5G also adapts this terminology for the definition of stakeholders and roles.

Every ecosystem needs a series of stakeholders that will eventually define and shape such ecosystem, some of them will be considered as key stakeholders and will integrate what is usually called the backbone of the ecosystem. Therefore, the process associated with the identification of key stakeholders is a cornerstone for every ecosystem to emerge however, one ecosystem that is made up of just stakeholders is an empty ecosystem. Indeed, for every ecosystem to work we need to identify the role they would play in it and connect all these functions among them in order to find and design a comprehensive logic that would eventually determine the meaning and viability of the ecosystem itself.

As per the above-mentioned definition, every stakeholder will play one or several roles in the ecosystem which actually means that it will have one or several goals to meet. However, each stakeholder's role does not end there, but rather acts as a spearhead for another stakeholder to start performing its role(s). And so on and so forth. This is an iterative process that actually

leads to connections and dependencies among stakeholders, and the role they perform leads to one step further: Relationships, meaning the logic that lies underneath.

5G PPP white paper on architecture [11] drills into the specifics within the 5G Industry and Research group and the 5G provisioning ecosystem. Figure 14 depicted below is actually a reflection that exemplifies the basic stakeholder roles for provisioning 5G network services. In this Figure 14, it can be visualized how different roles interact with each other to perform different business communication and business services provisioning activities, all towards BSS/OSS systems interfacing the virtual or actual infrastructure resources.

While further work is still ongoing for business models around 5G to emerge, this 5G-PPP analytical view on stakeholders, roles and the interactions and relationships is adopted by EVOLVED-5G, as it tends to also constitute the very basic ground for a later development of EVOLVED-5G business models in WP7.

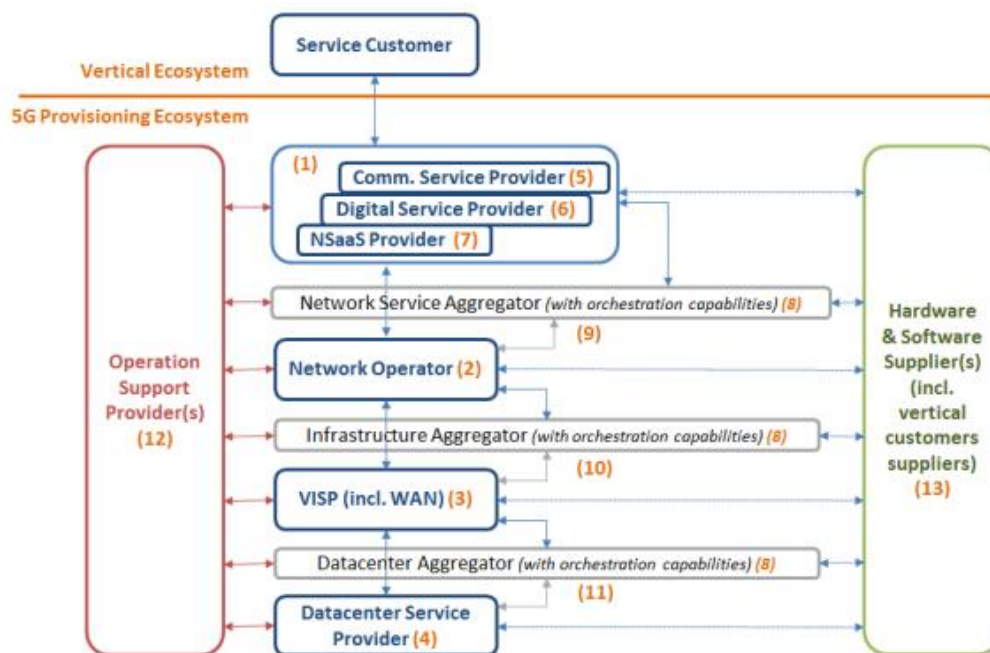


Figure 14. Stakeholder roles in the 5G ecosystem, February August 2021 [11]

The Stakeholder roles in a 5G ecosystem as described by 5G-PPP are the following:

- **Service Customer (SC):** It uses services that are offered by a Service Provider (SP). In the context of 5G, vertical industries are considered as one of the major SCs.
- **Service Provider (SP):** It comprises three sub-roles, depending on the service offered to the SC: Communication Service Provider offering traditional telecom services, Digital Service Provider offering digital services such as enhanced mobile broadband and IoT to various vertical industries, or Network Slice as a Service (NSaaS) Provider offering a network slice along with the services that it may support and configure. SPs design, build and operate services using aggregated network services.
- **Network Operator (NOP):** It oversees orchestrating resources, potentially from multiple virtualized infrastructure providers (VISP). The NOP uses aggregated virtualized infrastructure services to design, build, and operate network services that are offered to SPs.

- **Virtualization Infrastructure Service Provider (VISP):** It provides virtualized infrastructure services and designs, builds, and operates virtualization infrastructure(s). The infrastructure comprises networking (e.g., for mobile transport) and computing resources (e.g., from computing platforms).
- **Data Centre Service Provider (DCSP):** Provides data center services and designs, builds, and operates its data centers. A DCSP differs from a VISP by offering “raw” resources (i.e., host servers) in rather centralized locations and simple services for consumption of these raw resources. A VISP rather offers access to a variety of resources by aggregating multiple technology domains and making them accessible through a single API.

4.2 STAKEHOLDERS AND ROLES IN THE EVOLVED-5G ECOSYSTEM

As detailed in the previous section, the 5G evolution will allow the appearance of new use cases as well as the advancement of existing business models. Based on the distinction described in [10], the following sections delve into the different stakeholders and roles that have been identified as of special interest for the EVOLVED-5G project.

4.2.1 EVOLVED-5G Ecosystem Stakeholders

The background on 5G ecosystem reported above provides a detailed representation of the stakeholders and roles in the service provisioning phase. At the same time, EVOLVED-5G addresses the service creation phase, through the proposed NetApp development, verification, validation, and certification environments, revealing some extra roles and stakeholders to support this. The following Stakeholders have been identified as important for the EVOLVED-5G ecosystem. This is a basic and non-exhaustive list of all the possible actors that may be interested in NetApps, that is used to further drive the requirements analysis:

- **SME/Industry 4.0 SME:** Industry 4.0 SMEs are vertical providers and businesses that are interested in exploiting and bringing the new functionality provided by the 5G infrastructure so that it can be used in order to improve their new or existing applications (Vertical applications or VApps), exposing this functionality through the NetApps. Although main target is i4.0 SMEs, EVOLVED-5G also seeks impact on other 5G-enabled vertical industries. This broader vision makes the project to also consider SMEs from other verticals that would eventually benefit from the ecosystem.
- **Developers/Industry 4.0 NetApp Developer:** The NetApp developer, that can be an SME or a bigger software company, focuses on developing the NetApps with the aim to exploit the capabilities of the 5G network.
- **Technology providers/5G Equipment Vendor and Device Manufacturer:** These actors provide the hardware required in order to create a 5G infrastructure and to consume their services as end-users or during experimentation. They may be interested in making use of the NetApps for the implementation of the control software of the equipment.
- **Connectivity providers/5G Network Provider:** Traditionally this stakeholder refers to the MNOs (Mobile Network Operator) that have control over the network infrastructure and radio spectrum allocation required in order to provide wireless communication services to end users. From the point of view of EVOLVED-5G, MNOs are more interested in the certification of certain NetApps for usage within their networks, which can be distributed through the Marketplace. Nevertheless, as the Industry 4.0 business case has a strong footprint on Non Public networks (NPN) the role of the Network Operator within EVOLVED-5G, can be assumed by a company or research organization that has

the license and expertise to operate a campus network, thus providing the validation framework to onboard the NetApps.

- **5G Testbed Operator:** It is a distinctive alternative. The 5G testbed operator has access to a research network infrastructure. This infrastructure can be deployed inside a laboratory (making use of network emulators and other equipment) or include a real network infrastructure that can be used with commercial devices in a limited area, but which is not commercialized to end users. Such an example are the European Digital Innovation Hubs (EDIHs) or the 5G-PPP ICT-17 platforms, such as 5GENESIS.
- **Platform Provider:** It is a core stakeholder and addresses the software and hardware systems operation and the hosting of the vertical applications, services and NetApps. In relation to [11] the Platform Operator undertakes the role of VISP and data center provider. EVOLVED-5G is considering a clear separation between the 5G Network Provider and the Platform Operator stakeholder, for reasons of versatility as this separation allows more dynamic setups, including public or hybrid cloud infrastructures and revealing the potentials of more business models.
- **Open-source Community/Research Institutes/Universities:** These are higher educations that may be interested in designing training events, hackathons, or workshops around (but non-exclusively) the development of NetApps.
- **Policy Makers/Telecom certification organizations:** These are independent but leading organizations whose purpose is to ensure reliable and secure communication deployments according to international standards and criteria. Certain NetApps functionalities that are exposed through APIs could be a target for telecom certification organizations (like the Global Certification Forum) as main guarantors of interoperability in communications.

4.2.2 EVOLVED-5G Ecosystem Roles

In the context of EVOLVED-5G, the following Roles, with regards to the lifecycle of the NetApps, have been identified. Additionally, this section provides a possible mapping between some of the previously discussed stakeholders with regards to the different roles they are expected to take in the EVOLVED-5G ecosystem. This initial mapping, which is in no way exclusive, exemplifies how any stakeholder may take the lead on a different role, as it can be seen in Figure 15.

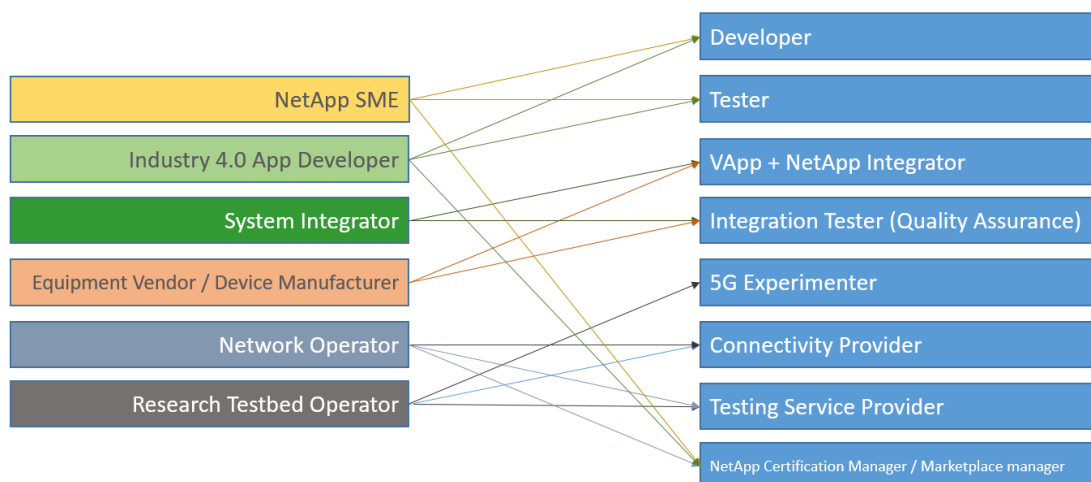


Figure 15. Mapping between stakeholders and roles in the EVOLVED-5G ecosystem

Table 1. Summary table of Roles and Stakeholders

Stakeholders	NetApp SME	Industry 4.0 App Developer	System Integrator	Equipment Vendor / Device Manufacturer	Network Operator	Research Testbed Operator
Roles						
Developer	✓	✓				
Tester	✓	✓				
VApp + NetApp Integrator	✓	✓	✓	✓		
Integration Tester (Quality Assurance)	✓	✓	✓	✓		
5G Experimenter	✓	✓	✓	✓	✓	✓
Connectivity Provider					✓	✓
Testing Service Provider					✓	✓
NetApp Certification Manager / Marketplace manager					✓	✓

- Development:** The Developers make use of the EVOLVED-5G SDK in order to create NetApps. They have a moderate understanding of the functionalities provided by the 5G APIs and their general usage procedure, albeit not necessarily an in-depth knowledge of the inner workings or the infrastructure below. Developers may be interested in creating NetApps that are specifically tailored for certain Vertical Apps, in which case they have a deep understanding of the requirements of that particular VApp and/or closely collaborate with the Industry 4.0 App developer, or may focus on the creation of generic NetApps that expose the 5G capabilities in a more flexible way, meaning that the NetApp functionality can be exploited by multiple Vertical Applications. The NetApp and Industry 4.0 SMEs App developers, given their knowledge in the NetApp development and the needs of the Industry 4.0 requirements are expected to take this role.
- Testing:** Testers are the actors that perform the initial verification of the NetApp. This includes the usage of the CI/CD pipeline provided as part of the EVOLVED-5G SDK Workspace and any other intermediate tests performed by other means (debugging tools, mocking, manual tests). In many cases this role will be fulfilled by the same actor that performs the Development of the NetApp but can possibly be another entity. As is the case for the Developer role, the expected actors for this role are the NetApp SME and Industry 4.0 App Developer SMEs, given their knowledge on the NetApp specifics. This role may be taken either by the same developers, or a different Q&A team within the same company.
- VApp + NetApp integration:** Stakeholders in this role perform the integration of an existing or new Vertical App with a NetApp that has completed the Verification Phase, in order to take advantage of the 5G functionality exposed by the NetApps. These actors have a deep understanding of the operation of their Vertical Apps as well as the required functionality to extract from the 5G APIs. The expected stakeholders for this role are the

System Integrators, Equipment Vendors and Device Manufacturers, given their interest in the creation of ready to use solutions.

- **Integration testing (Quality Assurance):** Integration testers collaborate with the Testing Service Provider during the Validation Phase, in order to assure the correct functionality of the Vertical App along with the NetApp in a 5G environment. As is the case for the Tester role, it is expected that this role will be also led by the same stakeholders as the VApp + NetApp integrator role, given their knowledge of the integration details.
- **5G Experimentation:** 5G Experimenter is a role that is interested in analyzing the integration/performance of Vertical Apps and/or NetApps as part of a scientific research, measuring and comparing 5G KPIs in different conditions. Research Testbed Operators are the expected stakeholders for this role, as they may be interested in using the existing infrastructure also for academic research.
- **Connectivity Provisioning:** Connectivity Providers have access to a network infrastructure in which a NetApp along with a Vertical App can operate. They also provide access to the underlying 5G APIs that are exploited by the NetApps. 5G Connectivity is expected to be provided by Mobile Network Operators and Research Testbed Operators, due to the availability of the required network infrastructure.
- **Testing Service Provisioning:** These actors provide the additional infrastructure necessary for performing the Validation Phase, on top of the network infrastructure provided by the “Connectivity Provider”. In the context of EVOLVED-5G, this infrastructure is based on the Open5Genesis Framework, however other validation frameworks may be used instead. The expected stakeholders for this role are Research Testbed Operators, as they have the required equipment for measuring the required KPIs for the Validation, however Mobile Network Operators may also assume this role in some cases.
- **NetApp Certification / Marketplace Management:** Stakeholders with these roles coordinate the certification and quality assurance of the NetApp, in order to guarantee that they meet the required criteria for being published in the Marketplace. They also provide support to end users and/or work on increasing the visibility of the NetApp in order to find new clients for their business. This role, which is more related to the market impact of the NetApp, is expected to be led by the Mobile Network Operator, who commercializes the NetApps, and NetApp and Industry 4.0 SMEs, who produce such NetApp.
- **End-User:** The end-user is whichever 3rd party making use of a NetApp published in the Marketplace, either directly (i.e., by integrating their own NetApp with their own Vertical App) or as a user of a Vertical App that integrates with the published NetApp. This broad role may be adopted by any of the previously discussed stakeholders, as well as any other party making use of the NetApp.

5 EVOLVED-5G NETAPP ECOSYSTEM REQUIREMENTS

The EVOLVED-5G vision on the 5G NetApp ecosystem, proposes an all-encompassing framework that follows the lifecycle of the NetApp from the development to the deployment and operation stages. To make sure that the analysis phase will capture all appropriate requirements for this broad architecture, the project has put special effort to define and follow a structured requirements gathering methodology that is presented in Section 5.1. As a result, the requirements are classified around key project topics, namely the:

- **Business-related requirements for the introduction of NetApps** in the Industry 4.0 era are presented in section 5.2.
- **5G network infrastructure requirements** are presented in section 5.3 in order to capture the innovative characteristics expected by the 5G communication network.
- **Compute and Data infrastructure requirements** are presented in section 5.4 to identify data center and virtualisation prerequisites to realise the end solution.
- **NetApp lifecycle requirements** are presented in section 5.5 in order to capture the EVOLVED-5G tool-chain characteristics.

5.1 THE REQUIREMENTS GATHERING METHODOLOGY

The project has followed an agile approach for the requirements analysis, following industry best practices¹. To ensure that the ‘Right People’ are assembled, and ‘Everyone in the Room’ is engaged, the requirements were revised in weekly calls with all consortium partners from early on in the project. Brainstorming has been facilitated in the ‘Record Information’ process, with the use of the project’s cloud repository and a collaboratively edited file in excel format with a type-checked structured manner. The requirement description was analytically defined as presented in Table 2, and champions per technical topic undertook the ‘Rinse and Repeat’ process to ensure the completeness and correctness per case. The target of this work has not been to provide an exhaustive and unruly list of technical details, but rather to determine the key demands to stir the design phase to identify the proper means to address them.

Table 2. Requirements Description Template

Field	Description
REQ-ID	A unique ID, in the form REQ-TASK-PRIORITY-TYPE-#, where: TASK = I4 IEM FOF SEC PLI 5G DEV PI <ul style="list-style-type: none"> • I4: Industry 4.0 • IEM: Interaction of employees and machines domain • FOF: Factory of the Future operations • SEC: Security guarantees and risk analysis • PLI: Production line infrastructure • I4MARKET: Industry4 Marketplace • 5G: 5G Technology • DEV: System & Software Development • PI: Physical Infrastructure
Short Title	Meaningful and not too long description.
Description	A brief text explaining the requirement, including the objectives where necessary.

¹ <https://www.dragonspears.com/blog/5-step-agile-approach-to-a-productive-requirements-gathering-phase>

Field	Description
Priority	Inspired by MoSCoW: <ul style="list-style-type: none"> • M: Must-have. Mandatory requirement. • S: Should-have. Desirable requirement. • C: Could-have. Optional requirement. • W: Will-not-have. Possible future enhancement.
Type	TYPE = FUNC DATA USE REL SEC PERF COMP MAINT PORT: <ul style="list-style-type: none"> • FUNC: Functional Suitability • DATA: Data • USE: Usability • REL: Reliability • SEC: Security • PERF: Performance Efficiency • COMP: Compatibility • MAINT: Maintainability • PORT: Portability
Topic	It is used to further cluster requirements around the intended functionality and phase of the NetApp lifecycle. Example topics are: Verification, Validation, Certification, Marketplace, vApp Pillar specific.
Primary Actor	The primary actor involved in or affected by this requirement.

5.2 BUSINESS-RELATED REQUIREMENTS

This section focuses on the requirements driven by the Industry 4.0 business, as expected by the vertical Apps (vApps) and the NetApps targeted by the project. EVOLVED-5G has classified the work around four main Industry 4.0 pillars, namely, innovation in the interaction of employees and machines (IEM); efficiency in FoF operations (FoF); Security guarantees and risk analysis (SEC); and agility in the production line infrastructure (PLI). The joint analysis of these pillars has resulted in a set of commonly identified requirements that are listed in Table 3. Specific requirements targeting particular vertical pillars were also identified and are presented in Table 4. In addition, pillar specific KPIs as identified are presented in Table 5 of Finally, requirements stemming from the overall EVOLVED-5G business enablers around the necessary certification and broad availability of NetApps through a marketplace are addressed in Table 6.

Table 3. EVOLVED-5G Industry 4.0 NetApp Common Requirements

REQ-I4-M-FUNC-1	NetApps - NEF standardised interaction		
Description	NetApps shall be able to interact with the NEF in the 5G network through the standardized northbound APIs specified in 3GPP TS 29.522 v7.1.0. [12]		
Priority	Mandatory	Type	Functional Suitability
	NetApp Interfaces	Primary Actor	NetApp Developer
REQ-I4-M-COMP-2	NetApps conformance to specifications		
Description	A NetApp shall be able to support one or more of the northbound APIs specified in 3GPP TS 29.522 v7.1.0 [12]		
Priority	Mandatory	Type	Compatibility
Topic	NetApp Interfaces	Primary Actor	NetApp Developer

REQ-I4-M-FUNC-3	NetApps - VApps interaction		
Description	Standalone NetApps shall be able to interact with the vertical apps (provided by vertical developers) through open-source Restful APIs that will be specified in the project.		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	NetApp Developer
REQ-I4-M-MAINT-4	NetApp remote operational control		
Description	The NetApp shall provide means for remote operational control from the vAPP.		
Priority	Mandatory	Type	Maintainability
Topic	NetApp Interfaces	Primary Actor	NetApp Developer
REQ-I4-S-SEC-5-	User authorisation to experimentation/development data		
Description	The EVOLVED-5G Framework should ensure that the Netapp developers/experimenters are authorized to perform tests and that they will not be able to access other experimenters' data.		
Priority	Desirable	Type	Security
Topic	Security, Verification	Primary Actor	NetApp Developer, Platform Provider
REQ-I4-M-SEC-6	NetApps - VApps secure communication		
Description	The connectivity link between NetApp and the vAPPs shall be secure, potentially with end-to-end encryption.		
Priority	Mandatory	Type	Security
Topic	Security	Primary Actor	NetApp Developer, 5G Network Provider
REQ-I4-M-SEC-7	NetApps user authentication		
Description	The NetApp shall support various levels of authorization (remote user / centralized user / administrator etc.) and identification.		
Priority	Mandatory	Type	Security
Topic	Security	Primary Actor	NetApp Developer
REQ-I4-S-REL-8	vApp QoS Alerting		
Description	NetApps should alert vApps if expected QoS cannot be reached in order to trigger adaptation mechanisms on vApps side. The QoS could be the output of monitoring values / performance metrics, such as latency, throughput, uptime, and QoS metrics specific to the NetApps and vApps being used.		
Priority	Desirable	Type	Reliability
Topic	Monitoring	Primary Actor	NetApp Developer

REQ-I4-S-REL-9	NetApp Behavior Monitoring		
Description	NetApps should be authorised to access exposed APIs based on continuous monitoring (behavior, traffic patterns, queries, etc.) provided by the platform. The monitored access can ensure appropriate behavior of the NetApps and the detection of any potentially malicious NetApps, which might misuse the exposed APIs (e.g., malicious NetApps performing DDoS-type attacks).		
Priority	Desirable	Type	Reliability, Security
Topic	Monitoring	Primary Actor	NetApp Developer
REQ-I4-M-FUNC-10	NetApp CAPIF capabilities		
Description	Trusted NetApp should support several CAPIF capabilities such as: <ul style="list-style-type: none"> The authentication and obtaining authorization and discovering using CAPIF-1 reference point as defined in 3GPP TS 23.222 [13] Invoking the Service APIs using CAPIF-2 referenced point as defined in 3GPP TS 23.222 [13], e.g. the T8 interface as defined in 3GPP TS 29.122 [14] or the NEF Northbound interface as defined in 3GPP TS 29.522 [15]. 		
Priority	Mandatory	Type	Functional Suitability, Security
Topic	NetApp interfaces	Primary Actor	NetApp Developer
REQ-I4-M-FUNC-11	NetApp onboarding capability		
Description	NetApp should be able to onboard the 5G network using standardized HTTP request methods, leveraging the CAPIF capabilities offered by the platform (CAPIF_API_Invoker_Management_API supported and exposed by the underlying network infrastructure).		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp interfaces	Primary Actor	NetApp Developer
REQ-I4-M-FUNC-12	NetApp offboarding capability		
Description	NetApp should be able to offboard the 5G network using standardized HTTP request methods, leveraging the CAPIF capabilities offered by the platform (CAPIF_API_Invoker_Management_API supported and exposed by the underlying network infrastructure).		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp interfaces	Primary Actor	NetApp Developer
REQ-I4-M-FUNC-13	NetApp service discovery capability		
Description	NetApp shall be able to communicate with the underlying network through CAPIF_Discover_Service_API using standardized HTTP request methods, to discover the published service API information. In this way NetApps act as service consumers.		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp interfaces	Primary Actor	NetApp Developer

REQ-I4-M-FUNC-14	NetApp security method negotiation capability		
Description	NetApp shall be able to communicate with the underlying network through CAPIF_Security_API using standardized HTTP request methods, to negotiate and obtain service API security method [PSK, PKI, OAUTH]. Upon receiving this information, the NetApp shall be able to authenticate and obtain authorization to access service APIs.		
Priority	Mandatory	Type	Functional Suitability, Security
Topic	NetApp interfaces	Primary Actor	NetApp Developer
REQ-I4-M-FUNC-15	NetApp event subscription capability		
Description	NetApp shall be able to subscribe to and unsubscribe from CAPIF events and receive subsequent notification of CAPIF events, leveraging the CAPIF_Events_API exposed by the underlying network.		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp interfaces	Primary Actor	NetApp Developer

Table 4: Industry 4.0 Pillar Specific Requirements

REQ-IEM-M-PERF-1	Time-Sensitive Data Processing & Networking		
Description	NetApps must allow vApps to manage time-sensitive data (strong synchronicity mechanisms, real-time required).		
Priority	Mandatory	Type	Performance Efficiency
Topic	(IEM) Interaction of employees and machines	Primary Actor	NetApp Developer, Vertical
REQ-IEM-DATA-2	Geolocalisation data		
Description	The NetApp should provide geo localisation data. This is important in order to confirm the detailed location of the machine (e.g. robot, airplane) within the plant (e.g. factory or airport) and retrieve related data for the necessary actions (ex. stir or repair).		
Priority	Mandatory	Type	Data
Topic	(IEM) Interaction of employees and machines	Primary Actor	NetApp Developer, Vertical
REQ-IEM-M-PERF-3	Multimedia files sharing		
Description	The NetApp must provide a file server to enable the vApp to share multimedia files (images, videos)		
Priority	Mandatory	Type	Performance Efficiency
Topic	(IEM) Interaction of employees and machines	Primary Actor	NetApp Developer, Vertical
REQ-IEM-M-SEC-4	Unique User Identification		
Description	The NetApp must be able to acquire a unique user ID for each UE.		
Priority	Mandatory	Type	Security
Topic	(IEM) Interaction of employees and machines	Primary Actor	NetApp Developer, 5G Equipment Vendor

REQ-PLI-M-COMP-5	NetApp to support ROS		
Description	The NetApp should have an interface or a wrapper for ROS (Robot Operating System) since all EVOLVED-5G robots as most robots use ROS to work.		
Priority	Mandatory	Type	Compatibility
Topic	(PLI) Production line infrastructure	Primary Actor	NetApp Developer
REQ-PLI-M-COMP-6	Interaction with integrated devices		
Description	The integrated devices should provide sensor input data, and linear/angular velocity control over ROS interfaces.		
Priority	Mandatory	Type	Compatibility
Topic	(PLI) Production line infrastructure	Primary Actor	NetApp Developer
REQ-PLI-M-COMP-7	Adaptive Data Traffic Management		
Description	AMS (Adaptive Management and Security System) has to be available for security measures, optimization of the throughput and service priorities (i.e. the transmission of robot commands must never be blocked by a bandwidth-consuming video stream). Two channels should be available for the robot if possible: one with a guaranteed bandwidth to send video, etc.; another one for a guaranteed latency to send/receive commands		
Priority	Mandatory	Type	Compatibility
Topic	(PLI) Production line infrastructure	Primary Actor	NetApp Developer

Table 5. NetApps Certification & Marketplace Requirements

REQ-I4MARKET-M-USE-1	Certification environment isolation		
Description	EVOLVED-5G shall provide the Tools and Certification Environment for Developers to Certify NetApps according to EVOLVED-5G Certification Process. Certification Environment configuration shall be clearly defined and separated from Validation Environment configuration, especially as shared infrastructure components can be used (e.g. both to be instantiated on the 5GENESIS Platform).		
Priority	Mandatory	Type	Usability
Topic	Certification	Primary Actor	Platform Provider
REQ-I4MARKET-M-FUNC-2	Certification report availability		
Description	A certification report shall be generated to detail the 3GPP APIs tested, and list the results (OK/NOK) of the functional/non functional tests performed. The results of the tests shall be available either by a validation report attached or as a reference/link that proves that the app is validated.		
Priority	Mandatory	Type	Functional Suitability
Topic	Certification	Primary Actor	Platform Provider
REQ-I4MARKET-M-REL-3	Certification verdict transparency		

Description	The certification verdict shall be traceable and results shall be reproducible to allow for transparency.		
Priority	Mandatory	Type	Reliability
Topic	Certification	Primary Actor	Platform Provider
REQ-I4MARKET-M-MAIN-4	Certification process automation		
Description	The certification process (based in CICD toolset) shall be invoked using APIs.		
Priority	Mandatory	Type	Maintainability
Topic	Certification	Primary Actor	Platform Provider
REQ-I4MARKET-M-FUNC-5	Certification report on target limitations and restrictions		
Description	Certification Process shall consider target execution environment characteristics and report on limitations and restrictions.		
Priority	Mandatory	Type	Functional Suitability
Topic	Certification	Primary Actor	Platform Provider
REQ-I4MARKET-W-DATA-6	NetApp licensing		
Description	The NetApp shall be accompanied by all the license files needed. An automated scan (such as black duck ²) should be performed in case of Open Source used during development.		
Priority	Future Enhancement	Type	Data
Topic	Certification	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-7	GDPR certification		
Description	Conformance with GDPR should be included either as attachment or as a reference/link.		
Priority	Mandatory	Type	Functional Suitability
Topic	Certification	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-8	Certification is integral to the Marketplace		
Description	Certification of NetApps must be successfully completed before the NetApp can be on boarded in the Marketplace.		
Priority	Mandatory	Type	Functional Suitability
Topic	Certification, Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-9	Documentation certification		
Description	Documentation on the usage/deployment of the NetApp shall be audited and included in the package to be uploaded in the Marketplace Product Catalogues.		

² <https://www.blackducksoftware.com/>

Priority	Mandatory	Type	Functional Suitability
Topic	Certification, Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-10	NetApp package distribution certification		
Description	NetApp metadata (i.e API endpoints, Smart contract details) shall be audited and included in the package to be uploaded in the Marketplace Product Catalogues.		
Priority	Mandatory	Type	Functional Suitability
Topic	Certification, Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-11	Marketplace repository		
Description	A public repository shall be available to store, search and download certified Apps and NetApps that are willingly uploaded (NetApp compiled version / artifact).		
Priority	Mandatory	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-12	Business registration in the marketplace		
Description	SMEs and Companies shall register in the Marketplace with all necessary information (such as Name of the Company, Social address, Country, Vertical domain or sector, Main contact point) so that to be properly identified as a business entity.		
Priority	Mandatory	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-13	SaaS NetApp Offering		
Description	The Marketplace shall market the NetApps as SaaS (Service as a Product), in other words as a centrally hosted productized service sold by the seller/vendor to the buyer.		
Priority	Mandatory	Type	Mandatory
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-S-FUNC-14	NetApp price in the Marketplace		
Description	The NetApp should require setting price before launching to the marketplace.		
Priority	Desirable	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-15	Marketplace payments		
Description	Payment Settlement shall happen outside the Marketplace using certified external payment gateways (ex. 3D-Secure platforms).		
Priority	Mandatory	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer

REQ-I4MARKET-C-FUNC-16	Marketplace Questionnaire		
Description	The marketplace may provide a questionnaire for the SMEs to fill out before uploading a NetApp in order to describe the list of features.		
Priority	Optional	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-17	Marketplace user engagement channels		
Description	The Marketplace shall provide the ability for user engagement through different channels. (E-shop, Mobile App, Bots etc).		
Priority	Mandatory	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-18	Wizard-Type interfaces		
Description	The Marketplace shall support wizard type interfaces for onboarding and order Management of NetApps.		
Priority	Mandatory	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-19	NetApp bundles in Marketplace		
Description	The Marketplace should provide CPQ (Configure, Price, Quote) functionality using Wizards. Bundles of NetApps shall be supported.		
Priority	Mandatory	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-M-FUNC-20	Marketplace dashboards		
Description	The Marketplace shall provide dashboards for publishers and consumers for monitoring revenue/balance, API performance, consumption etc.		
Priority	Desirable	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-S-MAIN-21	Marketplace implementation with Open APIs		
Description	The Marketplace should be implemented using Open APIs (i.e TN Forum) available.		
Priority	Desirable	Type	Maintainability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer
REQ-I4MARKET-W-FUNC-22	Marketplace should support Smart Contracts		
Description	The Marketplace should support the interface for deploying Smart contracts on a Blockchain platform.		

Priority	Future Enhancement	Type	Functional Suitability
Topic	Marketplace	Primary Actor	Platform Provider, NetApp Developer

5.3 5G NETWORK INFRASTRUCTURE REQUIREMENTS

This section gathers the requirements that relate to the 5G technology, relating to both the network equipment, access and core network components as well as the orchestration and monitoring capabilities.

Table 6. 5G Network infrastructure Requirements

REQ-5G-M-FUNC-1	NEF support in 5G network		
Description	The 5G network shall support a Network Exposure Function (NEF), which exposes one or more of the northbound APIs specified in 3GPP TS 29.522 v7.1.0. [12]		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Equipment Vendor
REQ-5G-M-FUNC-2	Minimum NEF northbound APIs support		
Description	The Network Exposure Function (NEF) shall support at least the following northbound APIs: <ul style="list-style-type: none"> • APIs that enable the vertical applications (via NetApps) to indicate to the 5G network the quality-of-service requirements for selected IP flows. • APIs that enable the vertical applications (via NetApps) to retrieve analytics information from the 5G network. 		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Equipment Vendor
REQ-5G-M-FUNC-3	NetApps compliance with underlying network		
Description	NetApps shall be able to interact with any 3GPP-compliant 5G network infrastructure, independent of the 5G network vendor.		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider
REQ-5G-M-COMP-4	Standalone 5G available		
Description	The 5G system shall support standalone mode of 5G operation.		
Priority	Mandatory	Type	Compatibility
Topic	Deployment	Primary Actor	5G Equipment Vendor

REQ-5G-S-USE-5	Straightforward 5G connection		
Description	Connecting hardware components (computer, mobile phone, augmented reality headset, etc.) to the 5G network should be easy (i.e. will require no specific configuration but using a valid SIM) for non-experts end users.		
Priority	Desirable	Type	Usability
Topic	Configuration	Primary Actor	SMEs
REQ-5G-M-FUNC-6	Spectrum allocation		
Description	The infrastructure shall allocate the radio-frequency spectrum required to achieve 5G throughput end-to-end.		
Priority	Mandatory	Type	Functional Suitability
Topic	Configuration	Primary Actor	5G Network Provider
REQ-5G-M-MAIN-7	vAPP deployment configuration		
Description	The orchestration platform shall enable proper configuration of vAPPs deployed at a network slice to be able to reach NetApp.		
Priority	Mandatory	Type	Maintainability
Topic	Configuration	Primary Actor	Platform Provider, NetApp Developer
REQ-5G-M-PERF-8	Guaranteed QoS per data type		
Description	5G infrastructure shall have a way to configure and to reserve a minimum bandwidth and latency for different types of data.		
Priority	Mandatory	Type	Performance Efficiency
Topic	Network Slicing	Primary Actor	NetApp Developer, 5G Network Provider
REQ-5G-M-FUNC-9	Mapping of NetApp to NSD		
Description	The NetApp blueprint shall be mapped to a Network Slice Descriptor in order to be usable by the Validation Framework.		
Priority	Mandatory	Type	Functional Suitability
Topic	Network Slicing	Primary Actor	NetApp Developer, 5G Network Provider
REQ-5G-S-FUNC-10	Slice Template in NetApps		
Description	NetApp package should include 5G Slice definition template (following GSMA definition). This template would be optional to use by the 5G Network Provider.		
Priority	Desirable	Type	Functional Suitability
Topic	Network Slicing	Primary Actor	NetApp Developer, 5G Network Provider
REQ-5G-S-PERF-11	Network Slice management from NetApps		
Description	NetApps should be allowed to manage and monitor network slices in order to obtain appropriate QoS for different type of data.		
Priority	Desirable	Type	Performance Efficiency
Topic	Network Slicing	Primary Actor	NetApp Developer, 5G Network Provider

REQ-5G-S-FUNC-12	Resource isolation		
Description	The infrastructure should provide means for resource sharing and multiple accesses support. In addition, it shall provide appropriate mechanisms for isolation of resource usage where applicable (i.e., for slicing).		
Priority	Desirable	Type	Functional Suitability
Topic	Network Slicing	Primary Actor	5G Network Provider
REQ-5G-S-FUNC-13	Network setting delegation to UE		
Description	5G Core infrastructure should support external network settings (e.g. network IP address, DNS servers, etc.) to the UE from the FoF system.		
Priority	Desirable	Type	Functional Suitability
Topic	Configuration	Primary Actor	NetApp Developer, 5G Network Provider
REQ-5G-S-SEC-14	NetApps extended user authentication		
Description	5G Core infrastructure should support extended user/UE (e.g. RADIUS/LDAP) authentication to the FoF AAA system.		
Priority	Desirable	Type	Security
Topic	Security	Primary Actor	5G Network Provider
REQ-5G-S-SEC-15	Dynamic discovery of and access to exposed NetAPP APIs		
Description	The infrastructure should support dynamic access of exposed APIs from NetApps. Dynamic and intelligent (traffic, context aware) authentication, authorisation and access control mechanisms to ensure access to the correct entities.		
Priority	Desirable	Type	Security
Topic	Security	Primary Actor	5G Network Provider, NetApp Developer
REQ-5G-M-SEC-16	Security, integrity and reliability of the communication link between NetApp and Network		
Description	The communication link between the NetApps and the APIs of control plane of a mobile network shall be integrity and confidentiality protected.		
Priority	Mandatory	Type	Security
Topic	Security	Primary Actor	5G Network Provider, NetApp Developer
REQ-5G-M-SEC-17	CAPIF-based user authentication for NetApps		
Description	The infrastructure shall support authentication and authorization of NetApps requesting access to exposed 5G APIs, based on OIDC/Auth 2.0 protocol.		
Priority	Mandatory	Type	Security
Topic	Security	Primary Actor	5G Network Provider, NetApp Developer
REQ-5G-M-SEC-18	NetApps identity authorization for service discovery		
Description	The 5G network shall be able to verify the identity of the NetApp (service consumer) and determine if the NetApp is authorized to discover the service APIs.		
Priority	Mandatory	Type	Security
Topic	Security	Primary Actor	5G Network Provider, NetApp Developer

REQ-5G-S-FUNC-19	5G network additional CAPIF capabilities		
Description	<p>The 5G network shall support the following CAPIF capabilities:</p> <ul style="list-style-type: none"> • Providing the service API access policy. • Logging of service API invocations. • Charging of service API invocations. 		
Priority	Desirable	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider
REQ-5G-M-FUNC-20	Service APIs administration support		
Description	<p>The 5G network enables the administration of the Service APIs. Such administration capabilities may include:</p> <ul style="list-style-type: none"> • Querying the Service API invocation log for auditing. • Monitoring the events. • Configuring the policies and monitoring the status of the Service APIs. 		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider
REQ-5G-M-FUNC-21	NetApps onboarding support		
Description	<p>The 5G network supports the CAPIF_API_Invoker_Management_API which allows the NetApp to onboard/offboard itself to/from the underlying network. Upon receiving the proper HTTP request message, the underlying network shall verify if it can determine authorization of the request and on-board/offboard the NetApp.</p>		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider
REQ-5G-M-FUNC-22	Service APIs exposure and discovery support		
Description	<p>The 5G network supports the CAPIF_Discover_Service_API which allows the NetApp to communicate with the CAPIF-enabled network platform to discover the published service API information. If the NetApp is authorized to discover the service APIs, the underlying network shall be able to return the filtered search results (list of service APIs).</p>		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider
REQ-5G-M-FUNC-23	NetApps-5G network secure communication methods		
Description	<p>The 5G network supports the CAPIF_Security_API which allows:</p> <ul style="list-style-type: none"> • The NetApp to (re-)negotiate the service security method [PSK, PKI, OAUTH] and obtain authorization for invoking service APIs; and • The 5G platform to obtain authentication information of the NetApp in order to authenticate the NetApp or revoke the authorization for service APIs access. 		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider
REQ-5G-M-FUNC-24	Events subscription and notification support		
Description	<p>The 5G network supports the CAPIF_Events_API which allows the NetApp to properly communicate with the platform to:</p>		

	<ul style="list-style-type: none"> Subscribe to and unsubscribe from CAPIF events (such as availability events of service APIs, change in service API information, monitoring service API invocations, API invoker onboarding events, etc.). Receive subsequent notification of CAPIF events. 		
Priority	Mandatory	Type	Functional Suitability
Topic	NetApp Interfaces	Primary Actor	5G Network Provider

5.4 COMPUTE AND DATA INFRASTRUCTURE REQUIREMENTS

This section contains the physical infrastructure requirements that in principle involve the data center capabilities that shall host the EVOLVED-5G solution including the edge technologies to be employed.

Table 7. Compute and Data Infrastructure requirements

REQ-PI-S-PORT-1	Integration of experimenter's complimentary components		
Description	The platform should support the integration of a virtual or physical infrastructure component brought by the experimenter in order to conduct the relevant experimentation and validate KPI related objectives. This may be permitted under certain conditions and safety regulations and is strongly dependent on the actual functionality provided by the component. For example, a new radio component that uses frequency that is not licensed cannot be allowed to be deployed.		
Priority	Desirable	Type	Portability
Topic	Configuration	Primary Actor	Platform Provider

REQ-PI-M-FUNC-2	NetApp deployment at Edge		
Description	When required by NetApps, Edge Infrastructure shall be available for deploying NetApps (Edge can be on premise, on local/private cloud environments or public cloud). Edge Infrastructure should support deployment of NetApps (i.e. Containers) using industry standard tools such as Terraform.		
Priority	Mandatory	Type	Functional Suitability
Topic	Deployment	Primary Actor	Platform Provider, Factory
REQ-PI-M-FUNC-3	NetApp deployment tools		
Description	Compute infrastructure used for Deployment shall provide APIs and Tools to Deploy and orchestrate function virtualization via virtual machines or containers and virtual networking.		
Priority	Mandatory	Type	Functional Suitability
Topic	Deployment	Primary Actor	Platform Provider, NetApp Developer
REQ-PI-M-FUNC-4	Infrastructure VPN access		
Description	The infrastructure shall provide Virtual Private Network (i.e. OpenVPN) access to the vApps, Netapps and robots for remote operation.		
Priority	Mandatory	Type	Functional Suitability
Topic	Security, Maintainability	Primary Actor	Platform Provider, NetApp Developer
REQ-PI-M-FUNC-5	NetApps Public deployment		
Description	NetApps shall support being instantiated in a "Public Infrastructure provider" to be defined.		
Priority	Mandatory	Type	Functional Suitability
Topic	Deployment	Primary Actor	NetApp Developer
REQ-PI-M-FUNC-6	NetApps artifacts deployment		
Description	Downloaded NetApp binaries/artifacts, shall be "easily" instantiated in Private Cloud Environments (K8s clusters, Openstack?) using standard K8s tools.		
Priority	Mandatory	Type	Functional Suitability
Topic	Deployment	Primary Actor	NetApp Developer
REQ-PI-S-PERF-7	Cloud native elasticity		
Description	NetApps should implement scale in/out or up/down standard procedures in containers/VMs in order to support high volumes of traffic and number of users.		
Priority	Desirable	Type	Performance Efficiency
Topic	Deployment	Primary Actor	Platform Provider
REQ-PI-M-MAINT-8	Monitoring, Logging, Alerting		

Description	The platform shall provide monitoring, log and alert access to the vAPP control plane applications. The monitoring should include the following information (not exhaustive): application availability (could be quantified with a ratio between request failures and total requests), uptime, performance metrics which indicate how well the vAPP is running (these will be different depending on the vAPP), latency (latencies per API method between the 5G infrastructure, the NetApp, and the vAPP), consistency (e.g., when creating or removing an object, how soon is the effect observable), resource usage (e.g., CPU utilization/load, memory used, disk space used), dependencies on external services/apps, such as payment processing systems (availability, latency, throughput), database monitoring if there is one (capacity, throttling, utilization, connections, lag time), and network-related monitoring.		
Priority	Mandatory	Type	Maintainability
Topic	Monitoring	Primary Actor	Platform Provider, NetApp Developer

5.5 NETAPP LIFECYCLE REQUIREMENTS

The requirements related to the NetApps development environment, verification, validation and testing activities are summarised in Table 8.

Table 8. NetApp Lifecycle Requirements

REQ-DEV-M-FUNC-1	NetApp Blueprint		
Description	The developer shall provide a NetApp blueprint that describes how the NetApp is built, deployed and communicates.		
Priority	Mandatory	Type	Functional Suitability
Topic	Development	Primary Actor	NetApp Developer
REQ-DEV-S-MAINT-2	Availability of the NetApp Code		
Description	The NetApp code should be publicly available to promote further development & extensions or new NetApps.		
Priority	Desirable	Type	Maintainability
Topic	Development	Primary Actor	NetApp Developer
REQ-DEV-S-USE-3	NetApp repository access		
Description	NetApps' development environment repositories should be programmatically accessible by some tool (e.g. Command line interface (CLI)).		
Priority	Desirable	Type	Usability
Topic	Development	Primary Actor	NetApp Developer
REQ-DEV-S-FUNC-4	NetApp repository characteristics		
Description	The development environment of NetApps should allow (1) creating branches, (2) commit changes, (3) pull and push and (4) creation and cloning to/from repositories. (5) Different member's options should be available (e.g. owner, contributor, collaborator), (6) ticketing/issues tracking system (7) support different status identification (e.g. draft, internal testing, etc.).		
Priority	Desirable	Type	Functional Suitability
Topic	Development	Primary Actor	NetApp Developer
REQ-DEV-M-FUNC-5	EVOLVED-5G SDK Automation		
Description	EVOLVED-5G SDK (Software Development Kit) will provide the Development Tools and Environment for developers to code NetApps, and automated Tests to complete the NetApp Verification.		
Priority	Mandatory	Type	Functional Suitability
Topic	Development/Verification	Primary Actor	NetApp Developer
REQ-DEV-M-PORT-6	Verification tools virtualization		
Description	Verification tools shall be virtualized (e.g. dockerized) to provide a quick execution of an isolated environment.		
Priority	Mandatory	Type	Portability
Topic	Verification	Primary Actor	NetApp Developer

REQ-DEV-M-USE-7	5G APIs Emulator providing GUI		
Description	An emulator of the 5G Northbound APIs shall be made available to be used for the first-phase development of NetApps, and shall offer a graphical user interface towards the NetApp developer to test the available APIs.		
Priority	Mandatory	Type	Usability
Topic	Verification	Primary Actor	NetApp Developer
REQ-DEV-M-COMP-8	5G APIs Emulator 3GPP compliant		
Description	The 5G APIs emulator shall support request/response and Subscribe/Notify communication as defined in 3GPP TS 29.501 (Section 4.6) [16]		
Priority	Mandatory	Type	Compatibility
Topic	Verification	Primary Actor	NetApp Developer
REQ-DEV-S-FUNC-9	5G APIs Emulator capabilities		
Description	The 5G APIs emulator shall allow the NetApp to: (1) have access to API calls for "reading" and influencing traffic routing in the network; (2) have access to information regarding various analytics in the 5G network in order to be able to make decisions/high-level functions based on the overall network status; and (3) to inquire the 5G network for information concerning devices' ipv6 and mac addresses.		
Priority	Desirable	Type	Functional Suitability
Topic	Verification	Primary Actor	NetApp Developer
REQ-DEV-M-FUNC-10	5G APIs Emulator simulation tools		
Description	The 5G APIs emulator should provide simulations of traffic (packet exchange) within a 5G network and be able to "cooperate" with a developed NetApp or vertical application that needs to inspect/snoop packages (at least provide access to a sample subset of exchanged packages).		
Priority	Mandatory	Type	Functional Suitability
Topic	Verification	Primary Actor	NetApp Developer, SME
REQ-DEV-M-USE-11	Exclusive verification tests		
Description	The developer shall be able to execute verification and smoke tests in an isolated environment on the validation platforms according to EVOLVED-5G Validation Framework.		
Priority	Mandatory	Type	Usability
Topic	Validation	Primary Actor	NetApp Developer, Platform Provider
REQ-DEV-M-USE-12	NetApp validation automation		
Description	Tests provided during Development/Verification, Validation and Certification need to be 100% Automated based in EVOLVED-5G CI/CD tools		
Priority	Mandatory	Type	Usability
Topic	Validation	Primary Actor	NetApp Developer, Platform Provider
REQ-DEV-S-MAIN-13	Open-sourced validation tools		
Description	Validation tools should be open-sourced, unless specific contractual obligations prevents this for some components or parts of the code.		

Priority	Desirable	Type	Maintainability
Topic	Validation	Primary Actor	NetApp Developer, Platform Provider
REQ-DEV-S-PORT-14	Validation framework containerization		
Description	Validation framework should be virtualized (e.g. containerized) whenever possible, to provide a quick execution on an isolated environment.		
Priority	Desirable	Type	Portability
Topic	Validation	Primary Actor	Platform Provider
REQ-DEV-M-FUNC-15	Cloud-native compatibility		
Description	The Validation Framework shall support the deployment of cloud-native functions.		
Priority	Mandatory	Type	Functional Suitability
Topic	Validation	Primary Actor	Platform Provider
REQ-DEV-M-FUNC-16	Testbed-Experimenter collaboration		
Description	Specific details about the verification tests (scope, implementation) shall be agreed between the experimenter and the testbed owners.		
Priority	Mandatory	Type	Functional Suitability
Topic	Validation	Primary Actor	NetApp Developer, Platform Provider
REQ-DEV-M-FUNC-17	Validation results availability		
Description	The validation framework shall be able to generate results/reports that are accessible to the experimenter.		
Priority	Mandatory	Type	Functional Suitability
Topic	Validation	Primary Actor	NetApp Developer, Platform Provider

6 EVOLVED-5G USE CASES

6.1 INDUSTRY 4.0 PILLARS

Manufacturing has undergone several eras of change from the first industrial revolution (use of steam power and mechanical production), to the second (use of electricity and mass production) and a third era defined by increased automation of manufacturing processes due to the use of information technology (IT). The fourth era of change – Industry 4.0 – refers to the technological evolution from embedded systems to cyber-physical systems. Decentralized intelligence helps create intelligent object networking and independent process management, with the interaction of the real and virtual worlds representing a crucial new aspect of the manufacturing and production process” [17]. Industry 4.0 will play a significant role in transforming traditional companies into Smart Factories with the help of Internet of Things (IoT) and Cyber Physical Systems (CPS) [18].

According to the project “EVOLVED-5G: Experimentation and Validation Openness for Long Term Evolution of Vertical Industries in 5G era and beyond”, this wide-range innovation across all manufacturing phases and processes is summarized to four pillars of smart manufacturing, namely: innovative interaction of employees and machines (through Augmented Reality (AR) features and remote-control capabilities), efficiency in Factory of the Future (FoF) operations utilizing novel predictive maintenance applied on digital factory twin, security guarantees and risk analysis (for the FoF communication and management systems), agility in the production line infrastructure (through automation and robotic parts). On the other hand, according to Boston Consulting Group (BCG) the vision of Industry 4.0 is described through nine digital industrial technologies/pillars, namely: Autonomous Systems/robots, Additive Manufacturing, AR, Simulation, horizontal/vertical integration, Industrial Internet of Things (IIoT), Cloud Computing, Cyber Security and Big Data and Analytics [19].

These two perspectives include all the required manufacturing phases and technologies towards Smart Factories. The only differentiation is that the pillars that have been defined by BCG can be characterized as technological pillars as they describe the technologies needed for the full completion of Industry 4.0 whilst the pillars that the project has defined can be characterized as operational pillars as they describe the manufacturing phases and processes that are required. There are also several opinions/definitions from different studies about the pillars. One of them supports that Industry 4.0 uses a series of enabling technologies that can be categorized into 10 pillars. The first nine pillars come from the study by the Boston Consulting Group [19], while some authors [6], [20] add an “other enabling technologies” category. This latter category includes a series of equally significant innovations, but with limited application domains, such as agrifood, bio-based economics, and technologies supporting the optimization of energy consumption [21], [22]. Another study [22] recommends training and continuing professional development as priority areas for actions within industry 4.0 implementation.

According to this study [23], key elements towards Industry 4.0 are the Learning Factories (LF) that appear as highly complex learning environments that allow the development of high quality and autonomous competences [24]. LF are three pillar-based models (didactic, integrative and engineering) that EAFIT University is applying to transform both the practices of the production engineering curriculum and its physical infrastructure [23]. From another perspective and according to another study [25], seamless ubiquitous Internet access, communication between intelligent machines (M2M communication) and advanced analytics methods can be considered

as pillars of Industry 4.0 revolution [26], fostered by the Industrial IoT [26] and CPPS (Cyber-Physical Production Systems) [28] paradigm. Accordingly, the following application domains are the levers that will drive the development of Industry 4.0 [29] asset utilization, quality control in manufacturing, supply chain management, product monitoring, and workplace safety. In addition, according to another scenario [32] the two strong and influential pillars of Industry 4.0, but not the only ones, are the IoT and the knowledge economy, because both have strong beneficial influences on industrial production organizations.

An alternative study [33] refers that the basic pillars of Industry 4.0 were Smart Solutions, Smart Innovations, Smart Supply Chain, and Smart Factory. Smart Solutions is constituted of Smart Products and Smart Services [34]. In addition, a different scientific publication [35] suggests as main pillars of Industry 4.0 the following ones: Cyber-Physical Systems, IoT, Cloud Computing, Cognitive Computing. Carol Senn's approach [36] proposed the: IoT, Augmented Reality (Safety Training by using AR, Streamlined Logistics, Maintenance by using AR), Simulation, Additive Manufacture (Design 3D, Prototyping: 3D, Low-Volume Production), System Integration, Cloud Computing, Autonomous System, Cyber Security and Big Data Analytics, as the various systems of features describing Industry 4.0. According to the Deloitte [37] definition the vision of Industry 4.0 is described through the 7 following pillars: Industrial Internet, Connected Enterprise, Smart Manufacturing, Smart Factory, Manufacturing 4.0, Internet of Everything and Internet of Things for Manufacturing. A different approach [39] by D. Burrell supports that the pillars that compose the Industry 4.0 are: IoT, Big Data, Cloud Computing, Advanced Simulation, Autonomous Systems, Universal Integration, Augmented Reality, Additive Manufacture and Cyber Security. On another hand, H. Fatorachian and H. Kazemi's analysis presents as the main pillars of Industry 4.0 the following: Industrial Internet, IoT, CPSs, Information Network, Software Systems, Cloud Computing and Big Data Analytics. In conclusion, Booth Welsh's study [39] ends to the following main pillars: IoT, Systems Integration, Simulation, Augmented Reality, Big Data, Additive Manufacture, Autonomous System, Cloud computing and Cyber Security.

Telecommunication networks have not played a major role so far in industrial automation. Now, it provides a very good opportunity for Telecom Operators to address this new market- Industrial automation as the demands of Industry 4.0 in ultra-low latency, very high reliability and very high data rates cannot be supported by the existing communications technologies. This is where 5G comes into picture. 5G will have a "massive impact" on industry as well as on social and economic development. 5G will allow manufacturers to automate end-to-end operations and achieve massive productivity gains by handling billions of sensors, machinecontrolled robots and autonomous logistics, all capable of communicating and operating remotely in real-time via 5G [40]. With massive Machine Type Communications (MTC), real-time control of machines, robot/human interactions and edge cloud analytics, 5G will be key to supporting the wireless connectivity and integrating technologies as IoT technology, cloud solutions, big data crunchers, and cyber security components needed to power these new "Smart Factories" that Industry 4.0 brings [41]. 5G endorses the vision where the world of NetApps follows the paradigm of mobile applications hosted in a related marketplace. The industry-oriented 5G NetApps will be tested, validated, and certified in a vendor-agnostic experimentation platform, and progressively define the first set of NetApps that the 5G marketplace will host and provide to compose a digitalized, secure, and automated generation of the industrial operations [42]. The objective of this text is to present the four main pillars of Industry 4.0, to identify the challenges and issues occurring with implementation of Industry 4.0 as well to study the state-of-the-art technologies related to Industry 4.0. The scope of the analysis will also include the target use cases as well the NetApp opportunity. Nevertheless, it is important to note that the **target uses cases described below**

aim to exemplify and illustrate the use of the EVOLVED-5G facility whose transversal vision seeks impact not only with additional use cases that may potentially come from the vertical industry of smart manufacturing but also on other verticals and industries too.

There exist four pillars in the EVOLVED-5G context: *Interaction of Employees and Machines, Factory of the Future (FoF), Security Guarantees and risk Analysis*, as well as *Production Line Infrastructure*. Each pillar is composed of SME's (Small Medium Enterprises) that play an important role in the EVOLVED-5G ecosystem by providing the necessary components and specifications (functional and non-functional requirements) as far as the NetApp development is concerned. Each pillar contains a leader SME responsible for the co-ordination of the members as well as the reporting directly to the Work Package Leader. In the following list we present the set of the SME's partitioned within the four pillars. In bold the leader SME of each pillar is mentioned:

- Interaction of Employees and Machines (IEM) pillar (**IMM**, INF, GMI-Aero).
- Efficiency in FoF Operations (FoF) pillar (**CAF**, ININ, QUCOMM).
- Security Guarantees and Risk Analysis (SEC) pillar (**8BELLS**, IQB, FOGUS).
- Production Line Infrastructure (PLI) pillar (**PAL**, UML).

6.1.1 Interaction of Employees and Machines (IEM) pillar (IMM, INF, GMI-Aero).

With the emergence of Industry 4.0, factories and manufacturers are pressured to increase their production and effectiveness by including new technologies and equipment. Industry workers are directly affected by these changes and as such they are more and more encouraged to interact with machines and collaborate using digital systems. The Interaction of Employees and Machines (IEM) pillar aims at addressing the challenges related to this new paradigm and help the involved parties to boost their work performance. Within the scope of EVOLVED-5G project, 3 main areas have been identified with respect to each of the 3 SME partners of the pillar:

- Supporting the work of employees via autonomous chatbot-driven systems (INF).
- Allowing efficient collaboration between remote workers (IMM).
- Facilitating verification and certification phases (GMI).

To solve each of these challenges, a suitable network infrastructure must be available within factories and 5G capabilities are at the heart of the envisioned IEM NetApps.

6.1.2 Efficiency in FoF Operations (FoF) pillar (CAF, ININ, QUCOMM)

In the Factories of the Future environment one of the most critical aspect where the 5G may bring several enhancements is the Operations Technology (OT) and Information Technology (IT) convergence in order to bring efficiency in the overall FoF operations capacity. In order to achieve that, 5G will be the mean to wire the manufacturing plant and allow a common infrastructure so the OT and IT systems will interplay. In this prism, the efforts related to EVOLVED-5G will mainly focus on:

- IoT and M2M based monitoring and digital twinning, with a platform that will allow monitoring information from manufacturing machinery, sensors and actuators to be collected and maintained modelled as digital replicas of the physical machinery (ININ).
- In addition, the issue of anomaly detection in both OT and IT network segments will be studied and demonstrated, for the detection and mitigation of detected anomalies, exploiting sensory and monitoring information coming from the 5G system as well as the machinery control and management (QUCOMM).

- Finally, safety of operations withing the busy factory environment will be tackled by an AI based video analyzer for industrial and robotics safety (CAF).

6.1.3 Security Guarantees and Risk Analysis (SEC) pillar (8BELLS, IQB, FOGUS).

Factories of the future heavily rely on interconnectivity between multiple devices, sensors, machines, and workstations. A factory can be visualized as a very busy hub of knowledge and data exchange, which requires a robust, secure, and reliable environment in order to operate properly. To this end, security-aware tools that enable accessing, storing, manipulating, and steering data streams and devices form the core basis for guaranteeing reliability in a factory of the future. To address this challenge, the pillar will devote resources towards:

- The development of a software L7-aware switch for smart function chaining (8Bells)
- Software for entity authentication, registration, and authorization (InQBit)
- A security information and event manager based on blockchain technologies (FOGUS).

6.1.4 Production Line Infrastructure (PLI) pillar (PAL, UML).

Agility in the production line infrastructure involves the advances in automating the production line with AI-driven assets, such as robotic arms and logistics robots. For this pillar the 5G-TSN connectivity in the factory environment will drive NetApps related to indoor production line automations, such as mobile robots and mobile platforms. Autonomous Mobile Robots (AMRs) have numerous applications in industrial and intra-logistics environments and will play an increasingly important role in the FoF. AMRs are essentially programmable machines able to execute multiple operations, following programmed paths to fulfil a large variety of tasks. AMRs can perform activities like assistance in work steps and transport of goods, materials, and other objects. AMRs are characterised by a maximum flexibility in mobility relative to the environment, with a certain level of autonomy and perception ability, i.e., they can obtain situational awareness and react with their environment. Within the scope of EVOLVED-5G project, both PAL and UML have identified 4 primary features to be included as part of our NetApp development:

- Indoor localization and mapping for mobile robots.
- Global localization using 5G technology to address the relocation issues when the robot gets lost due to the failure of localization mechanism.
- Global localization to manage multiple IoT devices with same coordinate reference frames.

6.2 INTERACTION OF EMPLOYEES AND MACHINES (IEM) PILLAR

6.2.1 State-of-the-Art and Current challenges

With the emergence of Industry 4.0, factories and manufacturers are pressured to increase their production and effectiveness by including new technologies and equipment. Industry workers are directly affected by these changes and as such they are more and more encouraged to interact with machines and collaborate using digital systems. Human-Computer Interaction (HCI) is thus at the heart of Industry 4.0.

According to the study [44], there at 7 main research challenges that HCI has to face. First, social information processing must consider multimodal communication facets. Secondly, there is a need to investigate on the nature of the cognitive processes that mediates, the psychological paradigms that engage them, i.e., goals, beliefs, expectations, and the emotional effects on

cognition. Thirdly, group interactions contribute to the development of creative ways and new ideas to solve problems (Group Cognition). Understanding the processes underlying individual and group cognition is fundamental for the development and implementation of theoretical and computational models that regulate cognitive behaviors in group interactions. Fourth, machine learning and artificial intelligence techniques must integrate contextual, multimodal and real-time processing capabilities from different types of inputs and stimuli (voice, movements of the head and body), and provide multimedia output that can adapt and meet the different users' needs, exhibiting autonomous behavior, context aware perception, and action control abilities. Fifth, databases of interactions need to be generated in order to enable researchers to train, test, and compare their systems as well as compare their performance and behaviors with humans. Sixth, the design of human-machine interfaces must focus on human end-users, their abilities, aptitudes, preferences, and desires. Moreover, interfaces must be accessible and usable by a wide variety of users. Seventh, the exploitation of intelligent, and socially believable ICT devices demands principled design methodologies that accommodate all potential users' requirements.

The Interaction of Employees and Machines (IEM) pillar aims at addressing the challenges related to this new paradigm and help the involved parties to boost their work performance. Within the scope of EVOLVED-5G project, 3 challenges have been identified, setting the path of introducing new technologies, each of which tackles a different aspect of the potential innovation.

The first IEM challenge is based on AI-driven systems to support the work of employees. Under the continuously changing conditions of a rapidly changing world, there is an increasing growth of AI's impact in Industry 4.0. Industrial AI is a systematic discipline, which focuses on developing, validating and deploying various machine learning algorithms for industrial applications with sustainable performance. It acts as a systematic methodology and discipline to provide solutions for industrial applications and function as a bridge connecting academic research outcomes in AI to industry practitioners [45]. The capacity to support and control big flows of information is one of the most important applications of Industry 4.0, which relies on the maintenance of artificial intelligence networks that could lead to newer and innovative methodical approaches for planning and development of products [46]. Hence, Artificial intelligence plays an important role in the efficient collaboration of Employees and Machines.

Chatbots are one of the most important applications of Industry 4.0. They combine artificial intelligence and Human-computer Interaction (HCI) [48][85]. According to the dictionary [49], a chatbot is "A computer program designed to simulate conversation with human users, especially over the Internet". It uses Natural Language Processing (NLP) and sentiment analysis to communicate in human language by text or oral speech with humans or other chatbots [50],[51]. Furthermore, in factories, chatbots have become so common because they reduce service costs and can handle many customers simultaneously.

Chatbots may have numerous applications in many different areas beyond the Industrial use cases such as education environments, customer service, health and robotics [51]. Across the study [52], two of the main challenges that chatbot design have to deal with are: managing the conversation context [53] meaning to handle NLP issues by mastering their syntax [54] and keeping the conversation flow [55] by learning the correct response [55]. AR-assistant for employees (IMM) will be another application of Industry 4.0. REVIIIEW is a mixed reality application to visualize and interact with 3D content in use cases carried by the Factory-of-the-Future. For example, with Hololens-based hat engineers will be able to see decision-making

instructions that will guide them through the most complex control operations. In conjunction with the 5G integration can be made some advances to the product: distant connection, share 3D file and share real area [59].

Currently, the traditional way that maintenance processes are being addressed, mostly rely on custom internal procedures which include the reporting of an issue and the assignment of the reported issues, in second time, to the appropriate personnel. Although this process might be working so far, it is limited in terms of automation, quick response time and workplace safety. For example, not all workers can undertake dealing with any issue of maintenance and thus their access to the respective documentation should be denied and the proper person should be notified. On the other hand, some malfunction could be in high priority and thus require as quick response time as possible. Additionally, given that a worker starts dealing with a reported issue, he would most probably have to rely on paper documentation. This could potentially be cumbersome and time consuming since the worker will have to fetch the corresponding documentation and then address the issue. Chatbots can easily address the issues mentioned above, since they are easy-to-use conversational agents that can support the engineers and technicians during daily workflows by using data collected from sensors and databases.

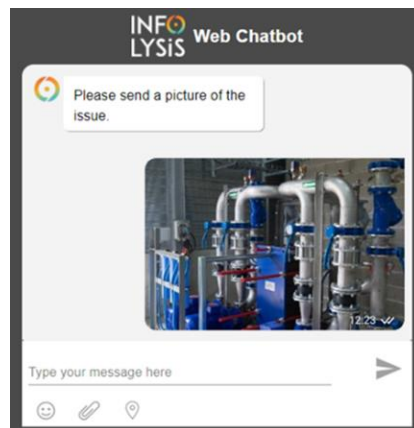


Figure 16. Demo Chatbot Interface and Feasibilities

However, such assistance systems require the appropriate network infrastructure within the factory in order to work and benefit both the factory and its workers to the maximum possible level. More specifically, for the described scenario, chatbots need to locate users to perform efficiently and provide to the worker the most relevant information for the machinery that is located in close proximity with the identified problem. This additional information will boost the performance of the chatbot and the efficiency of the assistance that is to be provided. Such requirements are currently not addressed in traditional factories but can be provided by the 5G System (5GS).

The second challenging IEM area concerns remote collaboration. Industry employees often need to work with remote colleagues that are not in the same factory or even the same country. For instance, many remote assistance and training scenarios involve a local worker who do not know how to repair a specific machine. In that case, a remote expert is needed to guide the local worker through the whole repair process.

Recent technologies like Augmented Reality (AR) are powerful tools for many industrial and manufacturing uses-cases, including remote assistance and formation. AR allows the remote expert to view the machine as if he was physically present in front of it (in other words, to view what the technician sees and does in real time). The expert can then guide local workers using

audio (*i.e.* oral explanations), by creating virtual objects (virtual annotations and drawing, textual notes positioned directly on the concerned machine component, and so on). Current AR head-mounted displays come with internal sensors and devices (micro, camera, orientation sensors) to support directly (some) of these features.

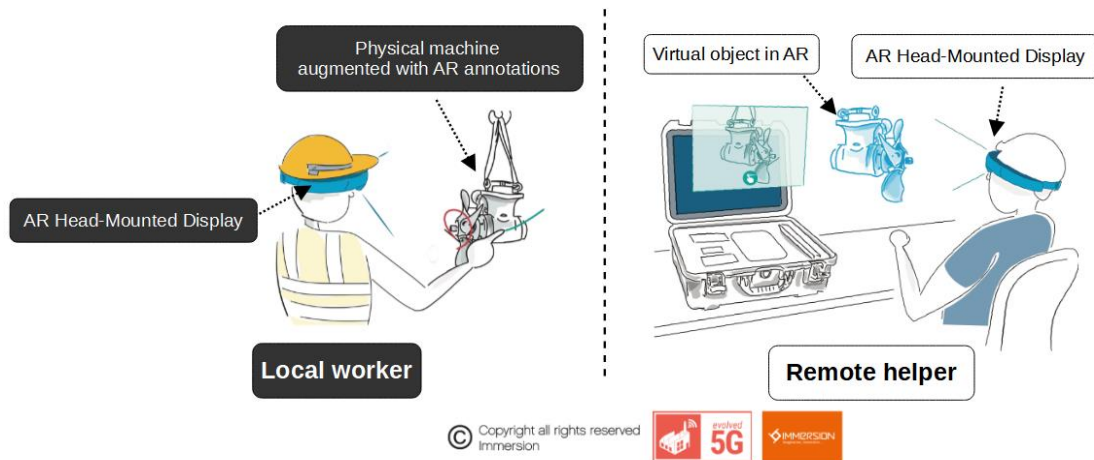


Figure 17. Demo remote collaboration from industry employees

Since the beginning, it was clear to the research community that one of the most interesting applications for AR could have been the support of industrial applications [60]. By that time, AR enabling technology was expensive [61]. After decades, and big advancements in AR enabling technologies and thanks to the evolution of information and communication technologies in general, AR now has entered the consumer market [62].

Industry 4.0 and Smart Factories are often associated with the concept of AR and it is no longer unimaginable to think of a factory where not only everything is connected, but it is also viewable and interactive. The use of AR on manufacturing processes regarding simulation, assistance and guidance has been proven to be an efficient technology helping on problems [63]. AR technology increases the reality operator's perception by making use of artificial information about the environment, where the real world is fulfilled by its objects [24][25] and also enables the remote-control capabilities. The authors [24][25] defined AR system features as: 1) the ability to combine real and virtual objects in a real environment, 2) the ability to align each other the real and the virtual objects, and 3) the ability to run interactively, in 3D, and in real-time.

Within different industries, the range of applications is broad. AR can be used for design and manufacturing applications [64], assembly operations, either in training [65] or as an online guidance system for operators [67]. In logistic, 'pick-by-vision' is a prominent concept utilising AR to indicate picking locations and quantities [70] [71]. Other areas where AR can also be used include warehouse operations [72] quality assurance [70], maintenance [63], supervisory control and data acquisition (SCADA) tasks, through-life engineering services [73] and visualisation of instructions [56]. AR technologies have played a massive role in human robot collaboration, e.g. safety enhancement and automotive case study. Additionally, AR promises to decrease the number of errors made, like picking or assembly errors and it provides an easy way to communicate with experts in maintenance tasks [74].

However, existing literature has reported on a variety of challenges in implementing AR solutions in the industry. Some of the challenges include hardware and software issues, weight, ergonomics issues, limited user acceptance, visual fatigue and concentration performance

issues, data transfer, integration and security issues, content authoring, adaptive instructions, marker tracking reliability and cost. That kind of studies uncovered that the complex industrial environment causes new challenges compared to laboratory environments. In addition to the complexity of conceiving an AR system adapted to industry worker needs, there is also a gap related to the network infrastructure. AR requires a significant bandwidth to exchange data in real time (including videos of what each user sees and virtual objects). An important or unstable latency would directly impact real-time interaction in AR, leading to confusion and errors that could be critical when repairing industrial machines. Moreover, another challenge comes from the technical limitation of current head-mounted displays. **Current AR devices cannot handle 5G and have limited computational power.** Heavy computations required to create augmented scenes may need to be offloaded from AR devices. Overall, there is thus a strong need for a network infrastructure adapted to AR usages and devices to achieve the remote assistance systems required by Industry 4.0.

Finally, the last IEM challenge focus on verifying and certificating the result of procedures, which are key aspect for industrial and manufacturing domains. These verification and certification phases are time-consuming and complex, especially in critical applications like aeronautics. In the case of aircraft composite repairs, specific conditions such as repair temperature, humidity and vacuum must be inspected to certify that the procedure was correct. This is especially the case when some repairs are carried out in places around the world with extreme temperature or humidity conditions, for example when the repair cannot take place in a hangar or a workshop. In such cases, it becomes necessary to check that the repair is in accordance with the tolerances imposed by the aircraft manufacturer, either by a thermal study or with a sample part.

Using digital twins is a promising approach to overcome this issue. The notion of digital twin refers to a set of 3 entities: 1) a physical entity (for instance, a production line in a factory), 2) a virtual replica of the physical entity and 3) the data connection assuring that both entities reflect in real-time the same state. In other words, real-time data collected from sensors will feed the virtual replica to make sure it is up to date. The other way around is also true: actions performed on the virtual replica (for instance, turning off a machine of the production line) can be triggered on the physical entity side.

Digital twins represent an active research area for Industry 4.0. They can allow expert users to remotely perform precise simulations on a virtual entity faithfully representing the physical workspace in real time. Nonetheless, building the digital twin of a complex object like an aircraft repair area represents a strong technical challenge. An adapted infrastructure and network architecture must be conceived and implemented to synchronize the physical and virtual entities in real-time. This will enable faster certifications processes, with higher level of confidence and at a lower cost.

A different application that the Industry 4.0 can offer is the remote repairing tool. An example of remote repairing tool is the haptic-driven console for industrial surface repairing (hot bonding). ANITA EZ consoles (designed & handling by GMI AERO) are the most appropriate equipment for the repair by bonding of high performance surfaces and structures. They are conceived as portable systems, light, handy for field application and their operations have been optimised to be simple. With Industry 4.0 and 5G integration, the requirements of repairs in low-latency and ultra-reliable connection are met .

6.2.2 The NetApp Opportunity

For the IEM pillar, the EVOLVED-5G project represents the opportunity to address the current limitations related to network capacities. 5G networking offers promising performance and features required to support the use cases of Industry 4.0. Each of the three SME partners in the pillar already have conceived some existing solutions (complete vertical apps or at least technological bricks) targeting the industrial gaps described in Section 5.2.1. During the EVOLVED-5G project, three distinct NetApps are envisioned and will be implemented. They will make the link between these existing components of the vertical applications and the 5G network.

These three NetApps will be key-components to address the previously mentioned 3 IEM challenges within the project, but also for other stakeholders interested in Industry 4.0.

6.2.3 Target Use Cases

6.2.3.1 5G-enabled Chatbot-driven technical maintenance - INF use case

The main goal of the INF target use case, within the scope of EVOLVED-5G Project, is to establish a dedicated series of actions that will take place in a factory environment in order to realize the handling of maintenance scenarios via a chatbot platform. The use case scenario is described in detail in the following template. Additionally, the following use case schema, shown in Figure 18 explains the sequence of actions that has been identified, while it also shows the interaction between the 5GS, the vApp, and the NetApp.

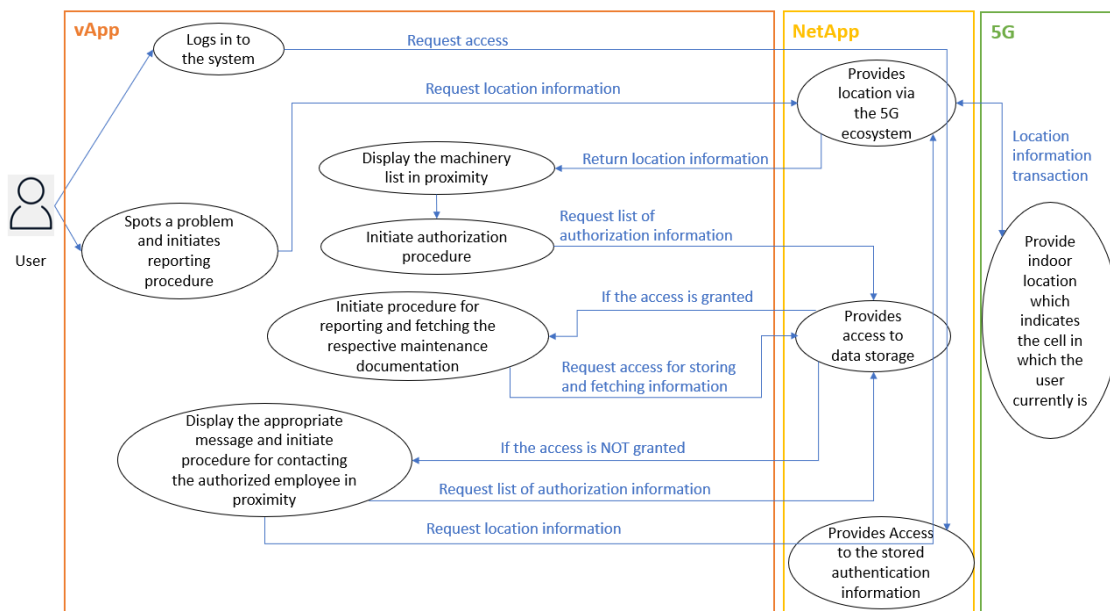


Figure 18. INF Use Case Schema

This use case targets the ways that maintenance scenarios are taking place within a factory. The goal is to introduce the chatbot application for reporting malfunctions and facilitating the course of actions needed to address and fix the reported issue. The NetApp that will need to be developed for this Use Case is a NetApp that supports location services, provide helpful information about the specific area to the user; user authentication restrict access to unauthorized personnel to specific areas; provide relative material or manuals about the equipment that is in the provided area. Also, can notify available specialized technicians to solve

a pending issue. Additionally the INF web-based chatbot platform will be modified to support and utilize the features provided from the described NetApp.

Since the factory manager decided to install a 5G non-public network, a NetApp will enable the use of a chatbot to help identify and solve possible malfunctions in a shorter time frame using a more user-friendly solution. Also, the 5G network can provide an ID for all the connected workers of the factory and their relative location. Workers can be connected from any devices. The NetApp can match the location to a predefined factory area (block or cell). It will also have a list with ranks and access of the employees so it can give a warning if a person is in a dangerous area (eg toxic exposure in the area) regardless the access status or notification for restricted access or even provide material relative with the area if the person has work to do there.

All workers have a mobile phone, or a tablet connected to the 5G network of the factory. At any point, a worker might encounter a faulty equipment then he/she can use the vApp to report the issue. Firstly, the NetApp gets the location of the worker, for example Area A. First step is to check if area A is safe for any worker to be. If there is some alert or warning for the area, a notification will be issued so an evacuation can take place in a quick and safe way always with health care in mind. If the area is safe, a second check take place regarding the access status of the worker in "Area A". In case the person should not be in the specific area he/she is prompted to leave. If worker is cleared a request for the manuals of the area can be made and further instructions to fix the damaged machinery. Finally, if the problem is not resolved the closest specialized technician will be notified to aid. In order to control accessibility to the areas and provide easy assistance with a friendly automated way are some of the benefits of this use case.

As far as the SME is concerned, an SME can have interest in this use-case since it gives a particularly good understanding on how the implemented NetApp can be used in a business scenario, thus making it easier for the SME to exploit and further develop the NetApp for its own use. In specific, an SME that requires a location NetApp in order to advance the provided functionalities of its services, could reuse the specific location NetApp in order to couple it with its vApp and advance the provided services.

In terms of benefiting, the Industry 4.0 App developer can be benefited by the location NetApp for the evolution of the vApp in order to support additional features and make it 5G-enabled. The Integrator can benefit from this use case in order to understand the proposed solution and finally use it to create a new product that can be licensed and sold to another stakeholder. An equipment vendor, such as a private 5G vendor and/or a mobile UE vendor for industrial spaces, could be benefited from the enhanced chatbot service for Industry 4.0 environments, and include the provided chatbot service and NetApp as a pre-installed feature. The MNOs could be benefited by including the location NetApp in their marketplaces for supporting the development of other vertical Apps that are requiring location info for their operation. The testbed operator could perform performance experimentation on the NetApp and vApp coupling by assessing the performance resilience and location accuracy under various reception conditions.

Concerning the current status of the situation. The web-based platform does not have access to location information for an indoor facility. Thus, making the described use case impossible to be implemented for the following reasons:

- The Chatbot is unable to provide a detailed list of the machinery in close proximity.
- The Chatbot cannot provide notify the proper technicians closer to the reported problem in order to effectively resolve any evolving issue.

As far as the EVOLVED-5G Innovations is concerned, utilizing the EVOLVED-5G Innovations, a NetApp with access to location and verification services can be developed solving not only the forementioned issues but also addressing the smooth operation of the factory workflow and the workers' safety as described in the Detailed Description section of the Use Case.

The evaluation criteria involve the following: Accurate location provision, Authentication process, Location classification and identification of authorized worker in close proximity.

Closing, as far as the considerations and the burdens one need to overcome, specifically for the NetApp used in this Use Case is the accuracy of the location that is going to be provided from the 5GS so the grid of the factory can be made, as well as a list with the necessary information to provide access or respective material to solve any pending issue.

6.2.3.2 Time-sensitive communications through the 5G network - IMM use case 1

Immersion identified two main use cases for their NetApp, each use case covering a different aspect of the envisioned system:

- The initialisation of secure, time-sensitive communications between remote users through the 5G network.
- The network monitoring and autonomous QoS adaptations from the NetApp.

The first use-case is the most straightforward one as it involves the initialisation of secure communications through the 5G network between end users. Upon arriving in front of the machine to be repaired, the technician (local worker) needs to prepare all the hardware (computer, additional cameras, AR head-mounted displays) and setup the communication with the expert (remote helper). This could be compared to starting a virtual meeting (audio + basic video) between these two end-users. From a technical point of view, the NetApp will that the required Quality of Service (QoS) can be reached via a secure connection (end-to-end encryption enabled).

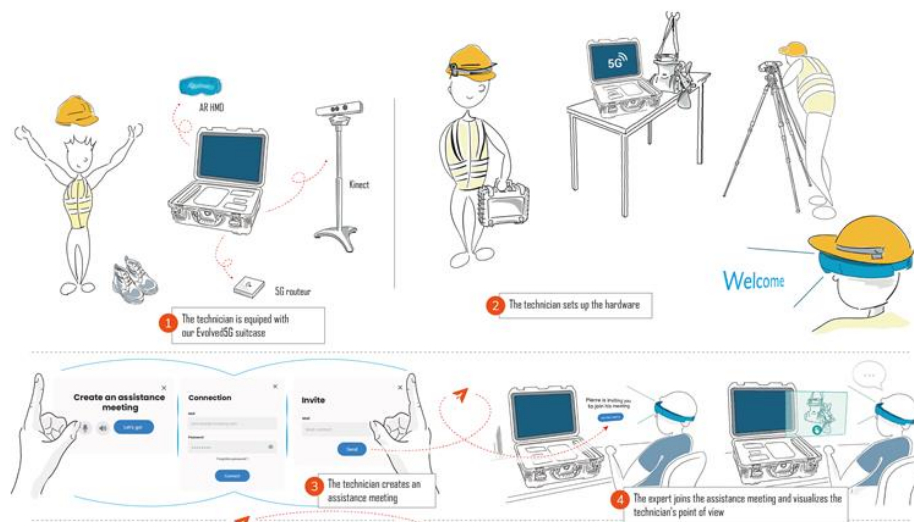


Figure 19. Demo secure communications IMM use case 1

Reaching a QoS required for remote assistance in AR will be a technical and innovation effort within the EVOLVED-5G project. The designed network architecture will have to address the absence of native compatibility between AR headsets and the 5G network. Current Head-Mounted Displays (HMDs) cannot handle 5G communications on their own, usually relying on Wifi. This limitation creates a significant bottleneck as QoS KPIs are envisioned. In particular a

stable connection is considered when latency of 40ms or lower is attained and lower than 60ms is a prerequisite. Moreover, AR interaction imply time-sensitive data (audio communication, real-time video from each user, interaction with shared virtual objects in AR) that must be synchronized. For this reason, the 5GENESIS Malaga platform is currently targeted for IMM use cases.

The goal is to allow a secure, fluid and real-time collaboration in Augmented Reality between Technician and Expert. Time-sensitive data must be synchronized. Additionally the goal of the NetApp will be to assure communication security and adapted QoS for communications and streamed videos. Involved mechanisms: TSN, network slicing. Upon installing the required hardware (including AR HMDs), users can start a virtual meeting. Once secure (encrypted) communications have been established, the machine maintenance task can start. Several video streams (from HMD cameras) must be synchronized to audio communications and user actions (detected by the Kinect and HMD). Potential actions from both users include: hand gestures, creating virtual annotations and drawings in the AR workspace, creating virtual objects.

Currently, some AR solutions already exist but are greatly limited by network capacities (no 5G) and HMD computational power. The innovations within the EVOLVED-5G, involves allowing a real-time AR distant collaboration for industrial maintenance scenario and to implement the appropriate NetApp and make it available on the Marketplace for similar applications. Finally, concerning the evaluation criteria, these involve mostly: latency (stable 40ms or lower would be nice, lower than 60ms is required) and bandwidth (minimum: enough for audio + at least two 720p video streams). Current AR HMDs cannot handle 5G communications on their own. Unstable latency is often worse than a bad stable latency because users cannot predict it and adjust their actions. Having more than 10ms of latency jitter would significantly impact user interaction.

6.2.3.3 Autonomous adaptation to network performance and user needs – IMM use case 2

The second IMM use case focus on the network state monitoring and QoS adaptations performed by the NetApp. The goal is to add some “intelligence” to the NetApp, letting it autonomously handling the monitoring of the 5G network. In case of network issue, the NetApp will notify the vApp and propose a temporary QoS. This QoS will be the optimal compromise between the initially requested QoS and the current state of the network. The envisioned KPIs are based on the rapidity of the proposed adaptations (time to be notified and time to be operational). The relevance of the adaptations (quality of the compromise) will also be an important evaluation criteria. Other related scenarios are envisioned. For instance, the NetApp could allow VApp developers to configure a set of priorities (specific data transfer which should not be disturbed) used by the NetApp to make propositions/decisions. Overall, this use case as at the heart of the envisioned NetApp because it could be a valuable tool for many AR/VR developpers looking for ways to benefits from 5G network capabilities. The vApp needs to adapt itself if the normal QoS cannot be reached, for instance by notifying end-users, degrade temporarily video quality... But such adaptations need to match with the current network performances, which are only known by the NetApp. The vApp developpers: configure thresholds (latency, bandwidth...) in order to define the initial expected QoS and pass them to the NetApp. As far as the NetApp is concerned, it monitors the state of the network/slice. In the defined QoS cannot be reached, notify the vApp and request temporary QoS adaptation (choice made by the vApp, for instance reporting secondary data transfers). As a next step, we let the NetApp propose an appropriate QoS instead to find the best compromise with the current network status. Finally, as a bonus feature we can also imagine scenarios where the NetApp

could allow VApp developers to configure a set of priorities (specific data transfer which should not be disturbed) used by the NetApp to make propositions/decisions. Such a customization could also be attractive for Marketplace users interested in this kind of NetApp. The SME/Industry 4.0, facilitates adapting the vApp features to the current network performance. Finally for the Marketplace end-user, the access to a more complete, “intelligent” NetApp working as a standalone autonomous agent is provided and it is able to monitor network status, notify the vApp and request/propose temporary compromises for the QoS. The current status: “not yet started” and as far the EVOLVED-5G Innovations is concerned, the Standalone NetApp to autonomously adapt to network conditions to match expected QoS or propose adjustments.

6.2.3.4 *Check communications between end-users devices - GMI use case 1*

As far as the GMI use case is concerned, the application entitled: “Check communications between end-users devices” , the current app refers to the scenario where both end-user, on the primary Anita and on the secondary Anita, need to initialize secured communication necessary for the realization of the twin repair. The expected outcomes involve the checking that a satisfying QoS can be reached and the Security (Authorize users). Concerning the Current Status, the Anita HMI should be adapted with the authentication process and the communication settings . Additionally, Anita cloud system and database are already deployed and in the context of EVOLVED-5G Innovations, the goal is to enable sufficient quality of service to be achieved through 5G infrastructure, and to also benefit from authentication services that may be offered. As far as the Evaluation criteria are concerned, the KPI: Quality of connection is of crucial importance. The expected outcomes include the check whether the NetApp can allow both vApp to communicate. Additional prerequisites, constraints, restrictions involve the Anita computer actually use a wifi antenna for Internet access, or it may be necessary to use a dongle to reach 5G. The target location has been selected to be the 5GENESIS Malaga (Indoor only).

6.2.3.5 *Retrieve UE location information - GMI use case 2*

Concerning the second contribution of GMI entitled: “Retrieve UE location information”, the objective is to retrieve information about the geographical location of both devices: primary and secondary Anita. Moreover, for any type of composite repair, it is important to document the process as much as possible. In the case of the twin repair, geographic location information will be essential and should be included in the curing report. This information, gathered through the location service, can be used to obtain other data regarding climatic and environmental conditions, always with the goal of documenting the repair as much as possible. The user can also enter other information manually in the location and environment category. Finally, the expected outcomes are to obtain and store the geographic location information for both devices involved in the twin repair. Concerning the current status, currently there is no notion of location on the Anita device. On the other hand, the curing cycle report exists, and will have to be enriched with these last data. Concerning the EVOLVED-5G Innovations, we are concerned for the accurate location information that will provide a real benefit to repair documentation

6.2.3.6 *Start repair on primary Anita, retrieve and process data on secondary Anita – GMI use case 3*

The third contribution of GMI as far as the use case is concerned, consists in ensuring that the communication will be maintained during the process. The name of the use case is “Start repair on primary Anita, retrieve and process data on secondary Anita”. This third and final step is to initiate the repair cycle. It is essential that the data be transmitted continuously to ensure the

twin repair process. On the primary Anita side, the probe data and the setpoint instruction must be sent. On the other hand, on the secondary Anita, the data has to be read and then evaluated. Either to apply the same setpoint on the sample repair in real time, or to store the data for a study by a thermal study software. The setpoint instruction must be refreshed, received and processed by the secondary Anita, every 10 to 20 seconds maximum to ensure proper twin repair. The transfer time of the data packet must respect this refreshment constraint. Concerning the expected outcomes, we are interested in both the verification if a satisfying QoS can be reached during all the process, as well as the data integrity. Currently the status is that we have the possibility to transfer the baking data to our cloud database. This data are evaluated by web applications. It will be necessary to develop a reading module that will be used in the case of a slave Anita. EVOLVED-5G Innovations: Implementing an efficient architecture for our system to fully use the capabilities of the 5G network in terms of QoS (bandwidth, latency). In conclusion the evaluation criteria involve mainly the bandwidth and stability. Concerning the prerequisites, constraints and restrictions, the transfer time of the data packet must respect the refreshment constraint of 10/20 seconds maximum. The target location involves the 5GENESIS Malaga (Indoor only).

6.3 EFFICIENCY IN FOF OPERATIONS (FoF) PILLAR

6.3.1 State-of-the-Art and Current challenges

The concept of the Factory of the Future provides a focus for manufacturing research roadmaps and will support further initiatives in other industrial sectors. In 1986, Irwin Welber, the former vice president of AT&T Technologies, described the FoF as: a very large scale intelligent machine that operates with a highly integrated and well-organized base of knowledge which must be flexible with regard to changes in demand, technology, economic conditions, and competitive pressures [75]. The technologies required in the FoF are largely already available. The FoF will make better use of these technologies, whilst the supporting software and systems will make the technologies easier to access, monitor and control. Adaptive control will tend towards self-learning and there will be emphasis on transition to fully automated systems [76]. According to the study [77], the European Factories of the Future research programme focuses on the following research and innovation priorities: Advanced Manufacturing Processes, Adaptive and Smart Manufacturing Systems, Digital Virtual and Resource Efficient Factories, Collaborative and Mobile Enterprises, Human-Centred Manufacturing and Customer-Focussed Manufacturing.

The two dominant trends [78][76] that are expected to have significant impact on the Factory of the Future are the influence and use of automation & robotics along with the consequences of environmental pressures and zero waste approaches on the recycling of materials and products within the supply chain. Moreover, another trend that many respondents mentioned is 3D printing. These trends are discussed later in the text. Industry 4.0 embraces different technologies connecting and integrating physical devices, intelligent machines and human resources to enable the digitisation and automation of the supply and value chain [79] [81]. The most common groups of technologies and methods are the following: big data and analytics, simulation, Internet-of-Things (IoT), CPS, cloud computing, virtual reality, machine learning, integrated with new high-tech production processes, such as 3D printing and hybrid manufacturing, and adaptive and smart manufacturing equipment and systems as collaborative robots and machine-to-machine communication [82][83][84][85][86].

The definition of IIoT, one of the technologies that have significant impact on the Factory of the Future, is the following: the industrial internet is an internet of things, machines, computers and

people enabling intelligent industrial operations using advanced data analytics for transformational business outcomes, and it is redefining the landscape for business and individuals alike [87][88]. A different definition of "Industrial Internet" that first coined by General Electric (GE) is: The definition of the Industrial Internet includes two key components: The connection of industrial machine sensors and actuators to local processing and to the Internet.

The onward connection to other important industrial networks that can independently generate value. The main difference between the consumer/social Internets and the Industrial Internet is in how and how much value is created. For consumer/social Internets, the majority of value is created from advertisements [88][89].

Hence, it follows that IIoT is effectively IoT in the industrial sector and Industrie 4.0 concepts are effectively a subset of IIoT. According to the study [90], IoT applications are spreading to various sectors including smart grid, intelligent transportation systems, e-health, etc. [91]. All these application areas repeat the same basic model: a large number of smart devices, interconnected over wired or wireless media, interacting and coordinating to achieve a goal. One of the numerous applications of IIoT, is the IoT/M2M remote monitoring platform. That platform is provided by ININ and is a cloud-based management system for remote gateway and sensor control. IoT/M2M-based remote monitoring platform benefits from the 5G integration will be the following: extending capabilities of the IoT/M2M system components to support automated deployment, components scaling and lifecycle management, reduced IoT/M2M system service deployment time, extending capabilities of the IoT/M2M Gateway to support operation with 5G NSA/SA capabilities and also extending the network performance monitoring capabilities of the system to include Industry 4.0 network and applications metrics. One different application of IIoT that is relevant with 3D analyzer has been presented by CAF solutions and that is the AI based video analyzer for industrial and robotics safety.

CAFs Analyzer detects whether or not Personal Protective Equipment (PPE) is being worn by employees and provides near real time a warning signal directly to the control room when any element of PPE equipment is not being detected. 5G integration in conjunction with distributing the image analysis to local processing near the user can reduce the load on the network as only results from the image analysis are transmitted further in the network.

Another equally important IoT's application with the two mentioned above has been coined by QCOM. That is the ML-driven anomaly system for industrial processes. This system provides the means of detection and classification of network anomalies that influence industrial performance, contribute to information leakage, and potentially breach multitenant isolation. A tight integration of this app with the respective NetApp would take advantage of: the capabilities of the Network data analytics function (NWDAF) and the integration with the NSSF function which can enable mitigation actions when a slice isolation breach or anomaly in its operation is detected. These were just some examples of the IIoT's applications in the Factories of the Future but there are still numerous relevant examples. Next, we will present the challenges that FoF operations have to face.

Some of the challenges that FoF functions face according to the study [92] are presented below. Smart manufacturing systems are considered to be faced by security issues, challenges in implementation of interoperability, challenges in safety of human-robot collaboration, challenges with handling multilingual operations, lack of system integration, lack of return of investment in new technology and financial issues during the erection of new smart

manufacturing systems and/or during the upgrade of existing industries with smart manufacturing technology.

A different study [93] presents a set of different challenges/trends that need to be solved in order to lead to the factories of the future. These include: transition from highly centralized to decentralized structures (with decision making/intelligence), transition from product to product-service (mass-customisation), adaptable (to new market conditions in a global supply chain) and reconfigurable, evaluation of various system and networks configurations based on lifecycle assessment, economic and risk assessment, quality, reliability, as well technologies and applications for distributed (networked) manufacturing systems, system synthesis and modelling/simulation/optimisation of all operations, technologies to convert information into knowledge for effective decision-making, enabling software for intelligent collaboration systems, integration: humans – software – hardware (machines), as well competitiveness: in terms of costs (e.g., lifecycle costs, investments) vs. Payoffs. Adequate to new manufacturing paradigms; sustainability and quality.

6.3.2 The NetApp Opportunity

The FoF NetApps developed during the project will increase the efficiency and safety of FoF operations. According to the FoF needs, it will allow to fully exploit the novel business opportunities such as:

- Industrial grade 5G connectivity hardware and applications.
- 5G network anomaly and telemetry detection applications.
- Applications for automated occupational safety analysis.

6.3.3 Target Use Cases

The following paragraphs are dedicated in the description of the use cases for the particular FoF pillar.

6.3.3.1 *Industrial grade 5G connectivity with assured QoS and integrated SLA/SLS monitoring capabilities – ININ use case*

The first use case goal is to provide industrial-grade 5G connectivity for the IoT and M2M devices with assured QoS, integrated SLA/SLS monitoring capabilities and local compute capabilities. Targeted vertical markets are all emerging sectors, such as ports, Industry 4.0, critical communications and other vertical industries targeting reliable and resilient 5G communications. Additionally, the main target of the use case is to provide industrial-grade 5G connectivity for various IoT devices being connected to the IoT Gateway via various physical interfaces (e.g. serial, USB, Ethernet). Supported novel features of the FoF IoT gateway are:

- To provide 5G SA connectivity from the IoT devices to the application components deployed in the FoF cloud.
- To enable fast and scalable local pre-processing and storage (Docker based packaging formats) of the data collected from the deployed IoT devices (e.g. video streams and local sensor data).
- To assure the concept of IoT OAM (Operations, Administration, and Maintenance) supporting continuity check of the network path and applications, connectivity verification (based on emulation of the network and transport services and applications) and to provide performance measurement and monitoring of the network/transport paths and applications.

FoF IoT System architecture is depicted on the figure below and consists of Industrial IoT GW and Backend System Components with the following functions:

- FoF IoT Management; a centralized management of IoT probes/IoT gateway with status monitoring and OTA updates options.
- FoF IoT Collector; data collection function (centralized or distributed deployment) used to store KPIs and metrics from IoT probes/IoT gateway.
- FoF IoT Reporter; real-time analytics and alerting.

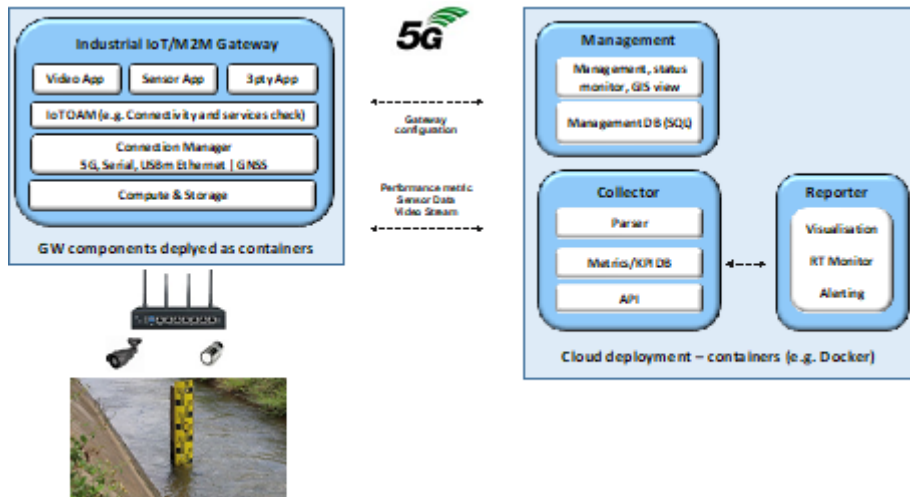


Figure 20. FoF IoT System Architecture

Deployment concept of the FoF IoT System in the 5G-EVOLVED environment (5G UE side and 5G cloud) and envisioned integration with the 5G NEF is presented on the Figure 21 below.

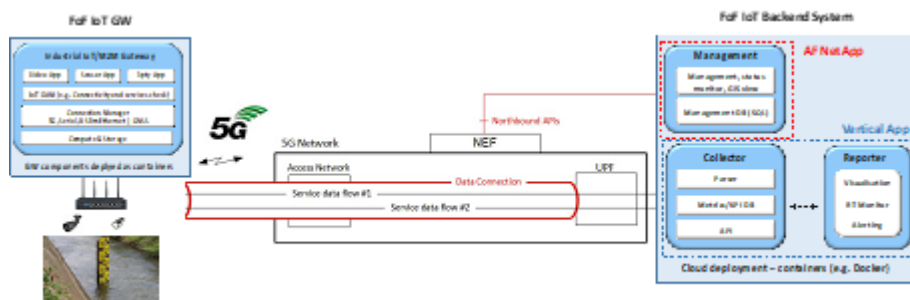


Figure 21. FoF IoT System Deployment in 5G-EVOLVED Environment

Autonomous FoF IoT gateway operation and distributed system architecture design will enable redundant local (on the FoF gateway) and centralized storage of the collected IoT data to the FoF end users. High-availability of the FoF IoT system and its zero data loss capabilities will be guaranteed with the concept of multiple parallel streaming outputs that can be collected on the distributed locations such as 5G edge and on the central cloud end-points. In addition, FoF IoT system will also assure end-to-end network and service performance monitoring based on automated collection of various radio, network and cloud related performance metrics (e.g.

RSRP, RSRQ, SINR, available radio capacity, network throughput, delay and jitter) that are used as a quality indicator of the 5G NR and as well of the mobile core and cloud capabilities are assigned to the FoF slice in the operational industrial environment. Novel continuous network status and performance monitoring capabilities integrated in the FoF gateways will assure additional Industry 4.0 use cases that are providing, to the deployed cyber-physical systems and factory operators, continuous network and services (SLA/SLS) monitoring and application continuity check.

ININ serves as a new actor in the Industry 4.0 domain providing FoF IoT System and added-value support. The Integrator, Design, deployment and operation of the FoF is the IoT System in the targeted FoF environment. Also the FoF Connectivity Service Provider (CSP) providing 5G mobile system build over the public or private mobile infrastructure. Concerning the Factory, system engineer in the factory preparing requirements (defining IoT devices CSP capabilities and SLA/SLS requirements). Providing operational support (monitoring SLA/SLS). Following the Current Status: The baseline technologies used on the IoT Gateway supports only 2G/3G/4G capabilities and are controlled with monolithic back-end system. The solution does currently not support any interactions (e.g. via API or protocols) with the OSS of the mobile system and operates in the OTT (Over-The-Top) system mode only. EVOLVED-5G Innovations: Envisioned 5G technological advancements such as eMBB, mMTC, URLLC, NFVI, NEF and its incorporation into the IoT/M2M-based remote monitoring platform will enrich system capabilities with the industrial-grade and mission-critical capabilities required to build the Factories of the Future. In particular the following are main technology benefits the solution will gain due to the EVOLVED-5G: Extending the capabilities of the IoT/M2M Gateway and backend components to support 5G NSA, 5G SA and NEF capabilities. Extending the network performance monitoring capabilities of the system to support collecting of Industry 4.0 network and application specific metrics. Reduced IoT/M2M system service deployment time. Technological and operational validation, interoperability check and verification of the system operational use in the Industry 4.0 environments. As far as the evaluation criteria, as part of the FoF IoT System operation several network and services KPIs will be collected in passive and active way from the deployed IoT gateway and from the network and services sub-systems. These metrics can be used to control expected operational SLA/SLS targets from the end users and as such can be used also to evaluate the successfulness of the innovation proposed. Concerning the prerequisite, constraints, restrictions, in order to support demonstration of the solution and its capabilities, the 5G SA mobile system with exposed NEF capabilities needs to be available supporting one of the following 5G Sub-6 bands n78 or n79 (SA TDD). Also, for the deployment of the IoT System backend components, cloud environment needs to be available and integrated with the on-site 5G mobile system. VM or docker based packaging formats needs to be supported in the cloud. The target location that the experimental setting will take place, will be the 5GENESIS Athens (Indoor, Outdoor, Edge).

6.3.3.2 5G network anomaly detection – QUCOMM use case

The QUCOMM contributes Qucomm NetAnalyser in the following manner. The described scenario will be integrated in an FoF pilot, where the EVOLVED-5G components will be integrated and will monitor the network. The next step will be to initiate an attack scenario to gain access to the industrial data node and start the malicious data transfer. The Qucomm NetAnalyser NetApp will receive 5G raw Network Analytics from the 5G NPN and forward processed analytics data to the Network Anomaly Detection vApp in order to detect anomalies

and attacks and either alert through the Analytics Dashboard or ii) apply mitigation measures through dynamic policies, such as application blocking, firewall rule enforcement, etc.

The QuComm (network analytics company), will develop Qucomm Network Analyser NetApp to work with QuComm Anomaly Detection and Telemetry vApp for protecting industrial 5G NPNs. Concerning the role of the FoF Operator, this will be to deploy a monitoring app with anomaly detection capabilities with integration with the communication network deployed in the factory. Another stakeholder role would be that of the Attacker whose role is to take advantage of vulnerabilities of the internal FoF network in order to damage/delay production and/or leak data from the OT or IT systems. Finally, the Integrator's role is to integrate the Anomaly Detection vApp with the 5G NPN management and network/edge infrastructure in order to enhance cybersecurity capabilities. Currently the Status is: Anomaly Detection framework is evolving in order to address particular threats relevant to FoF environments (e.g., PLC infrastructure).

As far as EVOLVED-5G Innovations is concerned, the NetApp that will be developed will take advantage of the provided APIs that expose 5G Core information, reducing the need for probe deployments and including information from all UEs connected to the 5G Core. Closing, the evaluation criteria involve:

- KPI.1: Update frequency - Telemetry updates received per second (how often updates are being processed by the NetApp).
- KPI.2: System Utilization – NetApp utilization.
- KPI.3: Memory Usage.
- KPI.4: Mitigation latency: How long is required for an anomaly to be detected and mitigation actions or alerts to be issued.

Concerning the Prerequisites, constraints, restrictions, we refer to the amount and level of information from 5G Core is available at NEF. Attack profiles with synthetic traffic to be used at validation stage. The application will be deployed both in Malaga and Athens benchmark premises.

6.3.3.3 Occupational safety analysis – CAF use case

The particular contribution provided by CAF, has ultimate goal to employ computer vision software to detect whether or not Personal Protective Equipment (PPE) such as hardhat, safety glasses, protective gloves, is being worn by employees and provides near real time a warning signal directly to the control room safety officer when any element of PPE equipment is not being detected. The video from the factory is collected using a CAFA AMR robot, a wheeled platform that carries stereo cameras that cover a 360-degree field of view around the robot. The robot has a 5G communication device that transmits the videos to the 5G MEC-based CAFA Analyzer NetApp, which is used to analyze whether workers are wearing PPE.

The CAFA (robotics company) will be developing CAFA Analyzer and AMR robot with stereo-cameras. The Integrator, will install CAFA AMR robot and install C2 and CAFA Analyzer applications to the 5G MEC and conduct tests. Finally, the Factory (safety department) sets the terms of reference - the rules and which PPE is mandatory and where. NetApp send alert to safety officer if CAFA Analyzer detect missing PPE. Safety officer also make post-analyse of situations where NetApp have detected infringements of rule wearing PPE.

Currently the Status of the Analyzer of the NetApp and AMR robot stereo cameras system development is ongoing. As far as the EVOLVED-5G Innovations is concerned, is to finalise,

verificate, validate, certificate and operate with Analyzer NetApp and AMR robot with stereo cameras.

Concerning the nature of the KPI's, CAFA is proposing the following two:

- **KP1**- Video analysis is based on 5G MEC, i.e., the video stream does not need to be streamed. To achieve this KPI, it is important to equip the MEC with a sufficiently powerful GPU (such as the Nvidia Tesla 100).
- **KP2** - Violation of PPE wearing rules is detected in less than 2 seconds. It is possible to intervene close to in real time to prevent the situation from becoming more dangerous.

The deployment of NetApp is planned to be tested on both Malaga and the Athens platform. NetApp must be pre-installed on the Edge or 5G MEC. The CAFA camera is carried by an AMR robot that needs a connection over a 5G network. The tests are performed both indoors and outdoors.

6.4 SECURITY GUARANTEES AND RISK ANALYSIS (SEC) PILLAR

6.4.1 State-of-the-Art and Current challenges

The new quality of information transparency and digital opening of physical systems [94] raises numerous issues concerning the cyber security of systems [95][98]. A simple definition of the cybersecurity concept that is given by Huxtablea & Schaefera [88] is: *“the protection of theft or damage to IT hardware, software and the data stored on the systems”*. In the current fast moving scenario, it is expected that cybersecurity will become an integral part of the strategy, design, and operations of companies that embrace Industry 4.0 paradigm. The work and future activities have to aim at supporting a holistic view of cyber security of Industrial 4.0 production sites.

The following security's threats have been identified by the Federal Office for Information Security (BSI) [98]: direct attacks on an external access, indirect attack on the IT systems of the service provider for which the external access has been granted, exploiting unknown vulnerabilities or zero-day exploits enable unknown attack vectors without detection capabilities, components are infected by non-targeted malicious software and impaired in their functionality, intrusion into neighboring networks or network segments (for example the existing office network). In order to address these problems/threads, companies should undertake a vulnerability assessment process able to identify and assess potential vulnerabilities of systems [81].

According to NIST [99], risk is “the level of impact on organizational operations (including mission, functions, image, or reputation), organizational assets, or individuals resulting from the operation of an information system given the potential impact of a threat and the likelihood of that threat occurring”. Security risks related to information systems depend on the loss of confidentiality, integrity, or availability of information or information systems [100] In general, any of the impacts identified translate into a drop in the company productivity and competitiveness [102] .In other words, the company incurs higher costs and loss of profitability [104].

Moreover, with the aim to keep the protection up-to-date, it is necessary to continuously update the implemented security controls on device level (installing new security patches), network level (updating firewall signatures of new threat) and plant/ factory level (monitoring and

analysing the actual log sources) [105] [102] To this way one of the most adopted countermeasures according to the literature seems to be encryption [105].

According to Huxtablea and Schaefera's review, industries have to focus to the following fields in order to support to its connected products: cybersecurity consulting to give advice and guidance with regard to cybersecurity strategy, risk management to prevent cyber-attacks, threat monitoring and detection to provide software and hardware, cyber incident response to limit damage and prevent further cyber-attack, training to limit the likelihood of attacks taking place, cybersecurity packages in relation to the products being sold. Below are some of the applications that deal with cyber security issues in Industry 4.0 environments.

A really important application that is going to change the game in the field of cybersecurity has been developed by 8BELLS. That application is about a L7-aware Whitebox Switch with Dynamic SFC and TSN Support. As far as the current status is concerned, the software switch can only measure traffic directly on the interface. With the 5G integration expected that the application will allow the switch to compare readings with the 5G Core in order to detect significant traffic that is unknown to the network [22]. In addition, another important application has been provided by IQBT. Blockchain Data Brokerage Engine used to enable trust and privacy in data brokerage and sharing, applicable in data marketplaces and for internal knowledge sharing and collaboration needs within and across an organisation.

Some of the benefits that 5G brings to the blockchain world and the specific application are the following: very low latency communication, replacement of the network slice broker with a distributed blockchain-based one and the blockchain-enabled device authentication with traceability [22]. SIEM (Security information and event management) system is another application in the cybersecurity field that FOGUS has deployed in order to provide a complete log-management and event visualization system, including features such as data analysis, system monitoring, threat assessment and automated management. As a result, conjunction of 5G capabilities and NetApps integration will enable: network and service quality monitoring, automation and user level authorization [22]. Above there are mentioned some of the most important applications in the cybersecurity field as well as the evolution that are expected to show with the 5G integration according to the 5G Infrastructure Public Private Partnership .

Next, we will present the challenges that cybersecurity has to face. Next, according to the studies [106] are presented some of the security threats that Industry 4.0 players need to focus on, and try to mitigate its impact are: Enterprise Cyber-Espionage, Confidential Information and Intellectual Property, as well Denial-of-Service (DoS), Supply Chain and the Extended Systems, and finally Smart Security and the Smart Factory.

6.4.2 The NetApp Opportunity

For the security guarantees and risk analysis pillar, EVOLVED-5G undeniable represents an unique opportunity to support the security management and threat detection in a smart factory environment.

Indeed, business opportunities related to access to a rich stream of information from the core of a 5G network arise as NetApps of this pillar will allow analysis of congestion status of network devices and subnetworks, as well as access to APIs exposing data for traffic volume. This is of great importance in smart environments where traffic management is essential for efficiency, health and safety. Also, 5G-enabled authentication and authorization mechanisms for the

NetApps where revoking access rights can be implemented to detect by suspicious or malicious behavior of NetApps is of critical importance in terms of traffic security management.

6.4.3 Target Use Cases

In the following lines we describe the use cases for the particular pillar, split into three use cases (one per SME).

6.4.3.1 L7-aware Software Switch traffic management -- 8Bells use case

We begin with the *8Bells Use case*, whose goal is the accurate measurement of traffic over an interface, specific to a device and perform a simple check of “unregistered” traffic outside the 5G Core network. This will use the NetApp designed by 8BELLS for the Pillar (name still under development) and the applications Involved is called the: “8BELLS L7-aware Software Switch”. As far as the current status is concerned, the software switch can only measure traffic directly on the interface, the novel element within the EVOLVED-5G context is that the EVOLVED-5G NetApp will allow the switch to compare readings with the 5G Core in order to detect significant traffic that is unknown to the network (and potentially harmful). Concerning the evaluation criteria, a good possible indicator would be the accuracy (% of traffic not reported by the 5G Core APIs) of detecting traffic generated outside the 5G network and reporting on its behavior. As far as the prerequisites, constraints, restrictions are concerned, the L7-aware switch must be able to access a part of the data traffic. The traffic may even be encrypted – this use case does not utilize the L7-awareness aspects of the software. Finally, the target location is selected to be the 5GENESIS Athens (Indoor, Outdoor, Edge). The reason behind this selection is are picking Athens due to proximity to 8Bells establishment – since there has been no indication of strong preference over the two networks.

Another use case provided by 8Bells involves the lessening of the burden on a reportedly congested device in the network, applicable to many different aspects of a FoF. Once again, the EVOLVED-5G NetApps , will use the NetApp designed by 8BELLS for the Pillar, as well as the applications that are involved is the 8BELLS L7-aware Software Switch. The Target innovation has as a goal via an EVOLVED-5G Innovations. Through EVOLVED-5G project, this functionality of the switch can be combined with reports from the 5G Core in order to (automatically) determine the status of devices and act accordingly. Additionally, the Current Status of the situation is that the switch can redirect traffic throughout the network and set up smart function chains – however, these are mostly configured by the user who has a particular design in mind. The novelty within the EVOLVED-5G is that the NetApp will allow the switch to compare readings with the 5G Core in order to detect significant traffic that is unknown to the network (and potentially harmful). Once again as Evaluation criteria, a good possible indicator would be the accuracy (% of traffic not reported by the 5G Core APIs) of detecting traffic generated outside the 5G network and reporting on its behavior. As far as the prerequisites, constraints and restrictions are concerned the L7-aware must be able to access a part of data traffic and furthermore traffic should be available for DPI, passing via interface over a non-encrypted traffic (or must have a fast responding decrypter agent active). Last but not least the target location is selected to be the 5GENESIS Athens (Indoor, Outdoor, Edge) and the reason behind this selection lies to Athens proximity to 8Bells establishment.

6.4.3.2 NetApps identity validation -- IQBT use case

The goal of this use case is the provision of an authentication and authorization interface for the NetApps that request access to the 5G core network and invoke the northbound 5G APIs. The described scenario will be integrated all EVOLVED-5G pilots. Whenever an NetAPP is requesting

access to northbound 5G APIs, the IAM NetApp will be invoked and challenge the requesting NetApp. As soon as its identity has been authenticated, the IAM NetApp will authorize the access to the requested APIs through the API Exposing Function (or similar functionality that will be provided by the EVOLVED-5G). The scenario will include cases of NetApps that cannot be correctly identified due to erroneous identity validation, or lack of concrete and trusted identifiable attributes, as well as cases of malicious behavior of already authenticated and authorized NetApps, which will lead to the revoke of their access to APIs. Scenarios for exploiting the vulnerabilities of the proposed authentication schemes will be tested and validated and potential associated risks will be determined. As stakeholder roles and interests are concerned, we distinguish three major categories: *NetApp Developer*, *Connectivity Provider* and *Experimenter*.

NetApp Developer develops and configures the NetApps associated with the vertical applications and the EVOLVED-5G ecosystem. The developer will have a facilitated means of authenticating their NetApp and authorizing it to access their corresponding assets in their environment.

Connectivity Provider Initiates and configures the 5G infrastructure to facilitate and expose the northbound 5G APIs to be consumed by the NetApps. Can assign new security policies and privacy constraints to map dynamically changing requirements of vertical applications or the network's operation.

Finally, the *Experimenter*, requests access to exposed 5G APIs through the NetApps authentication module. They are challenged by the IAM NetApp and upon the validation of their ID credentials are allowed access to the requested APIs. Their authorization/access privileges are continuously monitored and accessed based on contextual parameters. If a malicious activity is detected the authorization is terminated and the NetApps (*Experimenter*) authentication status is revoked.

As far as the Evaluation criteria is concerned both Unidentified or Non-authorized NetApps cannot access the 5G APIs and already authorized NetApps that in the process of their operation develop malicious or abnormal behavior (determined by the IAM NetApp's behavioral monitoring algorithm) their access is revoked. Tentative KPIs: Number of unauthorized accesses should be 0.

Concerning the Prerequisites, constraints, restrictions, NetApps that need to access exposed 5G APIs need to be authenticated and authorized by the IAM NetApp, over the OIDC/OAuth2.0 protocol. Concerning the target location, 5GENESIS Athens (Indoor, Outdoor, Edge) is preferred based on proximity criteria only.

6.4.3.3 Secure and trusted event management system -- FOGUS use case

The goal of FOGUS use case is the provision of a secure and trusted event management system for 5GNPN where the direct access to the network and end nodes is restricted.

In more details, a vertical industry (Factory owner) need to monitor the network performance and the traffic flow on a 5GNPN established in their premises. Their IT department need to expand the security and event management system that they use to collect information from the 5GNPN as well. The vendor that provides the network allows for interaction through the standardized 5G Northbound APIs. A NetApp is needed to bridge the gap and enable the monitoring and event managements of the 5G NPN through those API's. Concerning the schema of Stakeholder roles and interests, we distinguish 4 different roles: *the NetApp Developer*, *the VerticalApp owner*, *the Connectivity Provider* and *the Experimenter*.

The NetApp Developer, develops and configures the NetApp that collects all the monitoring and events info from the 5G system in a secure and trusted way and passes that info to the vertical

app. The NetApp takes advantage of the NEF northbound APIs. The developers should have access to the experimentation infrastructure. The Vertical App owner, participates in the definition and development of the related NetApp and reuses (if possible) developments on the common /cross pillar NetApps. Plays the role of the experimenter as well. The Connectivity provider, initiates and configures the 5G infrastructure to facilitate and expose the northbound 5G APIs to be consumed by the NetApps. The appropriate (according to the standards) exposure of the APIs is assumed. Its role is critical for the validations process. The verification/development process can omit the actual infrastructure.

Finally, the experimenter, whose role is to run the validation tests. The set of specific test cases (and potentially the development of any probes) is requested from the experimenter. The validation results (KPIs) collection and analysis are also one of the responsibilities of the experimenter.

6.5 PRODUCTION LINE INFRASTRUCTURE (PLI) PILLAR

Human Robot Interaction tries to understand how to improve human-robot collaboration using innovative interfaces but creating a safe and trustworthy human-robot system is a complex challenge.

6.5.1 State-of-the-Art and Current challenges

An essential face of Industry 4.0 is autonomous production methods powered by robots that can complete tasks intelligently, with the focus on safety, flexibility, versatility, and collaboration [108]. Smart robots will not only replace humans in simply structured workflows within closed areas but robots and humans will work cooperatively, using smart sensor human-machine interfaces. However, the recent robotic technology does not provide predictability of the outcome and performance of the manufacturing process in real-time, and does not help in autonomously managing and optimizing the cost and time of this process [109].

Industrial robots in Industry 4.0 revolution will be designed more efficiently and collaboratively with humans and with other robots over networking allowing them to be self-aware and self-adaptable on new products and manufacturing processes. Industry 4.0 will utilize Internet of Things (IoT) such as for controlling and remotely monitoring industrial robots [102], Cloud Computing [91], processing Big Data and advanced information analytics will provide smart factories with many such robots. In addition, the robots will be able to autonomously detect degradation on product performance, and apply optimization to solve it.

In one hand, robots have to embrace some technologies in order to be cheaper, having sensors with higher quality, faster and cheaper processors, consuming less energy and being connected everywhere. These technologies include: Advanced Sensor Technologies, Artificial Intelligence, Internet of Robotic Things and Cloud Robotics.

On the other hand, a different study [110] supports that characteristic technologies of the next generation intelligent industrial robotics are: Artificial Intelligence, Advanced Sensing and Perception and Navigation Guidance systems, Utilization of Augmented Reality Technology in Robotics Controllers, and finally the Industrial Internet of Things Platforms and Wireless Communication Capability. According to the same study [110], there are two primary advantages of deploying the next generation of intelligent industrial robotics, in place of the current generation of robots: the ability of intelligent robotics to self-learn as well the mobility, free movement, and ability to collaborate. Industrial robots with various intelligent and sensory

capabilities are utilized in the manufacturing processes and shaped the factories of the future. These robots have several applications in the field of Industry 4.0. Below are some of the most important robots' applications [22].

An interesting application in the robotics field, provided by PAL, is the AI-driven Humanoid robot. This robot can safely interact with the environment and undertake any task that requires perception, mobility and manipulation skills. 5G capabilities will allow: breaking the limitation of the data traffic that can circulate on the current network settings and finally, offloading computational power at the edge/central cloud [22]. AI-driven logistics robotic fleets is a different application in the Industry 4.0 environment that has been provided by UNM. This platform addresses all the problems related to the centralized control of autonomous mobile robots and allows the extension of the robot functionality with additional sensors. Under the 5G integration in Industry 4.0, this application will take advantage of sliced service provisioning and will also be beneficial as computation offloading will enable enhanced functionality by robots. As mentioned above, some of the robots' applications in the Industry 4.0 environment as well as the evolution that are expected to show with the 5G integration according to the 5G Infrastructure Public Private Partnership.

Following, we shall present some of the challenges that industries have to face during the development of robots. According to the study of Bayram & Ince [109], there are many scientific challenges such as processing Big Data, dealing with uncertainty, perception in the real environment, cognitive decision making in real time, etc. According to a different study [111], 10 grand challenges that may have major breakthroughs, significant research, and/or socioeconomic impact in the next years are: New materials and fabrication schemes, Biohybrid and bioinspired robots, New power sources, battery technologies, and energy-harvesting schemes, Robot swarms, Navigation and exploration in extreme environments, Fundamental aspects of artificial intelligence (AI) for robotics, Brain-computer interfaces, Social interaction, Medical robotics, Ethics and security. Another study supports [112] that the seven challenges that companies will have to face when implementing new robotics solutions are: integration, standardization, flexibility, skills, education and training, technological bottlenecks, and social and ethical considerations.

The aim of the robotic pillar is to use the 5G technologies and the NetApps alongside mobile robots to support "Factory Automation and Indoor Logistics" in an agile production line. Two aspects of a production line will be highlighted in this pillar: the teleoperation and telemaintenance tasks using the TIAGo robot, the mobile manipulator provided by PAL Robotics; the orchestration of a fleet of mobile robots to enable the centralized control of autonomous mobile robots to perform logistics tasks in the agile production line. Before going into details about the two cases highlighted in the production line, when we talk about indoor mobile robots we have to take into account that indoor localization and mapping is a key enabler for pervasive use of robotic solutions. Simultaneous Localization and Mapping (SLAM) is the standard mathematical framework for iteratively optimizing 1) the trajectory (sequence of poses) or dynamics of a robot based on the predictions of its motion model as well as on the observations such as laser range, visibility or position of landmarks, odometry information coming from the wheels and 2) the position of the landmarks and the map itself. But sometimes the localization mechanism fails and the robot needs to use several strategies to try to be able to relocate itself. A new technology for global localization could arise with the use of 5G technology, with rich localization information providing GPS coordinates with the accuracy of 1 meter or less for the global localization of the robots in the industrial building and also among the floors of the

building if there is more than one floor. This is a common step that has to be taken into consideration for all mobile robots operating indoors in a production line so it is a common need for the whole robotic pillar.

The aim of the teleoperation use case applied to the TIAGo mobile manipulator of PAL Robotics is to develop an industrial internet telecontrol architecture for robots in a production line. The main objective is to realize teleoperation and telemaintenance tasks, which on the one hand meet user needs of the industry partners and can on the other hand be performed over the 5G communication infrastructure. While teleoperation of technical highly sophisticated systems has already been a wide field of development, especially for space and robotics applications, the automation industry has not yet benefited from its results. Besides the established fields of application, also production lines with industrial robots and the surrounding plant are in need of being remotely accessible. This is especially critical for maintenance or if an unexpected problem can't be solved by the local specialists. This problem was stressed even more during the current COVID-19 pandemic situation. Special machine manufacturers, especially robotics companies, sell their technology worldwide. Some factories, for example in emerging economies, lack qualified personnel for repair and maintenance tasks. When a failure occurs, an expert of the manufacturer needs to fly there, which leads to long down times of the machine or even the whole production line. With the development of data networks, a huge part of those travels can be omitted, if appropriate teleoperation equipment is provided. But to make the data travelling on the network for teleoperation, an infrastructure is required to guarantee some specific constraints of bandwidth, security and service priorities. We hope that with a 5G based teleoperation we can resolve these issues.

6.5.2 The NetApp Opportunity

The NetApp developed during the project will create opportunities for all the project partners. According to the robotic market and industries, it will allow to fully exploit the novel business opportunities that are raised from related market activities and business functions, such as:

- Global Localization NetApp with GPS coordinates for robots.
- MonitoringEvent API.
- MoLcsNotify API.
- AsSessionWith QoS API.

6.5.3 Target Use Cases

6.5.3.1 Common workforce - Global Localization – PAL/UNMANNED use case

The Goal and objective of the current NetApp is the Indoor localization and mapping for mobile robots Global localization using 5G technology. The goal is to address the relocation issues when the robot gets lost due to localization mechanism fails GPS coordinates with the accuracy of 1 meter. Mobile robotic platforms with 5G antennas and Navigation package are the SME's products that will be integrated to work for this case. A more detailed description reads as follows.

UML will collaborate with PAL Robotics in developing a NetApp that will allow an autonomous mobile robot fleet to localize in indoor environments and use a centralized command centre to deploy these assets over 5G and EDGE infrastructures for a logistics-based use case in a FoF setting. When we talk about indoor mobile robots, we must consider that indoor localization and mapping is a key enabler for pervasive use of robotic solutions. Simultaneous Localization and Mapping (SLAM) is the standard mathematical framework for iteratively optimizing two

aspects: the trajectory and the position of the landmarks. The trajectory (sequence of poses) or dynamics of a robot based on the predictions of its motion model as well as on the observations such as laser range, visibility or position of landmarks, odometry information coming from the wheels and the position of the landmarks and the map itself.

Sometimes the localization mechanism fails, and the robot needs to use several strategies to try to be able to relocate itself. In order to quantify the efficiency of a localization system, the robotics community has defined a problem called the 'Kidnapped Robot (KR)'. KR challenge essentially refers to a situation where an autonomous robot in operation is carried to an arbitrary location. Once at this new location, the ability of the robot to localize itself in a robust fashion is tested. The KR problem creates significant issues with the robot's localization system, and only a subset of localization algorithms can successfully deal with the uncertainty created. It is believed that this problem is even harder to solve in indoor settings due to the lack of information from a Global Positioning System (GPS). Therefore, a new technology for rich global localization could arise with the development of this NetApp that will be coupled with the benefits of 5G technology. The objective is to obtain information from 5G cells and the resulting GPS coordinates with an accuracy of 1 meter or lower for effective localizing of the robotic fleet in a factory. Furthermore, this information can be useful to localize the robot among the floors of the building if there is more than one floor. This is a common step that must be taken into consideration for all mobile robots operating indoors in a production line, so it is a generic need for the robotics community.

6.5.3.2 Common workforce Teleoperation – PAL use case

The goal is to provide a framework in which teleoperation and tele maintenance tasks is feasible within the 5G based teleoperation in order to resolve the issues on some specific constraints of bandwidth, security and service priorities. Reliable video-based and haptic-based interaction and communication. A list of NetApps that will be implemented in the current use case is UDP video and haptic feedback transfer with high bandwidth and QoS, Setting up VPN channels, Adaptive Management and Security System, Robot condition monitoring services with high frequency, Channels configuration and management for data transfer. A list of applications involved is the TIAGo mobile manipulator with 5G antennas and Force-Torque sensor on the wrist, Geomagic Touch haptic device and the Teleoperation package.

The aim of the teleoperation use case applied to the TIAGo mobile manipulator of PAL Robotics is to develop an industrial internet telecontrol architecture for robots in a production line. The main objective is to realize teleoperation and telemaintenance tasks, which on the one hand meet user needs of the industry partners and can on the other hand be performed over the 5G communication infrastructure. While teleoperation of technical highly sophisticated systems has already been a wide field of development, especially for space and robotics applications, the automation industry has not yet benefited from its results. Besides the established fields of application, also production lines with industrial robots and the surrounding plant are in need of being remotely accessible. This is especially critical for maintenance or if an unexpected problem can't be solved by the local specialists. This problem was stressed even more during the current COVID-19 pandemic situation.

Special machine manufacturers, especially robotics companies, sell their technology worldwide. Some factories, for example in emerging economies, lack qualified personnel for repair and maintenance tasks. When a failure occurs, an expert of the manufacturer needs to fly there, which leads to long down times of the machine or even the whole production line. With the

development of data networks, a huge part of those travels can be omitted, if appropriate teleoperation equipment is provided. But to make the data travelling on the network for teleoperation, an infrastructure is required to guarantee some specific constraints of bandwidth, security and service priorities. We hope that with a 5G based teleoperation we can resolve these issues. In order for the scenario to be fulfilled the following services are needed:

- Remote access to the plant and teleoperation of the robot are absolutely mandatory.
- It is crucial to have a reliable human communication channel and the possibility of file-exchange.
- Video-based and haptic-based interaction is a very important feature. The expert, who knows the robots very well, but is facing the context of the specific plant for the first time, needs appropriate situation awareness. Also, any kind of teleoperation is only feasible with proper feedback information, both video and haptic.

The setup of a stable and secure communication link between the telemaintenance center and the plant is essential for the teleoperation scenario. It requires several organizational and technical steps to reach this goal. The first step is the constitution of the Virtual Private Network (VPN) access to the company intranet and the implementation of the security measures requested by the cyber security team. The second step is the characterization of the connection which leads through several subnets. Teleoperation needs a special combination of services, requiring different bandwidth and sampling rates. As those requirements influence each other and the services need to be included with various security measures, the optimization of the throughput is a challenge. The services also have different priorities: the transmission of robot commands and haptic feedback must not ever be blocked by a bandwidth-consuming video stream. Therefore, an “Adaptive Management and Security System” (AMS) is needed. The AMS should permanently measure the quality of the communication link during the teleoperation scenario and estimate the optimal configuration for the required services.

As already described above, there is a chance for a rapid quality decline and bottlenecks in the network. After this has been discovered by measurement units, the AMS should decide which service configuration fits best for the altered network state. The AMS can decrease the video stream quality with graceful degradation measures or even stop the transmission of some of the video streams to ensure a safe transmission of the robot commands and haptic feedback and the primary video stream which serves as a feedback to the expert. Additionally, semi-autonomous help functions should be triggered dependent on the connection quality, to support the teleoperation. For example, the maximum velocity of the drive commands should be decreased before dangerous situations arise. In case of an extreme decline of the connection, the transmission of external robot commands should be interrupted completely to make the robot autonomously able to drive to a safe position. All described features should be performed autonomously by the AMS. To add an extra safety measure, there always should be a service technician near the robot, who is informed about the connection quality on his mobile device and can interrupt the teleoperation if he or she thinks it's necessary.

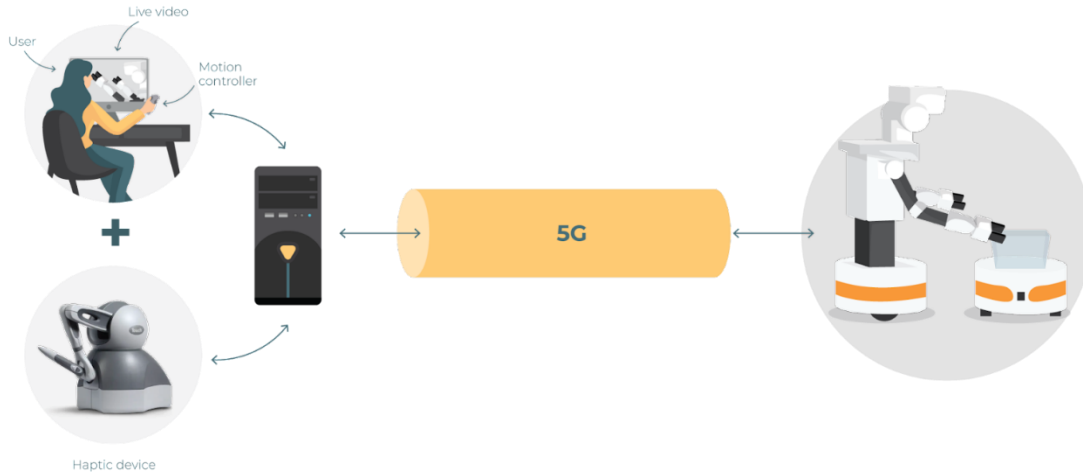


Figure 22. Common workforce Teleoperation

As far as the Target Innovations is concerned, the current status holds as follows. It is very difficult to have a reliable teleoperation because of issues on some specific constraints of bandwidth, security and service priorities. The EVOLVED-5G Innovations are: 5G based teleoperation needed to fill the void by resolving the issues on some specific constraints of bandwidth, security and service priorities. Additionally one other innovation would be the reliable video-based and haptic-based interaction and communication.

Concerning the evaluation criteria (metrics), logging of robot information (like speed, position, Force-Torque values, etc.) to check if they are traveling via the 5G network at minimum 100Hz rate, for the condition monitoring. The overall bandwidth available during the transmission via UDP of video streams. User satisfaction surveys for qualitative results and for the use of the teleoperation with the haptic device through the 5G network. Execution quality will be assessed also by task execution time, individual task success rates for the human teleoperator.

Concerning the restriction, prerequisites and constraints of the use case can be summarized in the following lines: The overall bandwidth available during the transmission via UDP of video streams is important during the teleoperation of the robot (e.g., 300 Mbps). The infrastructure and the NetApps have to support and allow communication via Virtual Private Network (VPN) to access the robot for teleoperation (security measures for cyber security here is an extra). AMS (Adaptive Management and Security System) has to be available for security measures, optimization of the throughput and service priorities (the transmission of robot commands must not ever be blocked by a bandwidth-consuming video stream). Two channels should be available for the robot if possible: one with a guaranteed bandwidth to send points cloud, video, etc.; another one for a guaranteed latency to send/receive commands. Robot information (like speed, position, Force-Torque values, etc.) have to travel via the 5G network at minimum 100Hz rate, for the condition monitoring and also 5G infrastructure should have a way to configure and to reserve a "channel" for different types of data. Concerning the geographical preference of the use case no particular need has been given.

6.5.3.3 Fleet Orchestration - Unmanned use case

Unmanned Life's Autonomy-as-a-Service platform addresses the problems related to fleet orchestration via a centralized control platform which can manage multiple autonomous systems concurrently. Due to its open platform approach, UML's solution fits well to the Factory of Future (FoF) environment by enabling collaboration between different robotic systems.

Additionally, our platform allows the extension of robot functionalities with sensors, hence bringing together the heterogenous robotic ecosystem with the ability to solve complex tasks. The given name to the NetApp(s) for this particular use-case is Global localization for indoor navigation of multi-robot fleet, as well as the application involved are the: Autonomy-as-a-Service, Multi-robot fleet management and the Sensor fusion.

UML's vision is that logistic processes and chains, like many other processes, will be autonomous and fully integrated from pick up to delivery of the packages. UML's Autonomy-as-a-Service platform aims to be the core of such systems by integrating and managing end-to-end processes autonomously. The goal of this centralized platform will be to minimize the heavy reliance on labor in the fields of logistics services by reducing associated costs and time of moving packages over a short distance in 5G-enabled warehouses and factories. UML will bring to the consortium its expertise in deploying AMR fleet controlled by its proprietary Autonomy-as-a-Service software platform. UML's fleet management software stack sits at the centre of the autonomous economy as enables users to deploy and manage AMRs in complex autonomous missions from a single management interface, on-demand and scale up cost- effectively over 5G.

Our Central Command Software platform (UL-CCP) orchestrates the movement of AMRs autonomously within the environment. The objective of the system is to achieve fast and efficient movements in a particular indoor setting using a fleet of vehicles which takes over repetitive and labour-intensive processes allowing the human worker to focus on value added tasks and process analysis. This will enable us to showcase the extended capabilities that autonomous robots can bring to various aspects of human life with the help of 5G. By taking care of monotonous and tedious tasks, AMRs will free up the human operator's time to focus on intelligent duties that are directed towards increasing the operational efficiency on the shop floors. Introduction of a human-robot hybrid warehouse management system within a factory also facilitates increase in profits for the organisation.

In the context of this project, the system is deployed to manage a fleet of AMRs with the goal to transport packages within the factory. The platform will be responsible in the orchestration of two AMRs. TIAGo mobile manipulator will navigate successfully inside a warehouse and pick an item. Once the item is picked, TIAGo will traverse to a delivery area where the UML's AMR will be waiting. TIAGo will place the item in the AMR and return to collect another item. Meanwhile, UML's AMR will collect the package from PAL's TIAGo mobile manipulator and move through the warehouse, to deliver the packages successfully to the endpoint. Once this action is complete, AMRs will travel back to the point of origin for the next task. Coupled with 5G capabilities to handle the volume of data from sensors and other sources, AMRs will be able to communicate with our interface to avoid collisions, help avoid mistakes, and carry out their assignments efficiently. AMRs are also equipped with sensors and our CCP will analyse the fused sensory data to process instructions and make intelligent decisions for safe navigation.

The current situation of the target innovation contains a mobile robot essentially is a programmable machine able to execute multiple operations, following pre-defined paths to fulfil a large variety of tasks. Therefore, a mobile robot can perform diverse activities that can be used in several sectors, such as urban transportation, logistics, space industry, household robotics, or healthcare. In the logistics industry they are mainly used in the transport of goods, materials and other objects. Mobile robot systems are characterized by a maximum flexibility in mobility relative to the environment, with a certain level of autonomy and perception ability, i.e., they can sense and react with their surroundings quite effectively. Such robotic systems make use of a middleware suite known as Robot Operating System (ROS), which is a flexible

framework for writing robot software. It is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms. ROS was built from the ground up to encourage collaborative robotics software development. UML envisions the use of Autonomous Mobile Robots (AMRs), i.e., a subgroup of mobile robots in the FoF production line. These vehicles are driverless and used to transport materials efficiently within a facility. They are monitored and controlled autonomously, which is necessary to get up-to-date process information, to avoid collisions, to assign driving jobs, and to manage the traffic of the robot fleet. Also, the mobile robots use sensory information from onboard sensors like cameras or laser scanners to localize and navigate themselves.

Concerning the EVOLVED-5G Innovations, the Autonomy-as-a-Service application will take advantage of sliced service provisioning as it needs both ultra-reliable low latency communications (uRLLC) and Enhanced Mobile Broadband (eMBB) slices. eMBB provides faster connections, higher throughput, and network capacity which improves the performance of the network in high traffic areas. uRLLC provides the reliability in network for mission critical applications such as robot control and navigation. The combination with Multi-access Edge Computing (MEC) will be beneficial as computation offloading will enable enhanced functionality of the robotic fleet to improve the network congestion and the performance in the applications which are running on the closest cellular provider's infrastructure. Therefore, 5G networks and APIs will facilitate augmented capabilities to improve the reliability of the fleet management activity. As far as the evaluation criteria are concerned, some parameters and KPIs potentially affecting the performance of these AMRs are the 5G reliability, the Bandwidth and the Network programmability. The latter will have an impact in the automation level and will increase the problem-solving capacity of robotic solutions in smart factories by achieving seamless performance. UML will look to enable the following features for the EVOLVED-5G trials:

- **Multiple AMR Platforms:** Standard fleet of AMRs composed of a generic mobile base platform and a mobile manipulator system to meet customer needs for loading, unloading, and transporting goods.
- **Fleet Management of Heterogeneous Platforms:** Integration of all sensors in the system as well as the external sensors on the AMRs for the indoor positioning/localization/navigation.
- **Data collection for analysis:** Data will be collected and processed to obtain meaningful information about the tasks.
- **Integration with 3rd party platforms:** Integration with PAL's TIAGo mobile manipulator. The package information will be collected and processed by UML to set the delivery destination for each package.

As the success criterion we consider the quality of fleet management and orchestration will be measured by the smoothness (control mechanism) of operation between the robots during task handover. Additionally, the ability to transport packages to endpoints autonomously and without incidents. Finally we consider the latency of peer-to-peer communication between different robotic systems. As far as the list of prerequisites, constraints, restrictions is concerned, we have come up with the following list:

- The integrated devices on the orchestration platform should be able to run virtual/dockerized environments.
- Each device on the orchestration platform should be Linux based or provide a VM.



D2.1 Overall Framework Design and Industry 4.0 Requirements

GA Number 101016608

- The integrated devices should provide sensor input data, preferably over ROS interfaces.
- The integrated devices on the orchestration platform should provide output action, services to perform individual tasks. Preferably over ROS interfaces.
- The integrated mobile devices should provide linear/angular velocity control. Preferably over ROS interfaces.
- Desired mean latency should be inferior to 10 ms.

7 SUMMARY AND CONCLUSIONS

In the journey towards fully exploitable 5G infrastructures we have reached the point where performance gains need to be made accessible to 3rd party innovators and SMEs through the development of NetApps (i.e., Software pieces that interact with the control plane of a mobile network by consuming exposed APIs in a standardized and trusted way). EVOLVED-5G project concentrates efforts in 3rd party innovators and SMEs belonging to the fourth industrial revolution or Industry 4.0, recognized as one of the major vertical industries by 5G-PPP. To this end, EVOLVED-5G works towards the specification of a NetApp ecosystem through the design of a functional architectural blueprint (i.e., the EVOLVED-5G facility) that will be made available to i4.0 vertical businesses and SMEs of the project.

This deliverable focuses on the specification of the all-encompassing reference architecture to be used as the basis for the definition of the EVOLVED-5G Facility as well as on the formulation of all appropriate requirements for the later implementation of the Facility. This is accomplished by addressing prior work on (1) 5G Openness, existing standards, and technologies (2) key Stakeholders and roles in the 5G ecosystem and (3) well-defined guiding concepts and design principles. To highlight the importance of the proposed ecosystem Industry 4.0-related use cases are also envisioned in the deliverable.

Based on the above, the high-level blueprint architecture is presented in this deliverable and is also extended with relevant functional blocks and specific tools that integrate the whole architecture in tiers. The tier description is also accompanied by an initial description of the NetApp lifecycle, that aims to illustrate the flow of different NetApp phases through the whole facility. The resulting reference architecture that is presented in this deliverable is the basis for the EVOLVED-5G further work and ensures interoperability beyond vendor-specific implementations. However, it is expected that more refinements will come out during the development of the different functional blocks and tools and the actual integration and testing; therefore, a more refined version of the reference architecture will be included in deliverable D2.3.

This deliverable also presents the conclusions of the requirements' gathering, harmonization, and prioritization activities based on the proposed architecture, targeting not to an exhaustive and possibly chaotic list of technical details, but rather to a balanced set of focused demands, formulated in an agile manner for the design phase to properly address them. A more refined version of the requirements will also be included in deliverable D2.3.

Finally, the deliverable also offers relevant insights on Industry 4.0-related use cases, by describing underlying challenges, needs for NetApps and expected impacts. In this process, the added value the NetApps will bring, existing problems they will solve and further enhancements are also revealed. As the definition of the use cases progresses over time in WP2, further analytical and fine-tune work will be necessary on requirements. In case of need, a revised version on the alignment between the requirements and the use cases will also be included in deliverable D2.3.

Being the first technical deliverable of the EVOLVED-5G project, it offers a digested view of the project's scope and objectives, a concise definition of NetApps, a detailed description of the EVOLVED-5G Facility, a well-structured list of main NetApp ecosystem requirements, and clarifies the approach that the project shall build upon. In this context, the deliverable is expected to serve as a fundamental reference guide for rest of work in WP2, but also on



D2.1 Overall Framework Design and Industry 4.0 Requirements

GA Number 101016608

subsequent implementation activities expected in WP3, WP4 and WP5 and the technical deliverables to come.

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