5G-EPICENTRE

5G ExPerimentation Infrastructure hosting Cloud-nativE Netapps for public proTection and disaster RElief

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	Youbiquo SRL	Italy	**YBQ**
	ORamaVR SA	Switzerland	**ORAMA**

List of abbreviations

Abbreviation	Definition
5G-PPP	5G Public Private Partnership
5GTS	5G Traffic Simulation engine
AdE	Adaptation Engine
aDrv	Analytics Driver
aggr	Analytics Aggregator
API	Applications Programming Interface
AuthM	user Authentication and Management block
CIR	Container Image Registry
CIS(M)	Container Infrastructure Service (Management)
CNI	Container Network Interface
CRI	Container Runtime Interface
CSI	Container Storage Interface
ctMANO	Cross-testbed MANO API
ctSSC(-M/T)	Cross-testbed Service/Slice Configurator (-Manager/Translator)
ctVNFCP(-A/M)	Cross-testbed VNF Chain Placement (-Algorithm/Manager)
DevOps	Development (“Dev”) and Operations (“Ops”)
DoA	Description of Action
E2E	End-to-End
eMBB	enhanced Mobile Broadband
EPI	Experiment Planning Interface
ETSI	European Telecommunications Standards Institute

EU	European Union
ExaaS	Experiments as a Service
ExCoord	Experiment Coordinator
ExCom	Experiment Composer
ExSch	Experiment Scheduler
GA	Grant Agreement
GDPR	General Data Protection Regulation
(G)UI	(Graphical) User Interface
HTTP	HyperText Transfer Protocol
ISG	Industry Specification Group
IT	Information Technologies
ITools	Insights Tools
K8s	Kubernetes
KPI	Key Performance Indicator
kpiM	KPI Monitor
MANO	Management & Orchestration
MCAC	Multi-container Application Composer
MCPTT	Mission-Critical Push-to-talk
MEC	Multi-access Edge Computing
ML	Machine Learning
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MoSCoW	Must Have, Should Have, Could Have, Won't Have
MUST	Minimum Usable SubseT

nappD	NetApps creation & management dashboard
NetApp	Network Application
(C/V)NF(C/M)	(Containerized or Cloud-native/Virtual) Network Function (Component/Manager)
(C)NFV(I/O)	(Cloud-native) Network Functions Virtualization (Infrastructure/Orchestrator)
NSBR	Network Service Browser
NSRepo	Network Service Repository
PaaS	Platform as a Service
PoP	Point of Presence
PPDR	Public Protection and Disaster Relief
PTT	Push-To-Talk
QoS/E	Quality of Service/Experience
qoseM	QoS/QoE Monitor
R&D	Research & Development
RA	Reference Architecture
RAN	Radio Access Network
RBAC	Role-Based Access Control
REST	Representational State Transfer
RP	Reference Point
SDN	Software Defined Networking
SME	Small and Medium-sized Enterprise
snbAPI	Software-defined NorthBound API
SoA	Service-oriented Architecture
TB	Testbed
UC	Use Case

URLLC	Ultra-Reliable Low-Latency Communication
VI(M)	Virtualized Infrastructure (Manager)
ViS	Visualisation Solution
VM	Virtual Machine
WP	Work Package

Executive summary

This deliverable describes the first version of the 5G-EPICENTRE federated experimentation facility architecture, along with a comprehensive set of the stakeholders' experimentation requirements elicited using online survey tools and questionnaires. A second, updated version of the contents of this deliverable will be provisioned at M24.

The intention of this document is to provide a comprehensive overview of the facility technical specifications, along with a functional viewpoint of the architectural building blocks that will comprise the final platform to be delivered. Therefore, no specific implementation detail will be implied in this document, rather a high-level overview of the envisioned roles, responsibilities and interrelationships among platform components will be documented to be used as guidelines for the development of the individual technological components in the context of WPs 2-4. A more elaborate description of the framework with initial interface descriptions will be provided in the context of the facility framework documentation due in M12 (D4.1), while the reference implementation will be provided in the updated version of this deliverable (D1.4) due M24.

This document will provide a thorough description of the methodology and tools used to elicit the platform stakeholders' (*i.e.*, experimenters expected to utilise the platform for the purpose of experimenting with their solutions) requirements, which have been analysed and classified into a comprehensive set of high-level functional and non-functional requirements for the 5G-EPICENTRE prototype integrated experimentation facility.

In addition, the document presents the methodology to define the architectural model, namely the various stages of the architecture design approach. These constitute a technology exploration step, followed by a top-down design approach and finally complemented by a bottom-up thorough specification of identified functional blocks. We then elaborate on the cloud-native approach, providing implementation reference frames for embracing cloud-native in the form of lightweight virtualisation technology (containers) and container orchestration tooling. Implications of the cloud-native approach to VNF orchestration on the ETSI-specified NFV-MANO architecture are thoroughly discussed.

Finally, three architectural viewpoints are defined, namely the *functional view*, *information view* and *deployment view*. The first specifies the roles and capabilities provided by the various functional blocks identified in the design process. The second defines a number of reference points as placeholders for the elaboration of component interfaces and cross-layer aspects in the context of T4.1. Finally, the third provides insight on deployment of the hardware and software artefacts, a process that will be thoroughly documented in the updated version of this document.

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1 Introduction

The aim of this deliverable is to define the initial architecture of the 5G-EPICENTRE experimentation facility based on a comprehensive set of platform requirements, which are outlined in this document. The contents of this deliverable are intended for the 5G-EPICENTRE technical component developers to use as a reference guide for the implementations to take place in the context of WPs 2-4. In line with the project's evolutionary approach, the requirements as well as the architecture specified in this deliverable can change over the course of the project, as aspects of the architecture will undergo verification during the development stages of the project. Therefore, the architecture described in this deliverable should be treated as an initial reference for describing what the components will be, what capabilities they provide, and what communication aspects should be considered in their implementation. In service of this purpose, no specific implementation is implied for the development, unless specified otherwise. This will be provisioned in the updated version of this deliverable due in M24 (D1.4).

Within the structure of 5G-EPICENTRE WP1, T1.2 was responsible for the elicitation of the stakeholders' requirements with respect to experimentation, leading to a first list of functional and non-functional requirements to describe the specifications that the platform should fulfil. On the other hand, T1.3 has been responsible for defining the first version of the system architecture, preparing the 5G-EPICENTRE development team for the prototypical implementation to be carried out in the context of the technical WPs (WPs 2-4, as specified above).

The document is structured as follows: Section 2 describes the activities, methods and tools used for eliciting the platform's experimentation requirements. Section 3 then elaborates on the architectural design approach, the current state of the art in testbed federation (technology exploration), provisions for embracing cloud-native technology to better align the platform to the demands of the PPDR sector and the three views of the architecture, namely functional view, information view and deployment view. Finally, Section 4 provides the concluding remarks. The document also possesses three annexes, where the specifics of the tools used for requirements elicitation can be found.

1.1 Mapping of project's outputs

The purpose of this section is to map 5G-EPICENTRE Grant Agreement (GA) commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed.

Table 1: Adherence to 5G-EPICENTRE's GA Deliverable & Tasks Descriptions

5G-EPICENTRE Task	Respective Document Chapters	Justification
T1.2: Requirements of 5G experimentation infrastructures for PPDR use case innovations *"Requirement extraction will be performed in order to obtain information on useful features from a sufficient sample of potential platform end-users (in this case, the SMEs and PPDR service providers who participate in the 5G-EPICENTRE consortium), collected in the form of a survey."*.	2.1 - Stakeholders' requirements analysis 2.1.1 - Electronic survey	In the corresponding Sections, the survey tools and methodology are described. The online questionnaire is provided for reference in Annex I.

T1.2: Requirements of 5G experimentation infrastructures for PPDR use case innovations *"This survey-based data collection will be complemented with qualitative research data obtained through face-to-face interviews involving a representative group of at least 60 users, thus allowing for the collection of more in-depth information."* *"Moreover, further in-depth qualitative interviews with key stakeholders (i.e., executives, product managers, technical leads and developers across SME technology divisions, but also product end-users, e.g. government, public and private safety organization decision makers and actual first responders) will be undertaken to allow for a greater understanding of the 5G-EPICENTRE requirements, taking into account the various different viewpoints expressed".*	2.1 - Stakeholders' requirements analysis 2.1.2 - Interviews	In the corresponding Sections, the results obtained from the interviewing process are described and analysed. Interview guidelines are added to this document as Annex II. The actual interviews are provided anonymously for reference in Annex III.
	2.2 - 5G-EPICENTRE platform requirements	In the corresponding Section, a first attempt at identifying and prioritising the platform's functional and non-functional requirements is presented at a system-level.
T1.3: 5G-EPICENTRE technical specifications and architecture *"This Task will address the 5G-EPICENTRE architectural design, including: i) specification of logical and deployment architectures with clear identification of the back-end components and environments, communication protocols, etc.; and ii) clear definition of interfaces, in order to ensure smooth communication and interoperability of all 5G-EPICENTRE components, as well as the adoption of a modular design and architectural style, which will allow for flexible integration of both new and existing building blocks (e.g. from partners' previous works as the core basis of the 5G-EPICENTRE platform)".*	3.5 - 5G-EPICENTRE architecture specification 3.5.4 - Functional view	In the corresponding Sections, a functional view of the architecture is provided, identifying the functional blocks required, along with well-defined roles and capabilities.
	3.5 - 5G-EPICENTRE architecture specification 3.5.5 - Information view	In the corresponding Sections, a view of the architecture from an information exchange perspective is provided, identifying reference points that facilitate exchange of information among functional blocks in the architecture.

T1.3: 5G-EPICENTRE technical specifications and architecture *“this Task will define a general architecture and specifications for the 5G-EPICENTRE VNFs, including properties, rules and best practices targeted at VNF developers in WP5, so as to fully support the 5G-EPICENTRE capabilities and foreseen VNF lifecycle”*	3.4 - Towards cloud-native enhancement of the federated platforms 3.4.3 - Cloud-native VNF architecture 3.5.4 - Functional view	In the corresponding Sections, implications of the 5G-EPICENTRE approach on the common standard for VNF implementation are detailed. The relationship between NetApps and VNF/CNF components is provided further as an example in Section 3.5.4.11.
T1.3: 5G-EPICENTRE technical specifications and architecture *“this Task will include an overview of legal requirements that the architecture must incorporate from a privacy and data protection by design perspective, ensuring 5G security mechanisms are natively embedded within the overall platform architecture, according to security-by-design principles”.*	2.1 - Stakeholders’ requirements analysis 3.5.7 - Security and privacy framework	In the corresponding Sections, requirements of the 5G-EPICENTRE platform with respect to its legal and ethical aspects are captured from the viewpoints of its stakeholders. Horizontal security aspects are addressed in Section 3.5.7.
T1.3: 5G-EPICENTRE technical specifications and architecture *“This Task will produce a “live” document, which will be kept updated to reflect the functional specifications of the 5G-EPICENTRE platform, with clear references to the architectural reference model described in Section 1.3.2”.*	3.2 - 5G-EPICENTRE reference architecture model 3.5 - 5G-EPICENTRE architecture specification	In the corresponding Sections, the reference architecture specified during the project preparation period is iterated. Updates address this model, introducing more functionality as the project requirements and implementation options become clearer.

2 5G-EPICENTRE experimentation requirements

2.1 Stakeholders' requirements analysis

The aim of this section is to analyse the requirements retrieved from a sufficient sample of potential end-users of the 5G-EPICENTRE platform, collected in the form of a survey. This sample includes the SMEs and PPDR service providers who participate in the 5G-EPICENTRE consortium (ADS, IST, ONE, IQU, NEM, EBOS, ATH, RZ, OPTO, YBQ, ORAMA), as well as firms in the private or public sector working on the design, the testing and the provision of PPDR services.

The survey is included in Annex I and is based on a Questionnaire that is structured as follows:

- Inform & Consent form for GDPR compliance
- Demographics to acquire information on the organisation that the questionnaire responder represents
- Role of the organisation in the telecommunications sector, *e.g.* network operator, PPDR service/ solutions provider, research/ experimental platform, standardisation body, *etc.*
- Role of the interviewee within the organisation, level of related experience, authority.
- Questions on potential user requirements of the 5G-EPICENTRE platform regarding important aspects of PPDR use cases.
- Questions on potential user requirements regarding the tools for booking the 5G-EPICENTRE resources for tests or the records of the experiment results after using the platform.
- Questions with respect to preferred pricing schemes that using the 5G-EPICENTRE testing platform.
- Question for the willingness of the interviewee to be interviewed

This survey-based data collection is complemented with qualitative research data obtained through face-to-face interviews, thus allowing for gathering more in-depth information. In-depth qualitative interviews with selective relevant interviewees in the PPDR market (*i.e.*, executives, product managers, technical leads and developers across SME technology divisions or from Network Operators serving public and private safety organizations and actual first responders) are undertaken to allow for a greater understanding of the 5G-EPICENTRE platform requirements, taking into account the various different viewpoints expressed.

The guidelines for the interviews are presented in Annex II. The following section refers to an in-depth analysis of the questionnaire and interview responses. In the following Sections, a quantitative and qualitative analysis of the feedback to the questionnaire is reported.

2.1.1 Electronic survey

2.1.1.1 Method and procedure

The electronic survey was conducted based on a questionnaire (see Annex I) made available electronically, through a platform that features a GDPR-compliant data centre and has in place tools for data privacy disclosures and opt-in statements in surveys. The survey link was disseminated to all 5G-EPICENTRE partners, who were asked to further disseminate it targeting experts of PPDR service provision in the private and the public sector. The survey remained online for a total of 40 days. After a necessary first step for filtering invalid responses, the data were then appropriately grouped and analysed.

2.1.1.2 Participants

A total of 40 individuals responded to the electronic survey, from 6 countries (Figure 1). As questions were not mandatory, the total responses per question are sometimes less than the number of respondents.

As seen in Figure 2, the majority of participants originate from the private sector, while a considerable per-

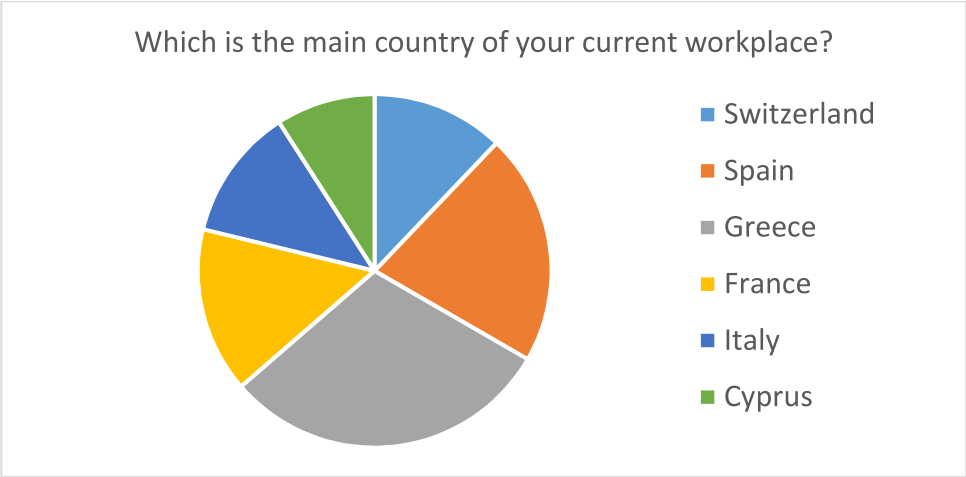

Figure 1: Country of responders' current workplace.

centage works in Academic organizations and a smaller one from Research Organisations. Approximately 60% of the participants were affiliated to members of the 5G EPICENTRE consortium. In addition, participants' organizations vary considerably in size, with half of the responders employed in relatively small firms (1-50 employees), and another third of the responders to belong to very large (more than 1000 employees) organizations.

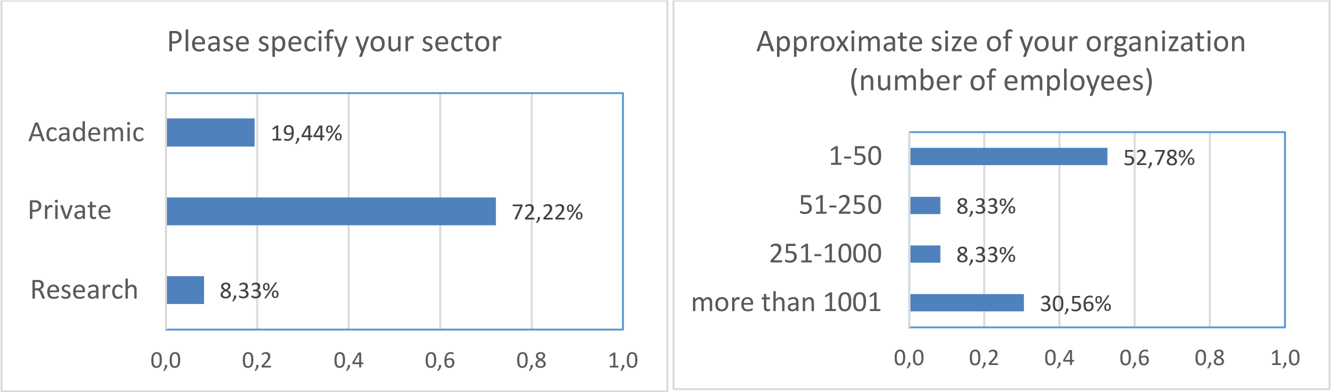

Figure 2: Participating organizations' information.

Regarding the roles of the participants' organizations in the telecom sector (Figure 3), participants were asked to select multiple options if applicable. Out of the total of 45 responses, it turns out that almost all organizations are involved as application or service providers (94.29%). A considerably smaller proportion corresponds to Network Operators and Research platform operators (11.43%). There were 2 responders that are involved in standardization procedures and one response in radio access network planning for PPDR service provision.

Regarding participants, nearly two thirds (45.16%) characterized themselves generally as technical people, followed by domain experts (36.11%). One third of the responders relate to business drivers (33.33%), followed by a smaller percentage of strategical drivers (22.22%), as illustrated in (Figure 4, top). Regarding their level of management, a considerable proportion of participants clarifying their role as engineers (45.71%) and researchers (37.14%), followed by management employees (executive officer 19.35%, administrative officers 17.14% and operative officers 8.57%). University professors represent 11.43% (Figure 4, bottom).

Furthermore, in majority, the participants have many years of business experience, with 63% in total working in the field for more than 10 years. In detail, 31.43% have more than 20 years of experience and 31.43% 10 to 20 years. One fourth of the employees have experience 2-5 years. Two participants reported experience of 5-10 years and another was two less than 2 years in the field (Figure 5).

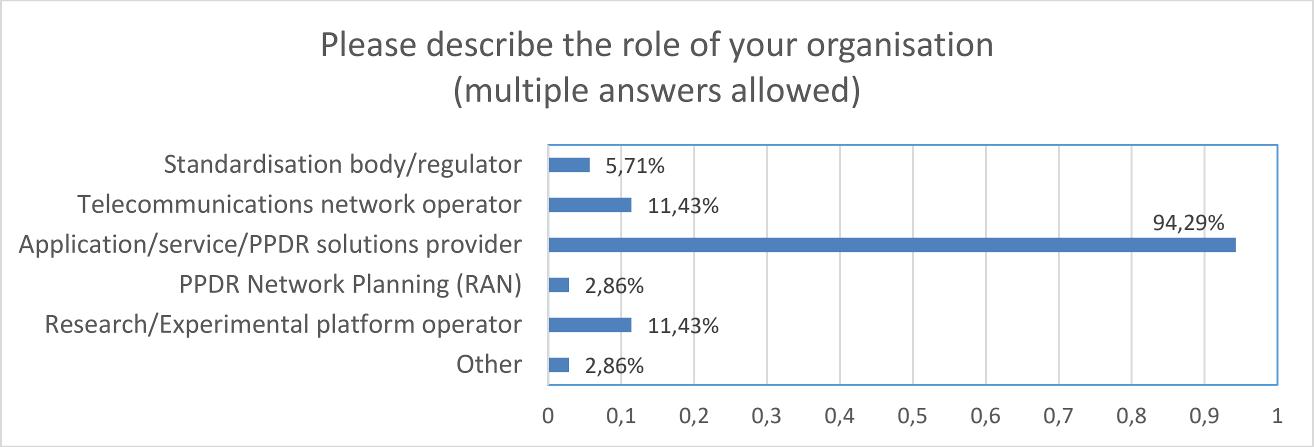

Figure 3: Business role of participants' organizations.

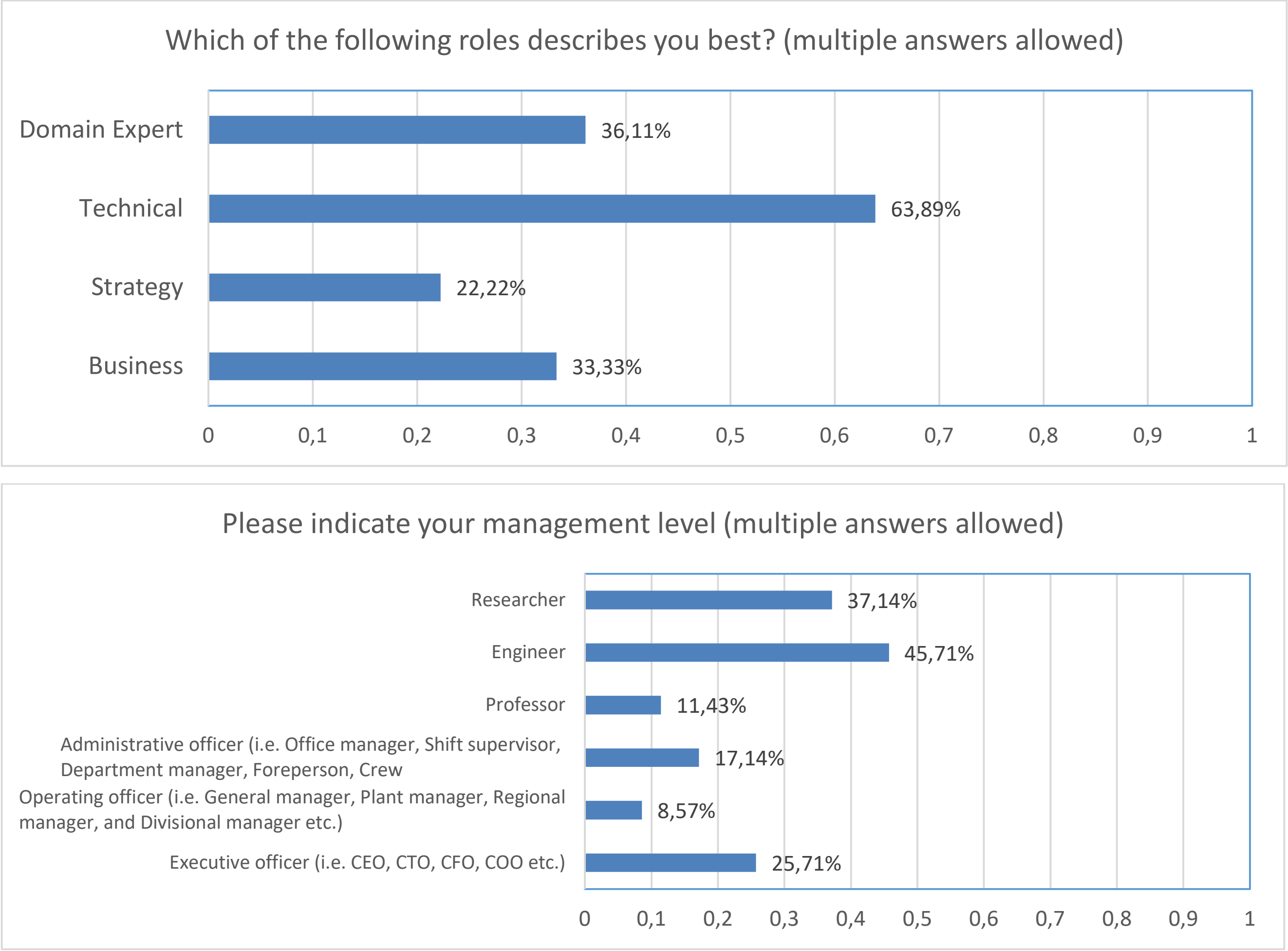

Figure 4: The role of participants in their organizations and level in management hierarchy.

Regarding the domain of PPDR services focused by the responders' organization (Figure 6), it is noteworthy that half of the participants declared Emergency Medical services (50%), followed by mission critical communications and Command & Control (each with 28,57%). Approximately one every six responders referred to surveillance

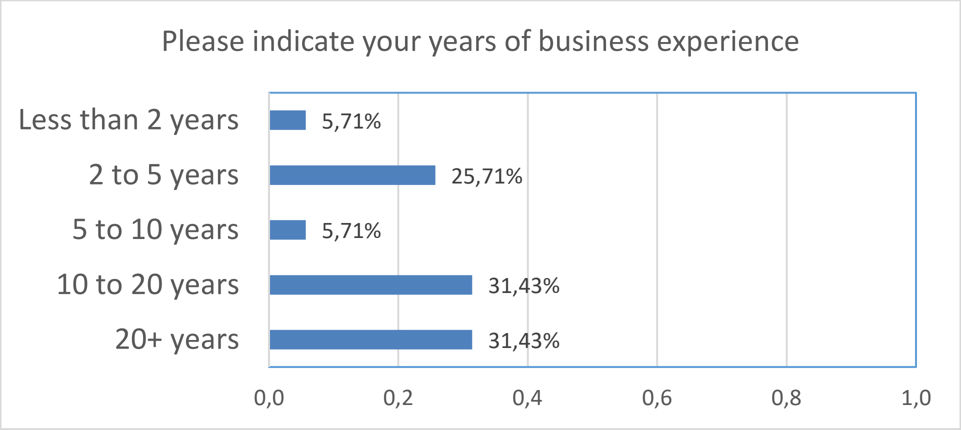

Figure 5: Participants' business experience.

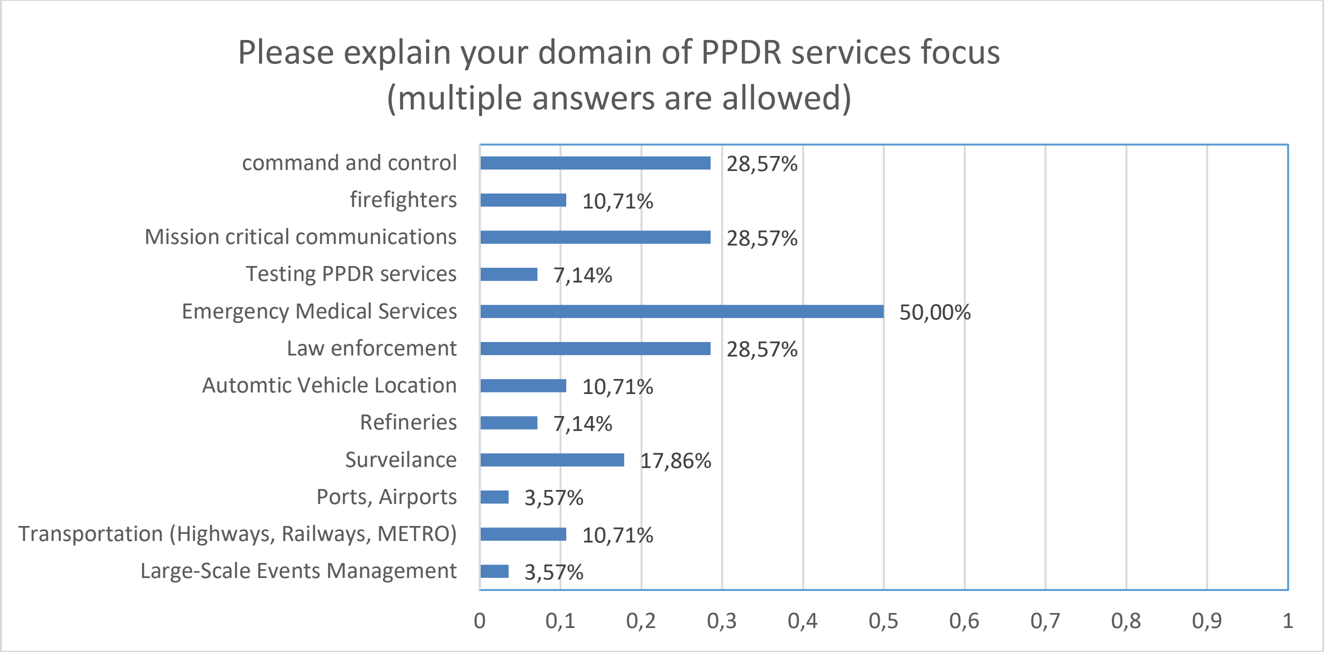

Figure 6: The PPDR focus of the participants' organizations.

(17.86%). Smaller percentage is recorded for automatic vehicle location (10.71%) and services provided to fire-fighters (10.71%) and refineries (7.14%). Finally, there was one responder's organization serving ports and air-ports and another one Large-Scale Events (mainly sports events).

2.1.1.3 Results

At first, the questionnaire explores aspects that may predispose organizations to use the 5G-EPICENTRE platform as a testing bed for novel PPDR services. Thus, participants were asked for their opinion about the limitations in provision of PPDR services from current networks and whether they are in the process of testing services they already develop/procure in operational environments and experimentation facilities. Their answers are shown in Figure 7 and Figure 8.

The majority of the participants (58% entered 4 or 5) believe that the PPDR services are limited by current net-works. Only 14% strongly disagree (they entered 1 or 2). As KPIs/PPDR service aspects that are limited by current networks the following were mentioned:

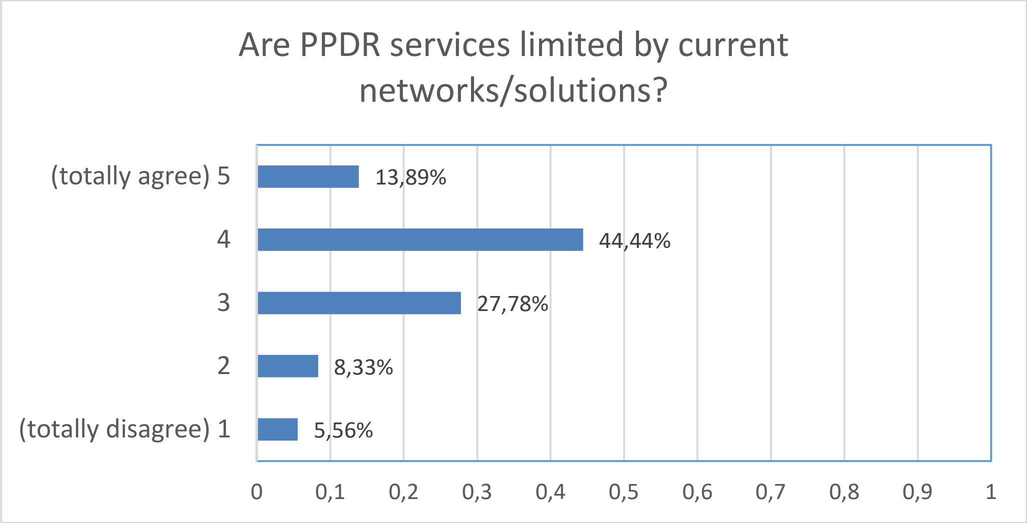

Figure 7: Limitations in current PPDR implementations.

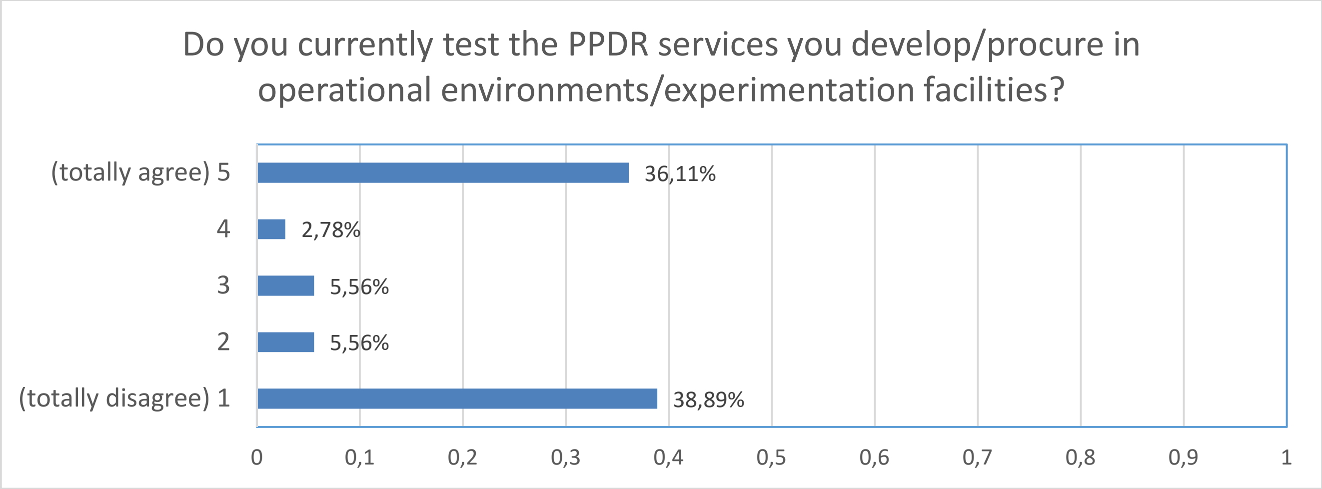

Figure 8: Current PPDR services testing.

General technical limitations:

- Network throughput.
- End-to-end Delay.
- Latency.
- Bandwidth.
- Network resiliency / robustness.
- Reliability.
- Availability under failure of resources.
- Throughput.
- Service priority.
- Guarantee of network access.
- Deployment simplicity and agility.
- Current PPDR systems are missing the following services: video communications, large file sharing.

Current commercial 3G/4G networks do not typically offer QoS guarantees or dedicated resources for PPDR flows. Hence, limitations of current commercial 3G/4G networks include:

- Having a dedicated QoS and dedicated resources for PDDR flows.
- Ability to easily deploy over a MNO with QoS guarantees, if you are not the selected integrated PPDR provider.
- Ability to use modern technologies (*e.g.*, 4g/5g networks) in case of an emergency with quality guarantees (*e.g.*, reserved bandwidth needed).
- Missing bandwidth for video services on current 4G networks.
- Latency problems (*e.g.* in retransmissions of high resolution video surveillance camera, end-to-end RTD). The latency of the 4G networks isn't able to quickly vehiculate information needed for real-time applications in PPDR activities.
- In terms of Augmented Reality solutions, mobile AR and real-time streaming cannot be accommodated by existing 4G technologies.
- Difficult to accommodate high mobility and variability in network traffic dynamics that are characteristic of PPDR scenarios.
- 3G/4G/5G coverage is not adequate in all places.
- Not enough Edge/Cloud server geographically close, resulting in latency problems and bottlenecks.
- Not easy to understand how to transit existing applications on the edge/cloud, while keeping the same performance as before.
- Lack of network slicing capabilities.
- Security aspects related with authorization, authentication, integrity, and privacy.
- Capacity issues: simultaneous number of multimedia PPDR users on the PPDR incident area.
- Location accuracy.

Limitations due to commercial/ market competition issues:

- The number of users are limited.
- Costs.
- Old narrowband technologies, such as TETRA, are still limiting the PPDR arena evolution.
- There are use cases that can be realized with lower latency and higher bandwidth, but for the most part the users are not even close to these limits.
- For commercial reasons, mobile networks often concentrate coverage on densely populated areas and/or major transportation corridors.
- Integrated services and applications approach.

Despite the above limitations, a considerable percentage ~39% of the responders reported that they test PPDR services, as seen in Figure 8 (answers 4 or 5, in a scale of 5). An equal percentage ~39% is not involved in any PPDR testing, while ~11% report that they are standby or mildly involved (answers 2 or 3, in a scale of 5).

The benefits expected from using the 5G-EPICENTRE platform as a testbed are shown in Figure 9. Almost all participants expect that the platform is used to test KPIs (percentage 94.12%), and to test performance in near operational environment (percentage 85.29%). Close to two thirds of the participants expect the platform to test performance in simulated extreme conditions (61.76%) and to collaborate with other providers to create a value chain (*e.g.* VNF implementers, application implementers, equipment providers, *etc.*) (also 61.76%). Approximately half of the participants expect the 5G-EPICENTRE platform to provide the ability to the end user to run their tests (52.94%) and the operators to test onboarding/operating of the service (38.24%). Finally, the responders expect compliance to the standards (47.06%) and the ability to define the business collaboration model between the involved parties (38.24%).

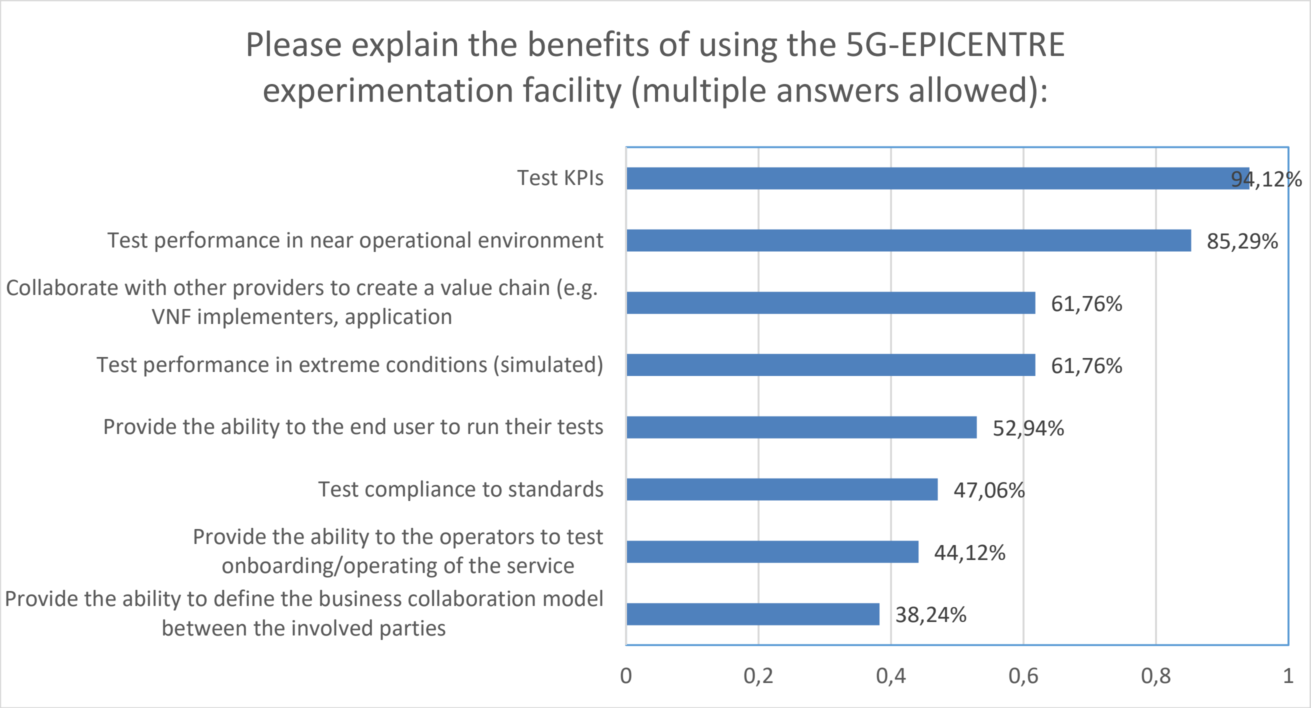

Figure 9: Benefits acquired from using the experimentation facility.

According to the participants, the functions of the 5G-EPICENTRE platform that are considered important include the following.

Above two thirds of the responders mentioned (at decreasing percentage):

- Ability to define test cases and KPIs.
- Friendly user interface guiding to perform test cycle processes.
- Visualization of KPIs measure and automated analysis vs required performance/advanced reporting.
- VNF/NetApps repository and ability to use.
- Network resources repository and ability to use.

Above half of the responders also mentioned (in the range 50-66%, at decreasing percentage):

- Service onboarding / parametrization functionality.
- Service setup latency.
- Scaling ability inspection.
- Slices parameter definition.

In the range 33-50%, the participants mentioned (at decreasing percentage):

- Traffic generator.
- Security inspection and security breach test.
- Simulate extreme operation condition.
- Other services repository and ability to use.

In the range 20-33%, the participants referred to standardization issues:

- Ability to test 5G releases.
- Standards compliance inspection.

A responder added to the list the following two features:

- Intuitive user friendly UIs and visualisation tools.
- fault tolerance of a service and self-healing.

Finally, there was no vote for Interference Inspection from the 5G-EPICENTRE platform.

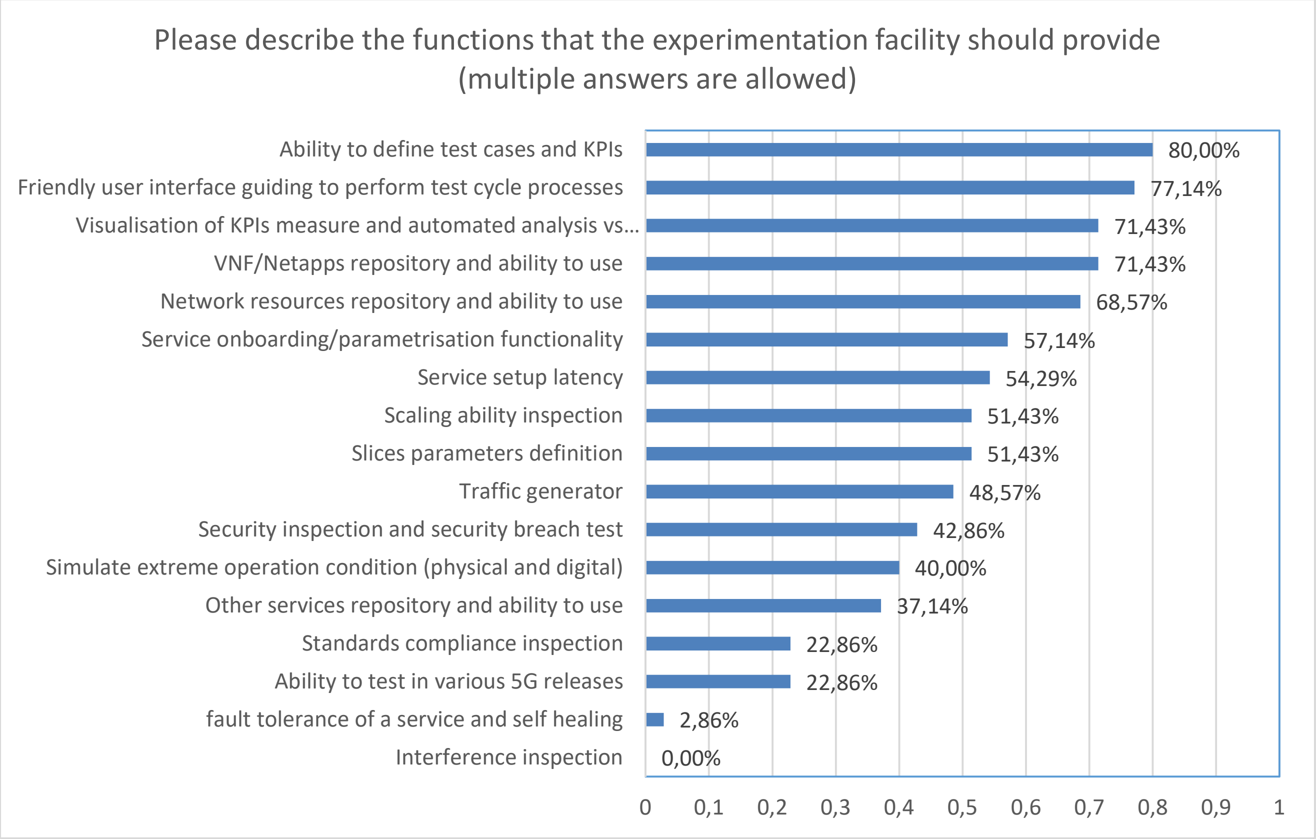

Figure 10: Desired functions of the experimentation facility.

Then the Questionnaire referred to three important specialized issues, namely, slice management, cross domain experiment support and cross-layer privacy. The responses are shown in Figure 11, Figure 12 and Figure 13, respectively.

In particular, almost half (48%) of the responders would like to fine tune parts of the network slice through NETAPPs, while an also important percentage 30% leaves such technical realization to the 5G-EPICENTRE experts or don't mind at all. Fewer responders would like to be able to manage the virtual machines hosting the VNFs (as well as manage and fine tune these VNFs) (5.71%), or to be able to manage the lifecycle of the involved VNFs and fine tune their operation (also 5.71%).

Cross-layer privacy (*e.g.* between the control and the management layer) is demanded by 20.56% of the respond-ers, while the rest either leave it to the 5G-EPICENTRE experts to decide (58.82%), or they don't know (20.59%).

Several participants referred to their involvement in specific use cases for experimentation that relate to the eight Use Cases of the 5G-EPICENTRE program. This provides valuable information about the potential users of the facility. In particular, they mentioned the following:

- Testing the performance and resiliency of a 5G private network with mission-critical push-to-talk (MCPTT), data and IoT services with slicing and edge computing.

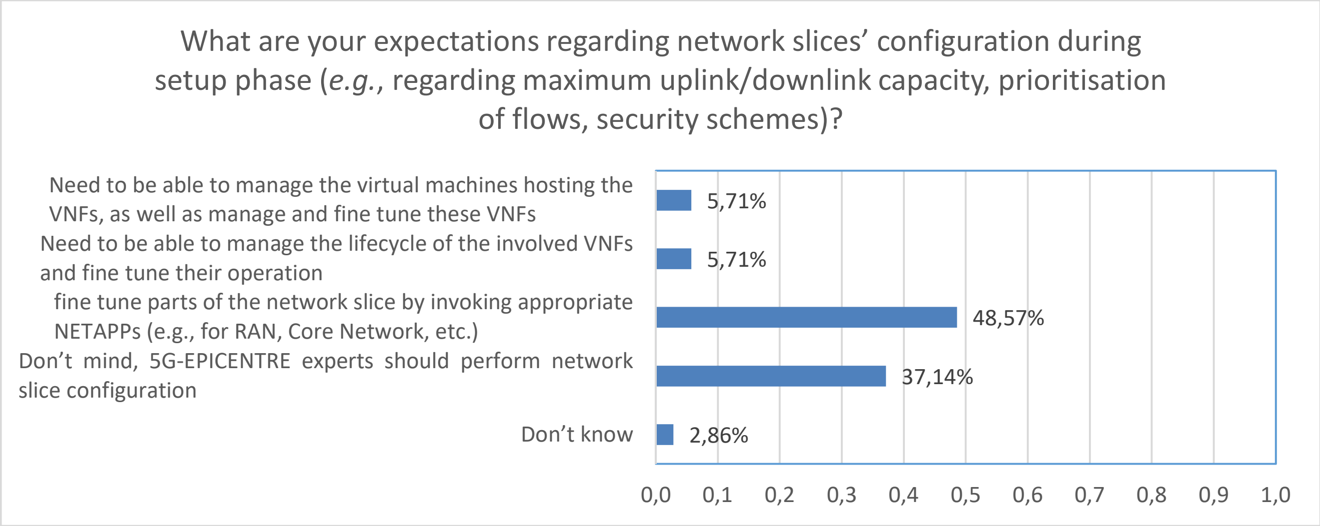

Figure 11: Participants' expectations regarding network slicing.

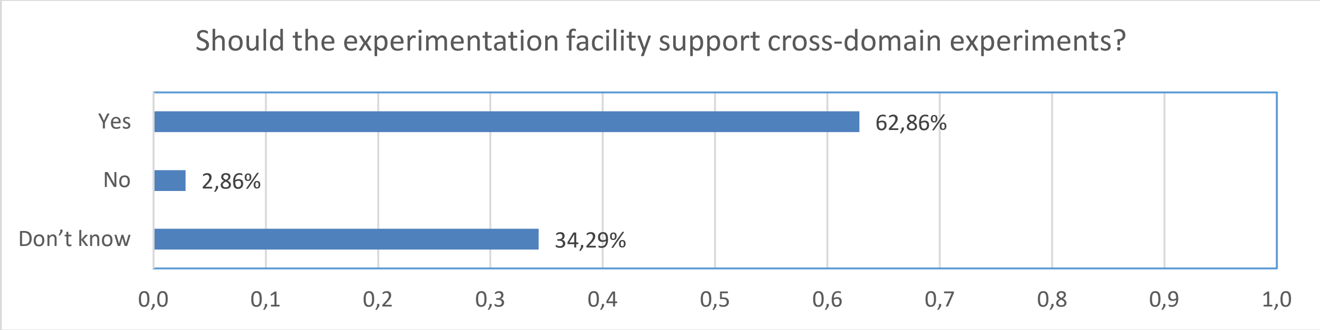

Figure 12: Expectations regarding Cross-domain experiments.

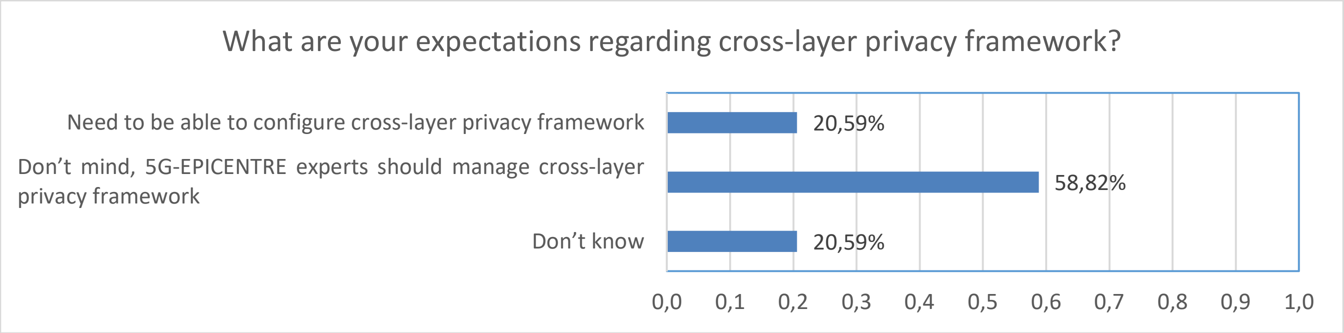

Figure 13: Expectations regarding cross-layer privacy.

- Test Mission Critical Services over 5G making use of the latest advanced research in this domain and validate the relevant 5G KPIs.
- Deployment of mission critical communications over NFV architectures.
- PTT Management of Biometric Sensor Data Secure video transmission from the field on emergency demanding conditions.
- Remote monitoring of vital signs for victims and transmission of video and biometrical data to hospitals.
- Experiments with holographic AR technology for emergency medical surgery teams, by overlaying deformable medical models directly on top of the patient body parts, effectively enabling surgeons.

- Test smart glasses with Augmented Reality and Artificial Intelligence features in 5G network conditions 1) real-time semantic segmentation, instance segmentation and edge detection for public safety officers 2) Real time first aid assistance by remote practitioners where an AR-based remote medical assistance is needed.
- Provide a common coordination between first responders' agencies in an emergency scenario for 3GPP Mission Critical communications.
- Capacity increase in a 5G cell due to the concentration of resources in an emergency situation. Carrying out a group call that includes all the resources deployed in the area of incidence, as well as resources deployed in different parts of the city (in a pre-alert state to intervene, if necessary).
- Testing Push-to-Video.
- Deployment of several PPDR agencies in a multi-tenancy environment.
- Host and operate real life PPDR services in collaboration with respective application implementers
- Operate commercially the experimentation facility.
- Building added value application on top of Mission Critical Services platform through published APIs.
- Test Multimedia Mission Critical Services.
    - Group and individual calls.
    - Group and individual messaging.
    - Group and individual multimedia messaging.
    - Individual video calls.
    - Emergency calls.
    - Location and map services.
    - Mission Management mobile applications.
- An experiment that combines several of the above, is described as follows: A situational awareness platform (Mobitrust) will be used in order to meet the pre-set goal of aiding Command and Control Centres (CCC) to obtain a full awareness of field operations. This includes monitoring of agents in the field through a set of geographical/indoor positioning, environmental and wearable biological sensors, as well as real-time text, audio and video transmissions. Data is then relayed over 5G and processed in the Command and Control Centre to be displayed in the platform frontend at the operator's request, together with alerts triggered by AI/ML algorithms to detect man-down situations and other critical looming situations (*e.g.* gunshots, environmental hazards, physical threats, *etc.*). For every alert, the platform will recommend proactive actions in order to mitigate the effects it may cause.

Regarding the question "Please describe the services that the experimentation facility should provide" the responders enumerated the following:

- NetApp development environment (cloud based).
- Documentation of how to use the facility. Good documentation of the available capabilities. List of services available.
- Remote / onsite training on how to use the facility in the available tests (on demand).
- Provide training on testing devices and monitoring equipment.
- Open reports of experimental results.
- Easy scheduling of tests.
- Remote monitoring of the experiment execution.
- Billing.
- Provide technical support for network configuration and service integration.
- Provide KPIs visualisation facility. Assistance in KPI/results analysis.
- Ability to simulate an extreme case and test against it.

- Ability to select the time window to run an experiment.
- The experimentation facility should allow function developers to onboard their network functions on top of the infrastructure and conduct testing.
- The experimentation infrastructure should allow experimenters/function developers to chain together available functions to create new service chains that can be stored and used in tests.
- The experimentation infrastructure should allow experimenters to easily recreate and repeat experiments and produce results that are reproducible (same experiment ran many times should yield similar results regardless of the experimenter).
- Bandwidth availability/test, downtime statistics.
- Comparison to standards.
- Abstraction of network resources.
- Testing Cloud services (computing, storage, databases).

According to the participants, the 5G-EPICENTRE should avoid:

- To be a sealed platform.
- To perform non-realistic tests or tests that are not focused on PPDR services.
- Services and functionality should not consider that end-users to have deep knowledge regarding 5G technologies and NetApp development.
- Overwhelm users with complex configuration of the testing.
- Overcomplicated User Interface.
- Overlaps among partners' competences, synergy should be exploited instead.
- Over-dimensioning: The experimentation facility should avoid exposing too many parameters/information about the underlying experiment environment without the user specifically requesting more control, because it will increase complexity.
- Lack of backup in case of failure, big/unexpected downtimes.
- Emulated interfaces and network nodes.
- The experimentation facility should avoid not to liaise/simulate real operational environments.
- Not standardized components constraining to make specific developments.
- Non flexible billing for the provided experimentation services.

Regarding the reporting of the experimental results, the respondents preferred customized reports (54%) over standard reports (40%). The detailed statistics are shown in Figure 14.

Regarding booking of the platform testing facilities, the participants prefer online tools provided by the 5G-EPICENTRE portal, by a wide margin (68.57%). A much smaller percentage would prefer direct contact to the experimental facility, either by online tools (25.71%) or by off-line tools (5.71%).

The last question pertained to the business model preferred for exploiting the 5G-EPICENTRE platform. There is a great variety of responses how to create revenue from PPRD agencies or users. It can be easily assumed that each responder selected the option that best fits the needs of their organization; therefore, in order to support the widest possible client base flexibility in options should be provided. The participants noted:

- 5G-EPICENTRE could create revenue by means of a VNF/NetApp marketplace, as well as a one-stop 5G Experiments as a Service marketplace for third parties to exchange assets and experimentation environment for companies to benchmark their applications.
- 5G-EPICENTRE facility could support licensing model to provide access to premium VNF/NetApp content.
- Simple billing scheme regarding resource usage or introducing a flat fee per case fee.

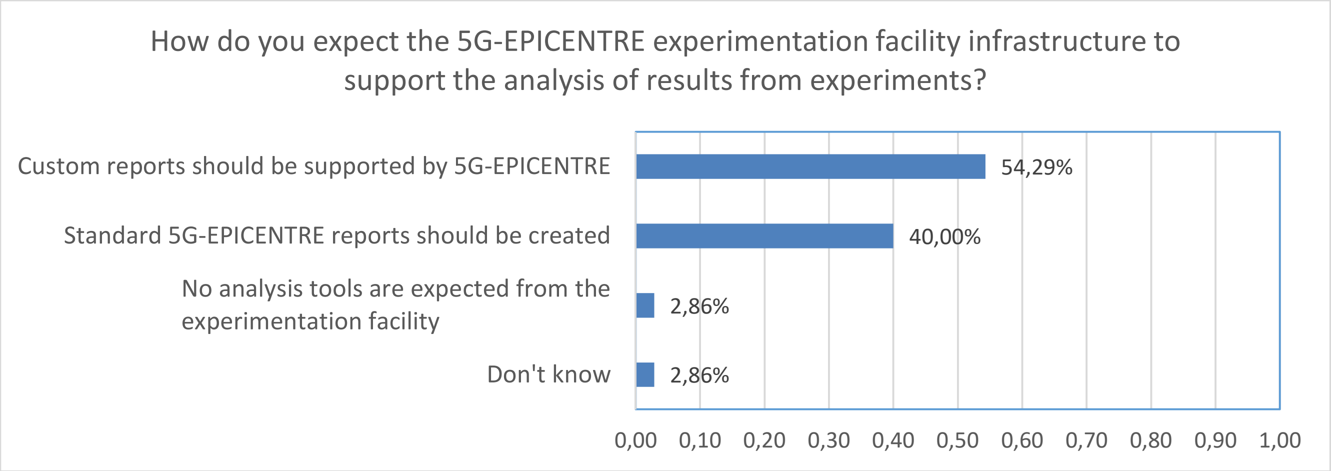

Figure 14: Types of reporting of the experimentation results.

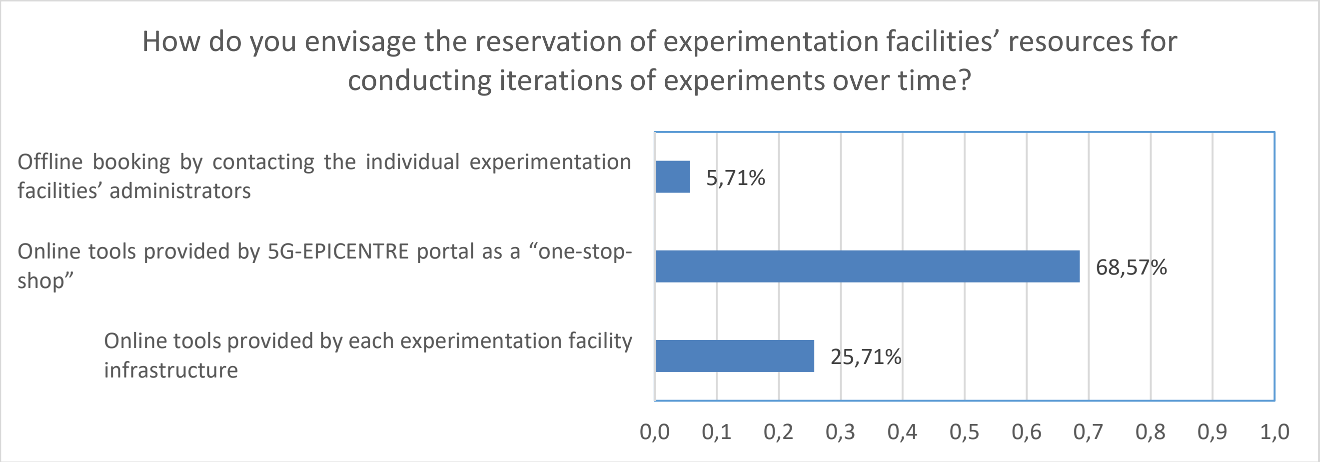

Figure 15: Reservation of the platform resources for testing.

- License payment for each resource used in the experiments. Payment by number of groups and by the size of these. Group calls consume a lot of resources from the test platform. Payment for the completion of reports or service metrics not contemplated in standard reports.
- Free-of-charge up under certain terms or to a pre-defined budget level.
- Flexible billing per experimental case above a specific level.
- In any case, the usage of the platform should not be expensive, at least during the lifetime of the H2020 funds.
- It might be possible to fund human resources, including technical support from platform experts and operational & business model advice, from PPRD agencies / users. This fee should be well-established in advance.
- A "Pay-as-you-go" business model will help businesses incrementally experiment and refine their use case.
- The facility should be offered as a service to application developers, manufacturers and operators. Both pay-per-use and subscription models apply.
- Usage business & remuneration model similar to what already exists for cloud infrastructures.

2.1.1.4 Requirements

This section consolidates the requirements, as they have been identified from the analysis of participants' responses to questionnaires. These requirements typically arise from favourable responses of a large majority of participants, or stem in similar form from favourable answers to multiple questions. The final list of stakeholders' requirements is summarized in Table 2.

Table 2: Stakeholders' requirements resulting from the online survey.

QR1	The platform should test performance in near operational environment, even under simulated extreme conditions.
Remarks	
The requirement emerged from a wide majority of responders, across private firms, research centres or academia, when asked to describe the functions and the services expected from the experimentation facility. The ability to test under extreme conditions was also considered as an important benefit from using the platform.	

QR2	The platform should test Key Performance Indicators.
Remarks	
The requirement is supported from a wide majority of responders, across private firms, research centres or academia. It was favoured by the majority of participants describing the functions and the services expected from the experimentation facility explicitly. It was also mentioned explicitly for use cases targeted by certain responders using the platform.	

QR3	The platform should provide network resource repository and the ability to use.
Remarks	
The requirement is supported by more than two third of the participants, regardless whether they belong to private firms, research centres or academia.	

QR4	The platform should provide VNF/NetApps repository and the ability to use.
Remarks	
The requirement is supported by more than two thirds of the participants as a desired service from the experimentation facility, regardless whether they belong to private firms, research centres or academia.	

QR5	The platform should provide service on-boarding / parametrization functionality.
Remarks	
The requirement is supported by the majority of the participants, regardless whether they belong to private firms, research centres or academia. It was propounded by responders in the questions about the functions and the services expected from the experimentation facility.	

QR6	Friendly user interface, guiding to perform testing.

Remarks

This requirement was identified by the majority of responders. It reflects the expectations regarding ease of access to the experimentation platform, as a prerequisite for using the service.

QR7	Visualization of KPIs measure and automated analysis.

Remarks

This requirement was identified by more than two thirds of the responders, when asked to describe the functions expected from the 5G-EPICENTRE platform. It is related to QR6 about the ease of use and the QR14 about technical support for operating the platform.

QR8	Scaling ability inspection.

Remarks

This requirement was identified by more than two thirds of the responders, when asked to describe the functions expected from the 5G-EPICENTRE platform.

QR9	Traffic generator should be provided.

Remarks

This requirement was identified by more than two thirds of the responders, when asked to describe the functions expected from the experimentation facility.

QR10	Support of custom reports.

Remarks

The requirement is supported by the majority of the participants, regardless whether they belong to private firms, research centres or academia.

QR11	On-line tools for one-stop reservation of facilities.

Remarks

The requirement is supported by more than two thirds of the participants, regardless whether they belong to private firms, research centres or academia.

QR12	Avoid complexity and over-dimensioning.

Remarks

This requirement stems from analysis of participants' multiple responses about what the 5G-EPICENTRE platform should avoid.

QR13	Provide technical support for network configuration and service operation.

Remarks

This requirement reflects an expectation of participants that is expressed in different wording in multiple responses about the services that should be provided, the characteristics of the user interface of the experimentation platform or the desired training on the 5G-EPICENTRE resources.

QR14	Different subscription schemes should be supported.

Remarks

This requirement stems from analysis of participants' multiple responses concerning the business and the remuneration model for using the 5G-EPICENTRE platform. The analysis revealed a desired expectation that the pricing model should provide flexibility in options, including for example fixed price subscriptions, packages, progressive prices, and pay per use.

QR15	Security inspection and security breach test.

Remarks

The requirement emerged from the responders when asked to describe the functions expected from the experimentation facility. In general, issues of security and integrity are considered important in the development of PPDR services, representing a current limitation in existing mobile networks.

QR16	Remote monitor of testbed execution.

Remarks

This requirement was identified by the participants in response to the question regarding the services that should be provided by the 5G-EPICENTRE platform.

QR17	Training of testing devices and monitoring equipment.

Remarks

This requirement reflects an expectation of participants that is expressed in different wording in responses to multiple questions about training on the 5G-EPICENTRE platform. It is also related to QR14 about technical support or QR6 about a friendly user interface of the experimentation facility.

QR18	Fine-tune parts of the network slice by invoking the appropriate NetApps.

Remarks

This requirement was identified by half of the participants and reflects the level the potential users of the platform to fine-tune slice for different parts of the network (*e.g.* for RAN, for core network, *etc.*).

QR19	Cross domain experiments should be supported.

Remarks

This requirement was identified by almost two thirds of the participants, regardless their occupation in private firms, research centres or academia.

QR20	Compliance to standards.

Remarks

The requirement was identified by half of the participants as a strong benefit of using the 5G-EPICENTRE platform. This requirement was also cross-checked by analysing other parts of the questionnaire, as compliance to standards was a recurring theme in questions regarding desired functions of the experimentation facility or in explicit comments about avoiding non-standardised components that would constrain making specific developments.

2.1.2 Interviews

2.1.2.1 Method and procedure

In the context of this task, a series of interviews have been conducted targeting experts in PPDR service provision or design. In detail, the 5G-EPICENTRE partners have performed ten one-to-one interviews with employees of a diversity of organizations that had direct or implicit interest in using the 5G-EPICENTRE experimentation facility, following the general guidelines described in Annex II.

2.1.2.2 Participants

The following table summarizes the role of each interviewee in the corresponding organization. All interviews are included in Annex III.

Table 3: Interviewees consolidated information.

Organization type	Role in the organization	Relation with 5G-EPICENTRE
Telecommunications operator & PPDR service provider	Network section manager	External
IoT company	Executive Officer	External
Network Operator/Cloud Services Operator	IT project manager	Partner
VR Medical Education R&D Researcher	Researcher	Partner
MCX Vendor	Executive Officer	Partner

Software/application developer	Executive Officer	External
Research Institution	Researcher	Partner
Mission Critical and PPDR expert	Engineer, former Network section manager	External
Research Institution	Researcher	Partner
Research Institution	Member of TCCA (The Critical Communications Associations)	Partner

2.1.2.3 Requirements

Overall, the interviewees expressed their eagerness for the results of the 5G-EPICENTRE testing platform that concern:

- Utilizing cloud architecture for low latency and ultra-high reliability (URLLC) and enhanced mobile broadband (eMBB) (high bandwidth) to ensure high reliability for critical missions.
- Exploiting slicing management and container orchestration technics to provide new opportunities for software/applications developers.
- Acting as an infrastructure and service provider that can accommodate external providers to test applications and deploy its mission critical services.

The findings that emerged by the interview analysis are summarized in the requirements list presented in Table 4. Although most of them are interrelated, a unique ID is given for each requirement, together with explanation remarks provided by the participants.

Table 4: Stakeholders' requirements resulting from the interviewing process.

IR1	Demonstrate improved KPIs such as installation time, resource utilization, platform independence and high mobility, using the appropriate architecture.
Remarks	
According to the interviewees, the success of the whole 5G-EPICENTRE project depends both on the creation of the appropriate architecture that will enable certain features as well as the adaptation of the existing applications to properly take advantage of them. In this direction, 5G-EPICENTRE represents an attempt to move past monolithic VM-based implementations and fully embrace lightweight virtualization and container technology. With an efficient dissection of monolithic applications into multiple components - microservices, the number of concurrent users can exceed the limitations of the current state-of-the-art. However, this dissection must be done in such a way that intercalls between components do not hinder the overall user experience by creating latency issues beyond a threshold.	

IR2	Improve on latency, benefiting from offload computationally-intensive processes onto cloud and edge resources.
Remarks	
The 5G-EPICENTRE architecture will allow AR applications to benefit by being able to offload computationally-intensive processes onto cloud and edge resources. In this respect 5G-EPICENTRE developments will impact latency and rendering, and as a result, frames-per-second (FPS). The aim/requirement is to beat guidelines	

recently reported in the literature, which suggest that latency of 20ms or higher becomes noticeable, while anything over 50ms cannot be tolerated in the context of AR/VR. Besides PPDR applications, the implications will be very relevant in other domains as well, such as in cultural applications, games, media and education.

Moreover, the platform should provide the latency results (as well as other useful KPIs) in suitable format that will allow fast (maybe on-the-fly) diagnostics that will dictate the correct tweaking of the preferences of the application instance on the edge towards amending potential problems.

IR3	Provide flexible billing and remuneration models.

Remarks

Several interviewees emphasized on commercialization of the 5G-EPICENTRE service that proposes to accelerate the development of the 5G ecosystem. Developers should be encouraged to evaluate new APPs (relative to performance indicators and resource utilization) in a controlled experimental environment that complies with the latest 5G standards. In this direction, the business and the remuneration model for using the service should provide flexibility in options, including for example fixed price subscriptions, progressive prices, and pay per use.

As an example for the case of SMEs, it was argued that flexible pricing packages should consider the size of the experimenter company. It is advantageous for all stakeholders to flexibly allow SMEs to experiment with novel APPs and devices, so that the 5G ecosystem grows. During an introductory phase, using a few resources in the platform could be relatively cheap or even free of charge. A subscription could be more appropriate once a firm demands facility usage above a certain level or for an extended period of time.

IR4	Provide efficient slice management and improve availability even in congested environments.

Remarks

All interviewees stressed that, by using network slicing, a dedicated bandwidth will be reserved for the requested PPDR service, thus the reliability is ensured compared to a best effort service under the current technologies, *e.g.* 4G. In that direction, the 5G core can be further optimized and special tailored PPDR services can be created by VNFs and NetApps.

IR5	Low latency and high availability under extreme congestion environments for voice services.

Remarks

The main PPDR service offered today by private networks worldwide is PTT Voice Group calls with central dispatching. Thus, it is imperative that the 5G-EPICENTRE platform meets stringent performance in Survivability and Immediacy of voice call transfer. That is:

- The network should succeed to transfer a talk burst even under heavy coexisting traffic load (related or not to Mission Critical and PPDR service), using novel implementations for call prioritization and network slicing.
- The network should transfer the talk burst with low end-to-end delay that is critical to user experience, concerning the time for establishing a call or the time from transmission to playback.

The platform should therefore also provide a traffic simulator during tests for voice PPDR services.

IR6	Required platform functions.

Remarks

According to the interviewees, the 5G-EPICENTRE testbed should provide:

- Adequate network abstraction policies, alternatives, *etc.*
- A user friendly user portal for all stakeholders.
- A requirements catalogue from the specific testbed (*e.g.* to test products or for POCs and Use-Cases).
- UE emulators processable by the network core (the core should be adjustable).
- A VNF/NETAPPs library.
- Federation with other testbeds especially on the VNF/NetApp library level can be considered as a plus.
- Analysis tools (internal or external).
- Tools to define the end-to-end experiment lifecycle according to the test owner needs (test scheduling, resources allocation, KPIs measurement, analysis of results, identification of problematic areas, reporting, billing, *etc.*).
- Security, IPR protection and GDPR compliance are significant issue.
- AI should be considered in the results analysis.
- Traffic generators and PPDR oriented scenarios simulation should be included in the testbed.
- Upgradability to comply to forthcoming 5G release updates.

IR7	5G-EPICENTRE functions facilitating PPDR service providers/application developers.

Remarks

The aim should be to ease on-boarding and testing of the service. Besides the flexibility, speed, service provisioning and quality of IT support that is critical to the success of the platform, solution developers need agility in testing and flexibility to be able to test their solutions. This requires network resources abstraction visibility, including:

- An API/interfaces for the developers and service providers.
- A requirements catalogue.
- eMBB and URLLC modes.
- A slicing configurator.
- Orchestration software that can adjust the base stations in such a way to deliver network slices to the specific requested service.

Furthermore, beyond the testbed equipment, it is relevant that the 5G-EPICENTRE accesses wide area testbeds.

An interviewee clarifies how the above will work towards the commercialization of the 5G-EPICENTRE platform. Although its use as a demonstration infrastructure is in effect a niche market, one expects that end-customer testing could be in high demand, especially during the process of PPDR agencies converging from their existing networks to broadband networks. For a significant period of time a PPDR agency will need to be able to use both communications networks simultaneously in operation and production. This functionality will not be provided by any service provider's laboratory test network but can be offered by 5G-EPICENTRE. Moreover, one cannot exclude combined efforts of the 5G-EPICENTRE and commercial PPDR networks to test applications in common pilot projects, to experiment with different wide area coverage and mobility patterns, resembling the typical daily operations of the first responders.

2.2 5G-EPICENTRE platform requirements

The primary scope of the aforementioned procedures has been to capture the end user requirements so as to process them in a meaningful way to formulate the initial set of high-level platform specifications. In addition, using draft templates of the platform architecture based on the preliminary specification during the project preparation period (see Section 3.3 for more details), additional information was collected, including the indication of the desired functionalities by the different functional blocks, along with a prioritisation of preferred functionalities following the well-known MoSCoW (Must Have, Should Have, Could Have, Won't Have) method. “Must Have” requirements provide the Minimum Usable SubseT (MUST) of requirements, which the project guarantees to deliver. “Should Have” requirements are defined as requirements that are important, but not vital. “Could Have” requirements are specified as wanted, or desirable, but much less important than “Should Have” requirements. Finally, “Won’t Have” requirements pertain to functionality and features the project team has agreed will not be delivered (at least as part of this timeframe). This classification of requirements was based on the feedback provided by project partners responsible for the functional blocks of the architecture, based on the perceived importance to perform the intended functionality. In this respect, “Must-Have” requirements take top priority, as the system cannot deliver on its intended functionalities without those requirements. “Should-Have” requirements deliver significant added value, but the system is deemed to be functional even if it does not fulfil those requirements. “Could-Have” requirements refer to functionality that does not hinder core function of the 5G-EPICENTRE platform, but are considered a plus if incorporated. “Won’t Have” requirements specifically address functionality that will not be included in the delivered system, and therefore, should also not be expected (at the time specified as such).

In this regard, the online surveys, interviews and MoSCoW analysis contribute as a provenance for capturing the needs of the platform stakeholders from a technological perspective, leading to a list of functional (Section 2.2.1) and non-functional (Section 2.2.2) requirements addressing: i) functionality that the platform should provide; and ii) criteria regarding properties that affect how the platform operates.

5G-EPICENTRE follows a component-based system development paradigm in which pre-fabricated and novel components will be integrated to deliver the overall system functionality. Each software component provides partial functionality (and may be characterized by individual requirements) toward being mapped to elicited system requirements. Hence, providing an analogy of requirements to a component architecture (Section 3) will be an iterative process, in which candidate functional blocks (filling as “black-box” components visible only through their interfaces) will be matched against the system context toward assuring an acceptable match between identified individual component roles and the elicited system requirements. In this respect, the functional blocks of the 5G-EPICENTRE architecture shall be mapped to the elicited requirements, with individual functionality and features being considered in the context of functional testing (T4.5, *“Lab testing, prototyping and validation”*) to ensure the proper functioning of each component according to the developer’s specifications.

2.2.1 Functional requirements

High-level platform functional requirements identified for the functionality expected by the different functional blocks comprising the 5G-EPICENTRE facility are summarized in the Table (Table 5) below.

Table 5: 5G-EPICENTRE platform high-level functional requirements.

FR1	**The system <u>must</u> allow a user to define experiments.**
Description: 5G-EPICENTRE will require to support tools for experiment definition. This will be achieved by means of functional components that will produce a well-defined experiment descriptor template, which will contain all information required to execute an experiment.	

FR2	The system must allow a user to define experiment-specific KPIs.

Description: 5G-EPICENTRE will require to support tools for experiment KPI definition and subsequent validation. A list of specific KPIs that will be computed along with related measurements should be entered into the descriptor.

FR3	The system must support onboarding of network functions (NFs).

Description: 5G-EPICENTRE must provide capabilities for introducing new NFs into the operational environment of the 5G-EPICENTRE experimentation facility, *i.e.*, uploading the NF package to the 5G-EPICENTRE catalogues, and creating and filling out the NF descriptor template for that function, so that it can be instantiated and utilized in full to deliver its full features over the platform.

FR4	The system must support testing of NFs.

Description: 5G-EPICENTRE must provide thorough capabilities for testing of NFs' functionality with real world traffic conditions, to ensure that they can achieve consistent performance for the customer intended NetApp deployment, monitoring and operational capacity.

FR5	The system must be able to manage and orchestrate NFs on top of virtualised infrastructure.

Description: The platform must provision management and orchestration capable software that can adjust deployment of virtualised computing infrastructure in such a way to support function virtualisation (via virtualisation methods such as virtual machines or containers) and deliver network slices to the specific requested service.

FR6	The system must support service function chaining of NFs into end-to-end services (NetApps).

Description: 5G-EPICENTRE must provide appropriate mechanisms for connecting NFs to form larger end-to-end services, or network applications (NetApps), which will handle network traffic flows in accordance to the service traffic requirements.

FR7	The system must support interoperability with existing network components from the testbeds' Network Functions Virtualisation (NFV) environments.

Description: 5G-EPICENTRE must ensure that NFs can work with NFV solutions, deployment, management, orchestration and testing mechanisms available in the underlying testbed infrastructures, ensuring that NF features and interfaces can be exploited by the federated facility.

FR8	The system should embrace lightweight virtualisation technologies.

Description: This requirement mandates that the platform supports lightweight virtualisation (*e.g.*, containers or unikernels) making NFs more flexible, portable and faster to start up.

FR9	The system should support provision of execution resources (compute and storage) close to the end users.

Description: The system should support execution of edge computing solutions to support low latency, high bandwidth, processing close to end users and computational offloading. Therefore, the 5G-EPICENTRE platform should support reconfigurable traffic routing through intelligent NF placement to deliver an optimal execution environment for demanding PPDR applications.

FR10	The system should support remote access to the definition and monitoring of experiments.

Description: This requirement mandates that the platform should support the capacity for experimenters to remotely define an experiment (for instance, over a web portal) and be able to remotely monitor its results in real time (with remote access to visualisations of different data outputs and network status information). Hence, the platform should support communication infrastructure with the access point to obtain information provided by the experimenter, run the experiment and return test results to the access point (portal).

FR11	The system should provide a proper abstraction of the underlying network technologies.

Description: In the interest of reducing complexity, the system will avoid exposing the full set of details about the underlying experiment environment and testbeds to ensure experimenters are not overwhelmed by its complexity. Information will instead be revealed upon the user's own request to exercise more control.

FR12	The system should expose easy-to-consume APIs toward the experimenter.

Description: In the interest of providing a more efficient and agile onboarding and testing experience, the 5G-EPICENTRE platform should expose interfaces toward developers and experimenters that enable more streamlined access to the facility, definition and scheduling of experiments, and retrieval of experiments' results.

FR13	The system should support performance testing in (simulated) near-operational conditions.

Description: The 5G-EPICENTRE platform should support processes for function developers and experimenters to test the speed, quality and stability of a NF, NetApp or application, by allowing them to monitor how any experiment performs in close-to-real network conditions so as to address any performance issues and introduce improvements wherever needed.

FR14	The system should be able to simulate extreme network traffic and mobility conditions.

Description: 5G-EPICENTRE should support validation of NFs, NetApps and vertical applications for 5G deployment by means of recreating real-world network traffic levels in an experimentation environment. Particular focus will be placed in the simulation and experimentation under highly congested network environments (mimicking conditions encountered during catastrophic events) for PPDR stakeholders.

FR15	The system should support the ability of NFs to scale in and out on demand based on a variety of metrics.

Description: The 5G-EPICENTRE platform should enable the NFs to automatically scale, *e.g.* increase or decrease in size based on resource utilisation metrics. It should hence support means to meet changing demands during the NetApp lifecycle, by reacting appropriately whenever resource shortages, or resource utilisation is detected to be below a specified threshold.

FR16	**The system should expose a requirements catalogue for the underlying network resources.**

Description: The front-end platform components should provide means to expose, whenever queried, to function developers and experimenters the full list of experimental capabilities provided by each platform federated under 5G-EPICENTRE.

FR17	**The system should provide a user with appropriate network resource inventories and means to means to configure and (re)use them.**

Description: The 5G-EPICENTRE will need to provide inventories for pre-specified network functions (NFs), NetApps, PPDR-specific experiment configurations and virtualised resources, enabling fine-tuning and parameterisation, using appropriate APIs and interfaces towards function developers and experimenters.

FR18	**The system should allow experimenters to repeat and re-parameterize experiments.**

Description: The 5G-EPICENTRE system must ensure experiment configurations are easily repeatable by supporting reproducible experimentation conditions. In this respect, the system will need to provide the means to store and delete experiment descriptors, as well as provide the means for users to explore and re-execute experiments from past descriptors stored on the platform, including the required network resources.

FR19	**The system should provide means to customize network slices for NetApp requirements under eMBB, URLLC and mMTC service types.**

Description: The 5G-EPICENTRE platform will support descriptor templates for NFs/NetApps determining network slice configuration (*e.g.*, minimum required slice), and expose those via appropriate APIs to allow more control over network slice creation and management, *e.g.*, for optimising allocation of the network resources or specifying a particular mode (*e.g.*, eMBB, URLLC) to use for the slice.

FR20	**The system should support automated experiment lifecycle management.**

Description: The 5G-EPICENTRE platform should eliminate manual processes involved in the deployment and scaling of applications over the lifetime of the experiment, controlling the operation of the experiment over the different stages of the experiment lifecycle.

FR21	**The system should provide means to calculate experiment analytics and metric information.**

Description: The system should support machine learning tools that aim at performing automated, near-real-time analysis on network traffic in order to detect anomalous incidents and/or trends to provide insights and notifications on services performance under anomalous conditions.

FR22	**The system <u>should</u> provide means to validate KPIs.**

Description: The system should support artificial intelligent tools that aim at performing KPI analysis, in order to validate target KPIs and provide reporting toward the experimenter. These will be realised by means of machine learning algorithms.

FR23	**The system <u>should</u> provide means to evaluate Quality of Service (QoS).**

Description: The system should support artificial intelligence tools that aim at evaluating QoS for experimenter-defined NetApps against experimenter-defined specifications. These will be realised by means of machine learning algorithms.

FR24	**The system <u>should</u> provide means to assess Quality of Experience (QoE).**

Description: The system should support artificial intelligence tools that aim at estimating QoE during the experiment execution, and provide measurements and insights on improving aspects of the service being offered. These will be realised by means of machine learning algorithms.

FR25	**The system <u>should</u> translate analytics into visualization formats suitable for interpretation by a human being.**

Description: The system should support visualisation of KPIs by means of different visual, graphical elements differentiated through spatial position, shape, colour or physics-based affordances, utilizing a variety of platforms to produce advanced, immersive and tangible visual representations of KPI and anomalies' information.

FR26	**The system <u>should</u> support the capability of producing customized reports based on users' needs and preferences.**

Description: The system should be able to identify specific aspects of the user (*e.g.*, by means of a profile), such as user preferences, and adapt the results visualisation/reporting environment to highlight those facts, insights and KPIs that the user is most likely to have an interest in.

FR27	**The system <u>should</u> provide guidance to the user in order to train them on using it.**

Description: Various components and subsystems comprising the 5G-EPICENTRE platform and exposing graphical user interfaces (GUIs) towards its end-users should provide means (*e.g.*, quick start guide) on how to use them, enabling both novice and experienced users to fully leverage the tools provided by the platform.

FR28	**The system <u>could</u> provide means to calculate security analytics.**

Description: The system should support automated, analysis to detect anomalies related to security incidents. These could be presented to the experimenter alongside performance analytics as part of the results reporting and visualisation.

FR29	The system <u>could</u> support cross-domain/cross-testbed experiments.

Description: A desirable feature of the 5G-EPICENTRE platform would be the capacity to support geographically distributed testbed infrastructure as points of presence (PoP). It will provide inter-connectivity among testbed infrastructures partaking in the federation, allowing testbeds to federate, albeit without losing control of their individual resources or administrative independence.

FR30	The system <u>could</u> enable the calibration of individual testbed components from a singular control point.

Description: This requirement mandates that the platform allow experimenters to combine the available resources to achieve different experimentation conditions of varying scale and diversity, specifying network slice parameters for each individual testbed without compromising its administrative independence. Facilitating a one-stop solution, the platform should be able to coordinate the parallel execution of multiple experiments in the different testbeds.

FR31	The system <u>could</u> support role-based access control (RBAC) policies.

Description: This requirement mandates that the platform supports limited access to its functionality exposed only to those that need it. In this respect, the system must provide a way for users to register an account under a specific role and be assigned a set of permissions in the form of key/value pairs for the different 5G EPICENTRE components. Then, the platform should be able to verify a user, and grant access to individual component functionality by means of these privileges.

2.2.2 Non-functional requirements

High-level non-functional requirements identified for the characteristics of the various functional blocks comprising the 5G-EPICENTRE platform are summarized in the Table (Table 6) below:

Table 6: 5G-EPICENTRE platform high-level non-functional requirements.

NFR1	The system <u>must</u> be secure.

Description: The system must be resilient to external attacks, ensuring all data (*e.g.*, experimenters', experiments' *etc.*) and IPR are protected against third-party intervention.

NFR2	The system <u>must</u> comply to relevant standards.

Description: The platform will ensure that components and interfaces comply with relevant 5G standards.

NFR3	The system <u>must</u> be privacy-compliant.

Description: The system shall put forth processes that aim to guarantee no data will be stored that can directly identify an individual, thus protecting experimenter privacy in accordance to international regulations (*e.g.*, GDPR).

NFR4	The system must be performant/responsive.
Description: The system components involving direct interaction with the end-users should be quick to respond to users' actions, limiting the time needed for users to wait until a specific operation of the system has been completed. This requirement may correspond to a wide range of interactions depending on the use case.	

NFR5	The system must be reliable.
Description: The system should consistently perform its functions and computations (*e.g.*, of KPIs) without failure, providing uninterruptable operation during experimentation and facilitating repeatability of the results (*e.g.*, experiment results are consistent between different experiment executions specified with the same platform configuration). This requirement may correspond to a wide range of outputs depending on the use case.	

NFR6	The system should be user-friendly.
Description: The platform components involving direct interaction with the end-users should be easy to learn, easy to use and easy to understand. The system should provide means to help a user learn how to use it.	

NFR7	The system should be cloud-native.
Description: The system should take advantage of cloud-native computing, in that it needs to support multicloud, microservices, containers and service mesh architectures.	

NFR8	The system could be adaptable.
Description: The system must accommodate mechanisms that modify its functionality and behaviour according to user preferences and expectations. It could also provide the means track usage patterns and time spent on particular features in order to re-rank and re-evaluate user preferences for future use.	

NFR9	The system could be documented.
Description: System components, particularly those that expose functionality toward end-users, will be thoroughly documented (*e.g.*, provide user manuals to support users learning how to use them).	

3 5G-EPICENTRE architecture

This Section is devoted to the preliminary description of the 5G-EPICENTRE federated experimentation infrastructure architecture. As a result, this Section contains an initial overview of all the functional components, along with their individual internal architectures, interfaces and information flow diagrams. The deliverable will serve as a guide for the development activities taking place in Work Packages (WPs) 2-4, toward the implementation of the architecture building blocks and their eventual integration into the preliminary (D4.4) and final experimentation facility (D4.5). Following the project's evolutionary approach, this architecture will be revised and updated in M24, taking thus into account updates on user requirements as well as feedback from the development, integration and testing of both individual components and the integrated prototype.

The structure of this Section will be as follows: Section 3.1 elaborates on general concepts used throughout this Section to refer to architecture definition activities. Section 3.2 reiterates the reference architectural concept defined during the project preparation phase to provide a basis upon which this architecture definition will build up on. Section 3.3 elaborates on the overall approach taken for the specification of the 5G-EPICENTRE architecture, including the description of the architecture definition phased processes and the activities of the dedicated online architecture design workshops, along with their outcomes. Section 3.4 elaborates on the augmentations needed in support of cloud-native network function management and orchestration. Finally, Section 3.5 addresses the fundamental structure of the 5G-EPICENTRE architecture, presenting the different architectural views (functional, information, deployment), which focus on: i) defined system elements as building blocks, their relationships, interfaces and internal processes; ii) the way information is stored, managed and distributed within the specified architecture; and iii) the physical characteristics and constraints of the architecture.

3.1 General concepts

Prior to describing the architecture definition processes in detail, it will be important to establish several key concepts that will be used throughout this document. Table 7 specifically highlights these general concepts.

Table 7: Architecture general concepts.

Concept	Definition
Architecture	An architecture comprises the organizational structure of an IT system or component, along with guidelines, principles and relationships that dictate its design, and its development over time ([9], [10]). From a system standpoint, an architecture should specify its rudimentary structure from the perspective of its elements; goals; relationships; interfaces; functions; limitations; behaviours; principles/rules; characteristics; and physical and logical properties.
Architecture reference model	A reference model in general refers to a solid model used as a frame of reference to describe the design of specific models in a given use case. It comprises a conceptual framework that contains the minimum number of necessary unifying concepts and connections that can summarize all interactions between entities inside a given environment. An architecture reference model is used to describe the structure of a system on a high level and provide guidance toward developing specific and concrete architectures through the relationships in its model.
Container	Containers are executable software offering computer resources virtualization, provisioning those resources into instance that can run software services (microservices) and applications. Container images contain an entire runtime environment (*i.e.*, the full application code along with all its dependencies, libraries and binaries), enabling an application to be deployed efficiently in multiple computing environments. Container images become containers at runtime.

3.2 5G-EPICENTRE reference architecture model

The 5G-EPICENTRE conceptual architecture shown in Figure 16 resulted from the earliest iteration of the design approach described in Section 3.3, which took place during the project preparation period and resulted in the conceptual model as presented in the Annex 1 (part A) of the 5G-EPICENTRE GA (Description of Action – DoA).

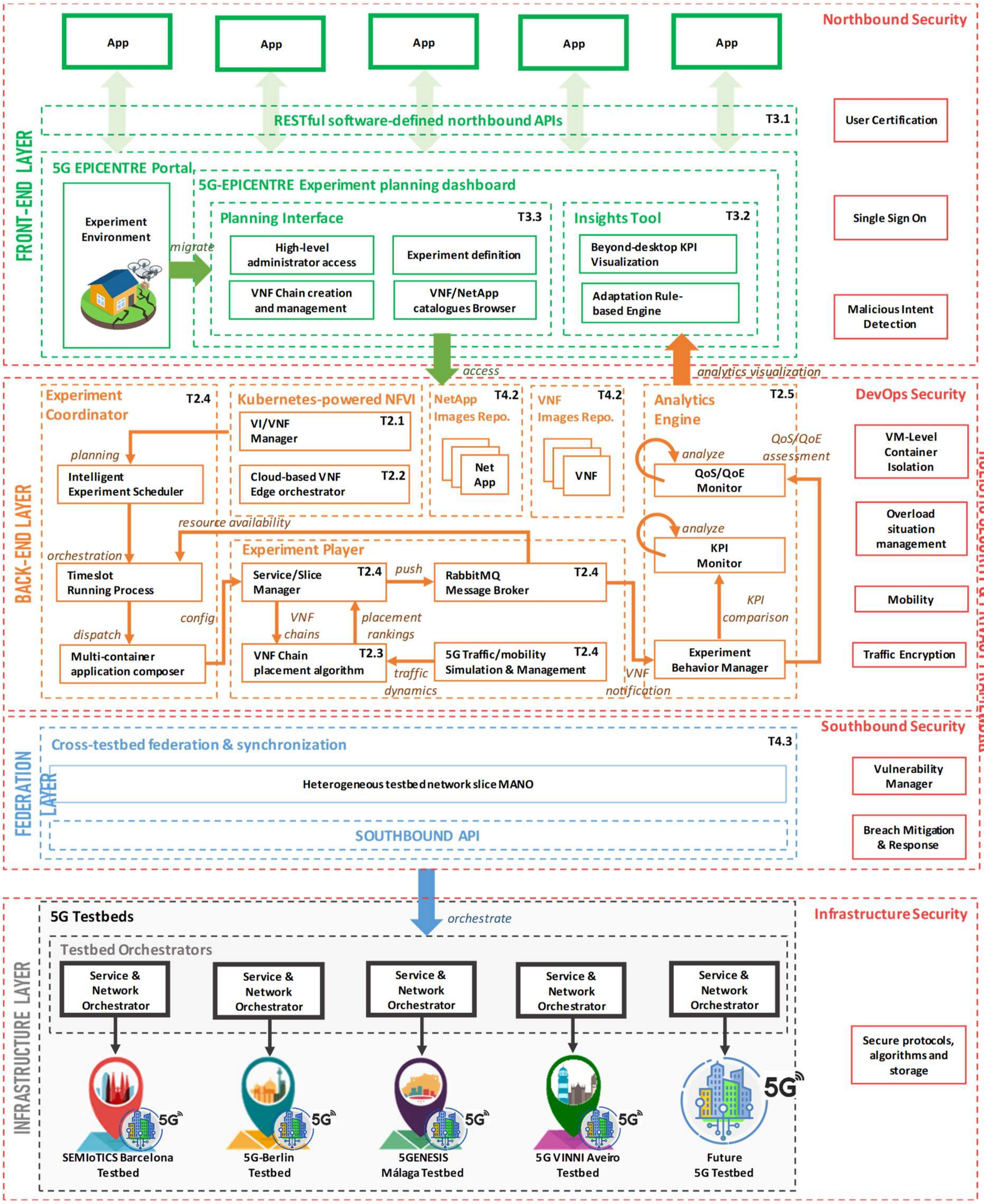

Figure 16: 5G-EPICENTRE conceptual architecture reported in the GA (GA RA) - deprecated.

The ultimate goal of 5G-EPICENTRE as identified during the preparation period, is to leverage federation of heterogeneous 5G testbeds developed under previous 5G-PPP phases to realize a one-size-fits-all experimentation facility that can satisfy varied, and sometimes contrasting sets of requirements for different types of PPDR applications. In this respect, the project aims at developing all necessary components to deliver a novel 'testbed of testbeds' supporting a 5G experiments-as-a-service (ExaaS) model. Hence, capitalizing on containerization technologies, the purpose of 5G-EPICENTRE is to fully realize the potential of combining 5G and edge computing paradigms in an open Service-oriented Architecture (SoA), which aims to gather technologies in the areas of software defined networking (SDN), network functions virtualization (NFV), cloud-native applications, and multi-access edge computing (MEC), to fully realize new business opportunities for PPDR application providers.

This early vision foresaw development of functional components of an underlying end-to-end (E2E) 5G experimentation platform, whose original conceptual architecture is shown in Figure 16. The depicted model provides a traditional segmentation of the envisioned IT architecture on a vertical axis, adopting a layered design to facilitate the development of novel solutions. The corresponding layers of this axis from top to bottom are 'Front-end', 'Back-end', 'Federation' and 'Infrastructure'. Each Layer was foreseen to implement security measures comprising a holistic 'Security and Privacy Framework'. The main technological components comprising this early conceptual architecture have since been refined and will be described in more detail in Section 3.5.4.

This reference architecture (RA) has since been updated following the second iteration of the process described in the following Section. Therefore, the RA depicted in Figure 16 is considered to be deprecated, and is included to highlight the changes made following the architecture design approach described below.

3.3 Architecture design approach

This Section outlines the approach followed in the context of Task 1.3 *'5G-EPICENTRE technical specifications and architecture'* toward specifying the reported preliminary version of the 5G-EPICENTRE architecture. The approach will involve at least two iterations (M1-M6, including the project preparation period; as well as M7-M24) where incremental versions of the architecture will be elaborated and refined to satisfy the elicited experimentation requirements (Section 2) and critical aspects of the project use cases (UCs, Deliverables D1.1-2 *'5G-EPICENTRE experimentation scenarios preliminary/final version*'). Within each iteration period, specification of the architecture along with the clear definition of components, communication interfaces and deployment considerations in the context of the 5G-EPICENTRE project is undertaken as a three-step process, as shown in Figure 17. The three steps include technology exploration, decomposition via a top-down approach taking into account UC specification and information processing via *bottom-up* processes. Actual activities undertaken in the context of these phases will be thoroughly described in the following Sections.

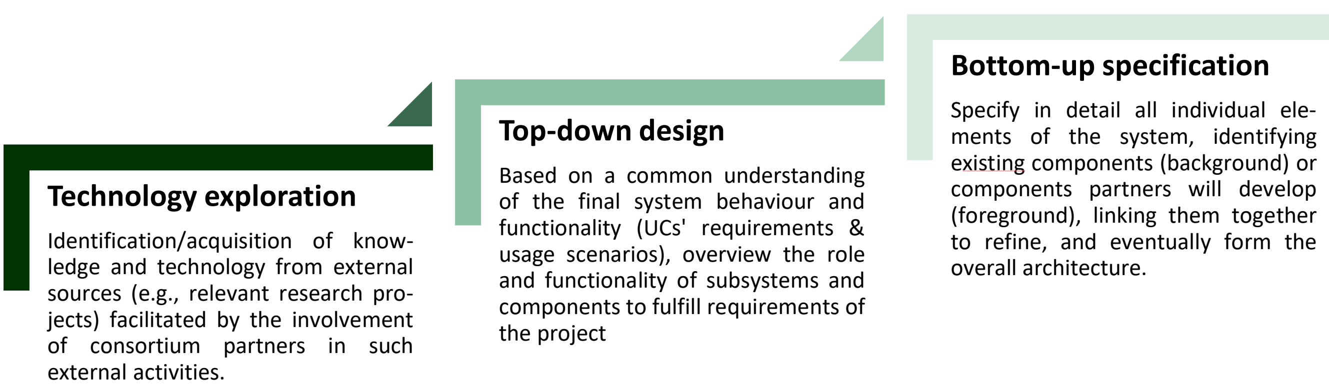

Figure 17: Architectural design approach within 5G-EPICENTRE.

3.3.1 Technology exploration

Technology exploration constitutes the first step toward the architecture definition process, where technologies relevant to 5G-EPICENTRE are surveyed and highly relevant results from other national and international (EU-funded) Research & Development (R&D) activities are considered as inputs into the architecture design. The role of this process is to: i) identify fundamental elements that existing technologies can deliver to 5G-EPICENTRE; and ii) provide evidence for compliance of aforementioned technologies with legal and ethical guidelines and concerns attached to the 5G-EPICENTRE technology and overall vision. A preliminary technology exploration process was carried out during the project preparation phase. This has since been enriched with additional information on projects that the consortium partners are either directly involved in, or have been made aware of during the first six months of the 5G-EPICENTRE project. Monitoring of relevant R&D activities will be a continuous process throughout the lifetime of the project, and the final results of the technology exploration analysis will be reported in the updated version of this deliverable *e.g.*, D1.4: *'Experimentation requirements and architecture specification final version'*, due M24 (December 2022).

This Section includes a high-level overview of related projects, with particular emphasis being placed on activities where the 5G-EPICENTRE consortium partners have been involved in. It will then conclude with an analysis of these projects outputs with respect to the goals and objectives of the 5G-EPICENTRE technology.

3.3.1.1 Relevant projects

A particular interest has been observed in the development of 5G testbeds that support ground-breaking research in mobile technologies. Particular focus has been placed in the federation, or interworking of testbeds' resources in heterogeneous and multi-domain scenarios, supported by a variety of EU and nationally funded research and innovation activities similar to 5G-EPICENTRE. Table 8 below includes high-level overview of selected projects that share similarities with 5G-EPICENTRE's own objectives.

Table 8: Relevant projects for the 5G-EPICENTRE technology exploration phase.

Project Acronym	Project Info	5G-EPICENTRE consortium partners involved
Fed4FIRE+	**Project name:** Federation for FIRE Plus. **Scope:** International, EU-funded. **Main goal:** Fed4FIRE was a project aiming to deliver federation of experimentation facilities for future internet experimentation communities, focusing on fixed and wireless infrastructures, services and applications. The project delivers a federation framework, based on an open architecture and specification toward providing a simple, efficient, and cost effective experimental environment addressing a variety of requirements. Fed4FIRE+ further improved on the outcomes of the Fed4FIRE federation, introducing upgrades and improvements to the facilities by including a variety of technical innovations. **Duration:** January 2017 – December 2021 (60 Months). **Website:** https://www.fed4fire.eu/	**HHI, UMA**
5GENESIS	**Project name:** 5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing.	**ADS, HHI, UMA, NEM, ATH**

	Scope: International, EU-funded. **Main goal:** To validate 5G KPIs for various 5G use cases, in both controlled set-ups and large-scale events. This will be achieved by bringing together results from a considerable number of EU projects as well as the partners' internal R&D activities in order to realise an integrated End-to-end 5G Facility, built on five diverse in terms of capabilities –yet fully interoperable- experimentation platforms distributed across Europe and interconnected with each other. **Duration:** July 2018 – December 2021 (42 Months). **Website:** https://5genesis.eu/	
5G-VINNI	**Project name:** 5G Verticals INNovation Infrastructure. **Scope:** International, EU-funded. **Main goal:** 5G-VINNI is aimed at accelerating the uptake of 5G in Europe by providing an end-to-end (E2E) facility that validates the performance of new 5G technologies by operating trials of advanced vertical sector services. **Duration:** July 2018 – December 2021 (42 Months). **Website:** https://www.5g-vinni.eu/	**ALB**, **HHI**
5G EVE	**Project name:** 5G European Validation platform for Extensive trials. **Scope:** International, EU-funded. **Main goal:** To implement and test advanced 5G infrastructures in Europe. The 5G-EVE concept is based on further developing and interconnecting existing European sites in in Greece, Spain, France, and Italy to form a unique 5G end-to-end facility. **Duration:** July 2018 – June 2021 (36 Months). **Website:** https://www.5g-eve.eu/	*None*
5G Berlin	**Project name:** 5G BERLIN e.V. **Scope:** National, funded by the German Government. **Main goal:** to fully exploit the potential opportunities offered by 5G technology and also create a networking platform for carrying out interdisciplinary projects. **Duration:** January 2018 – December 2028 (10 Years). **Website:** https://5g-berlin.de/en/	**HHI**
5GMediaHUB	**Project name:** 5G experimentation environment for 3rd party media services.	**FNET**, **FORTH**, **CTTC**, **IQU**, **EBOS**

	Scope: International, EU-funded. **Main goal:** Accelerating the testing and validation of innovative 5G-empowered media applications and NetApps from 3rd party experimenters and NetApps developers, through an open, integrated and fully featured Experimentation Facility. **Duration:** January 2021 – December 2023 (36 Months). **Website:** https://www.5gmediahub.eu/	

3.3.1.2 Analysis of outputs

Careful analysis of the aforementioned project's architectural aspects, as well as (where available) the technological solutions that 5G-EPICENTRE could exploit toward defining its own, are described in the following paragraphs. This process is aimed at identifying existing architectural/technological solutions at conceptual level, as well as identifying concrete 5G technologies (including facilities) to be inherited by 5G-EPICENTRE.

- The Fed4FIRE and Fed4FIRE+ projects proposed the use of standardized federation interfaces on top of heterogeneous testbed software frameworks [14], eventually leading to the largest federation of testbeds in Europe. More recent approaches are characterized by the requirement that individual facility sites partaking in the federation are built to accommodate specific features dictated by a unified reference architecture (RA). *5G-EPICENTRE will build on knowledge gained from these activities in terms of the common set of tools and interfaces developed in the context of the Fed4FIRE+ project to federate the testbeds in a uniform way.*
- In the context of the 5G-VINNI project, a common federation architecture is proposed to support end-to-end (E2E) network slicing, service deployment and testing, toward the construction of interworking testbed facilities in various locations in Europe [15]. In this way, network slices can be hosted in one or more geographically dispersed facilities. *The network slicing as-a-service approach followed in 5G-VINNI is of particular interest to 5G-EPICENTRE, which can gain on partners' expertise in pragmatic approaches followed to address challenges discovered, such as interfaces and information models, policy management, cross-layer and cross-domain coordination, monitoring and isolation. Also, 5G-EPICENTRE will use the ALB 5G-VINNI facility and its technologies in the 5G-EPICENTRE federation.*
- A federation blueprint is being developed in 5G EVE [8], where several facilities are unified in the federation employing an interworking framework enabling cross-site network slicing. *5G EVE will be closely monitored to discover insights on the interconnection of testbed infrastructures that can be useful in the approach to be followed in 5G-EPICENTRE.*
- The 5GENESIS project has proposed a common reference architecture for building integrated experimental platforms toward the validation of 5G Key Performance Indicators (KPIs) for various use cases in controlled set-ups and large-scale events [11]. It thus unifies heterogeneous physical and virtual network elements under a common coordination framework exposed to experimenters, while enabling E2E slicing and experimentation automation. *5G-EPICENTRE aligns much of its experiment coordination and lifecycle management approach on the approaches specified in the 5GENESIS architectural blueprint. In addition, 5G-EPICENTRE will use the UMA 5GENESIS testing facility as one of the base platforms of 5G-EPICENTRE as a stable starting point for experimentation in 5G technologies. The 5GENESIS automated orchestration framework further provides insight on deploying the 5G-EPICENTRE federation layer.*
- 5GMediaHUB is focused on the development of an experimentation infrastructure that will follow the DevOps approach to software development in order to more tightly couple development and operations of NetApps in order to support more simple testing and validation processes for third-party experimenters in the media and entertainment vertical. The conceptual architecture of the 5GMediaHUB project follows a multi-layer breakdown which brings together two well-established 5G testbeds in federation. *Of particular interest to the 5G-EPICENTRE architectural approach are the tools the project will develop*

to abstract the NFVI and facilitate cross-domain service orchestration, which aim to enable VNF chains to be instantiated on network slice instances that may utilize NFVI resources from both underlying testbed facilities. Given that the two projects will evolve together over the same period of three years, 5G-EPICENTRE will liaison with 5GMediaHUB to ensure lessons learned and best practices from that project are taken into account during the development of the 5G-EPICENTRE's cross-testbed MANO API.

- 5G Berlin provides a 5G standalone network including a high-performance test infrastructure. The researchers at Fraunhofer HHI will enable the project partners to test their novel algorithms and technologies in a real 5G mobile network environment. The test field is continuously developed, expanded and updated to the latest state of the art. *Of particular interest to 5G-EPICENTRE is the provided 5G hardware (as the testbed will be federated into the 5G-EPICENTRE end-to-end facility) and its software-driven management and orchestration solution*.

3.3.2 Top-down design

By definition, top-down refinement of an architecture design entails breakdown of the overall system into its compositional elements thus identifying (but not detailing) any-level subsystems and base components. The goal is to specify the role in terms of services and functions that each component provides, as well as a high-level overview of the interactions between them. A preliminary top-down design process was carried out during the proposal preparation stage, leading to an initial, conceptual specification of the 5G-EPICENTRE architecture reported in the Grant Agreement (GA), as seen in Figure 16.

During the top-down phase between M1-M6, and using the GA architecture specification as a reference model, a total of 13 individual main components specified in the RA (along with their sub-components, whenever sub-components were identified as building blocks for the main components during the project preparation top-down phase) were identified for further elaboration by consortium partners in the ensuing bottom-up processing. The final list of 22 base functional blocks resulting from this iteration of the architecture specification procedure for the elapsed period is presented in Table 9.

Components listed in bold represent the larger subsystems made up of smaller, individual components. These are further broken down until the entire specification is reduced to atomic elements. Whenever such a component cannot be further broken down, it is assigned a component serial number. During the first six months of the project, the process was re-iterated in the context of a series of architectural workshops (see Section 3.3.4), where gaps, weaknesses and other issues in the evolving architecture were identified and addressed in order to substantiate the envisioned 5G-EPICENTRE experimentation facility. An asterisk (*) is used to indicate a component that was included and/or identified in one of these architectural updates (not present in the GA RA).

Table 9: List of identified main (dark red) and total functional blocks in the 5G-EPICENTRE architecture reference model.

Component	Component No.	Sub-component(s)	Partner(s) responsible
5G-EPICENTRE Portal			**FORTH, ONE, NEM**
	-	**Experiment planning interface**	FORTH,ONE, NEM
	-	**Insights tools**	FORTH
Experiment planning interface			**FORTH, ONE, NEM**
	1	Experiment composer	FORTH

	2	User authentication & management component	FORTH, ONE
	3*	Network service (VNF/CNF/NetApp) Browser	FORTH, NEM
	4	NetApps creation & management dashboard	FORTH
Insights tools			**FORTH**
	5	Adaptation engine	FORTH
	-	**Visualization solutions (various alternatives)**	FORTH
Visualization solutions (various alternatives)			**FORTH**
	6*	Graphics and visualization dashboards	FORTH
	7*	2D/3D simulation engine	FORTH
Software-defined Northbound API	8	-	EBOS
Network service repositories	9*		NEM, IQU
Experiment coordinator			**UMA**
	10	Experiment scheduler	UMA
	11	Timeslot running process	UMA
	12	Multi-container application composer	UMA
Experiment player			**UMA, CTTC**
	13*	Cross-testbed VNF chain placement manager	CTTC
	14	5G traffic simulation engine	UMA
	15*	Cross-testbed service/slice configurator manager	UMA
Analytics aggregator	16*	**-**	IST

Cross-testbed MANO API	17	-	CTTC
Analytics Engine			**IST**
	18*	Analytics driver	IST
	19	KPI monitor	IST
	20	QoS/QoE monitor	IST
Cross-testbed VNF chain placement algorithm	21*	-	CTTC
Cross-testbed service/slice configurator Translator	22*	-	UMA

3.3.3 Bottom-up specification

In software development, bottom-up design entails the collection and interconnection of modules and components, which serve as building blocks toward designing larger, more complex systems. Within the context of the 5G-EPICENTRE architectural specification, the bottom-up approach followed the activities of the top-down architecture decomposition, involving the identification of technologies and software components that the individual technical partners envisioned to contribute to the project, either from their background or as a result of development activities taking place throughout the duration of the project Tasks (foreground) so as to fulfil the requirements of the components identified in Table 9. As was the case with the top-down phase, a preliminary bottom-up design process was undertaken during the proposal preparation stage, where partners were introduced in the 5G-EPICENTRE consortium based on their individual expertise and technological background, leading up to the detailed specification of the conceptual architecture components elaborated in the GA, and the initial linking to fulfil the requirements of the project.

Table 10: Component specification template for bottom-up design process.

[Name of new tool / component]	
Main functions	*Describe the main functions of the component and related to 5G EPICENTRE's objectives and milestones.*
Connections/Dependencies/Interfaces	*How the component relates with other components as well as 5G EPICENTRE's tasks and deliverables.*
Software dependencies	*Any dependency the component has on other libraries, frameworks, operating system etc.*
Functional Requirements	*Describe the functionality of the system.*

Non-Functional Requirements	*Describe the characteristics and features of the component.*
Input Parameters	*What is the input of the component (type and format).*
Output Parameters	*What is the output of the component (type and format).*

Following the revised top-down architecture design, and in order to coordinate the partners in collecting of detailed information of their contributed components, a component template (Table 10) was defined and shared using the project Confluence collaboration platform. Requests to fill in the template were addressed to the Task Leaders whose Task was identified as the Task responsible for the development/modification/update of each component. This full description of each component is provided in Section 3.5.4, where the functional architecture of the 5G-EPICENTRE experimentation facility is further elaborated.

3.3.4 Architecture workshops

During the architecture top-down and bottom-up design phases of this initial period (M1-M6), the 5G-EPICENTRE partners gathered together three times in online architecture design workshops organized under the responsibility of Task 1.3 Leader FORTH. Both technical and UC-leading partners were invited to partake in workshop activities in order to acquire a complete operational picture of the 5G-EPICENTRE architecture and its different views to be defined. Partners began deliberating on the architecture reference model specified during the project preparation period (Section 3.2, shown in Figure 16), refining its structure, relationships, interfaces and placement of its components to drive the top-down design phase. The final workshop of this period was held to finalize functionality that is to be provided by each module so as to produce the first stable version of the architecture described in this document.

3.4 Towards cloud-native enhancement of the federated platforms

3.4.1 NFV-MANO RA

In the early 2010s, Network Functions Virtualization (NFV) essentially addressed time and cost-saving provisions for the deployment of new network services, by means of decoupling software from purpose-built hardware (where one piece of hardware performed one software operation) to a single piece of hardware running several virtual machines (VMs) each performing a dedicated function known as a virtual network function (VNF). This paradigm shift has helped propel the development of 5G technology.

In 2014, the European Telecommunications Standards Institute (ETSI)-established Industry Specification Group for NFV (ISG NFV) defined the NFV RA framework, which identified the standards-compliant functional components and relationships between those components. In addition, the framework specified the base information elements involved in the NFV management and orchestration (MANO) system. These are summarized in Figure 18. As can be seen in the ETSI NFV RA diagram, three subsystems are defined inside the NFV-MANO component:

- The **Virtualized Infrastructure Manager(s) (VIMs)**, which control and manage the interaction of VNFs with the physical resources (computing, storage, network) under their supervision.
- The **NFV Orchestrator (NFVO)**, which is responsible for the orchestration and management of the NFVI and software resources, along with the onboarding and managing of the life-cycle of NetApps.

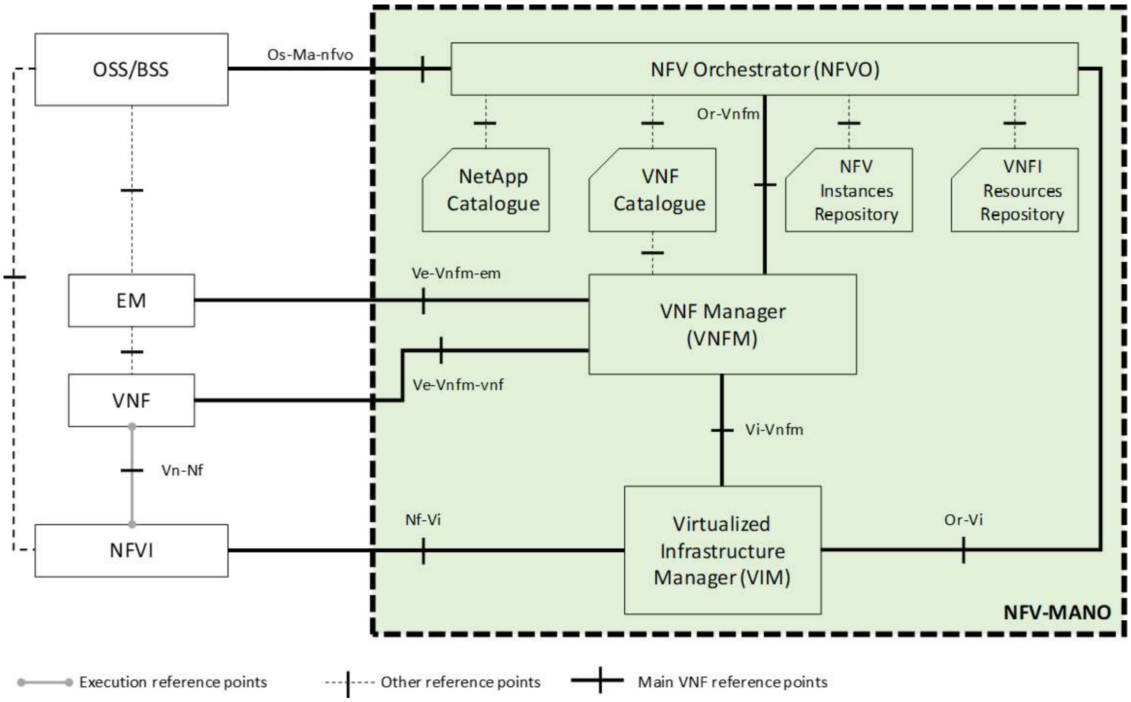

Figure 18: NFV-MANO reference architectural framework (Adapted from [4]).

- The **VNF Manager(s) (VNFMs)**, which is assigned lifecycle management duties of VNFs managed by the NFVO, coordinating the VIM for to facilitate the instantiation, update, scaling, querying and termination of the VNFs in its care.
- The **NetApp Catalogue** (specified in [4] as the 'NS Catalogue') is a repository of onboarded NetApps, which facilitates creation and management of all NetApp related templates (*e.g.*, the NetApp descriptor).
- The **VNF Catalogue** is a repository of onboarded VNFs, which facilitates creation and management of all NetApp related templates (*e.g.*, the VNF descriptor).
- The **NFV Instances repository**, which contains information on VNF and NetApp instances stored as records, updated during each instance lifecycle.
- The **NFVI Resources repository**, which stores information on the NFVI resources that are important for the reservation, allocation and monitoring.

The NFV RA further identifies the main reference points (RPs) that provide the interfaces facilitating exchanges of data between the aforementioned subsystems. The main RPs inside the NFV-MANO block are:

- The NFVO – VNFM RP (**Or-Vnfm**), which carries resource requests by the VNFM to the NFVO (*e.g.*, for the reservation of resources); configuration data by the NFVO to the VNFM for proper configuration of VNFs in the NetApp chain; and VNF state information queried by the VNFM to carry out lifecycle management of VNFs.
- The VIM – VNFM RP (**Vi-Vnfm**), which carries resource allocation requests by the VNFM to the VIM; along with virtual hardware state information and resource configuration to facilitate interaction of VNFs with the physical resources.
- The NFVO – VIM RP (**Or-Vi**), which carries resource reservation requests made by the NFVO as well as virtual hardware state information and resource configuration data.

In addition, inbound/outbound RPs include the following:

- A RP between the Operations and Business Support System (OSS/BSS) and the NFV-MANO block, and more particularly, the NFVO (**Os-Ma-nfvo**), which is used for requests for NetApp/VNF lifecycle management; NFV state information; policy management and data analytics exchanges; NFV related accounting and usage records; and NFVI capacity and inventory information.
- A RP between the Element Management (EM) and the VNFM (**Ve-Vnfm-em**). The EM is responsible for typical management functionality (configuration, fault management, accounting, performance measurement, security) for one or several VNFs. Hence, this RP is used for forwarding requests related to VNF lifecycle management (instantiation, run-time information querying, scaling, termination); and bidirectional exchange of configuration and events information between the EM and VNFM regarding the VNF. In case the EM is not aware of virtualisation, a direct RP between the VNF and VNFM (**Ve-Vnfm-vnf**) fulfils the above exchanges.
- A RP between the NFVI and VIM (**Nf-Vi**), which is used for assigning virtualized resources to address resource allocation requests by the VIM; the exchange of virtualised resources and hardware resources configuration and state information.

The NFV-MANO RA presented above specifies a high-level architectural reference frame along with implementation guidelines and interoperability via open interfaces, and is accommodated by the underlying 5G-EPICENTRE experimentation infrastructure platforms. The aim of 5G-EPICENTRE is to maintain those elements that can continue to serve their purpose when applying the transformation to cloud native Network Functions Virtualization (NFV), enabling augmentations and their replication to be introduced wherever necessary to accommodate the shift to cloud native solutions.

3.4.2 Cloud-native NFV-MANO

The ETSI NFV-MANO Group Specification on NFV-MANO describes a common frame of reference for the implementation of MANO capabilities on hypervisor-based virtualization environments, supporting deployment of VNFs as VMs. The majority of practical implementations of this architecture are built mostly on hypervisor-based virtualization environments, where the VIM is mostly based on VM orchestration tools, such as OpenStack[1] and VMware[2]. Evolution to cloud-native will involve deployment of network functions in the cloud in the form of microservices containers, introducing added complexity but also several advantages to the ETSI-compliant NFV-MANO systems [2]. Hence, in the ETSI GR NFV-IFA 029 [6], the ISG NFV identified additional components that the NFV-MANO should support for MANO of container-based VNFs:

- The **Container Infrastructure Service (CIS)**, which is responsible for delivering the runtime environment for one or more container virtualisation technologies that can be ran on top of both bare metal and hypervisor-based virtualisation environments.
- The **Container Infrastructure Service Management (CISM)**, which manages the deployment, monitoring, and lifecycle of containerized workloads and infrastructure resources containing computing, storage, and network resources.
- The **Container Image Registry (CIR)**, which stores container images and exposes them to other functions.

The ETSI ISG NFV presents various use cases for the utilization of containers, specifying that *"the CISM does not mean any other functional block than the existing NFV-MANO functional blocks, but a logical entity with functionality to be integrated in NFV-MANO architecture"* [6]. Several options for the enhancement of the NFV-MANO architecture with CISM functionality towards utilization of containers have been envisioned. Each enhancement has its pros and cons, leading to a comparison of architectural options but no concrete conclusion on CISM to NFV-MANO RA mapping [7]. Particular focus is placed on derivative architectures of the NFV-MANO RA block to support backward compatibility, as well as mapping to existing de-facto standards. Within 5G-EPICENTRE, it is

[1] https://www.openstack.org/
[2] https://www.vmware.com/

proposed that the cloud native infrastructure will be deployed as an overlay on top of the NFVI. The NFV-MANO underlay then acts as the resource orchestrator, allocating computational resources at Kubernetes clusters.

Kubernetes (K8s)[3] is the de-facto platform for automating container deployment and managing container lifecycle. It is responsible for scheduling and running containerized applications over one or more containers, while it is responsible for scheduling and running containerized applications over one or more containers, while simultaneously automating container operational tasks, such as creating, starting, organizing, monitoring and destroying containers. K8s internal high-level architecture is shown in Figure 19. Containers are grouped into a K8s *pod*, providing shared storage and network resources. Pods are assigned to run on *worker nodes*, which are sets of IT resources (*e.g.*, physical or virtual machines). A set of nodes running containerized applications is called a K8s *cluster*. A master node is assigned to be responsible for handling control of events in the K8s cluster.

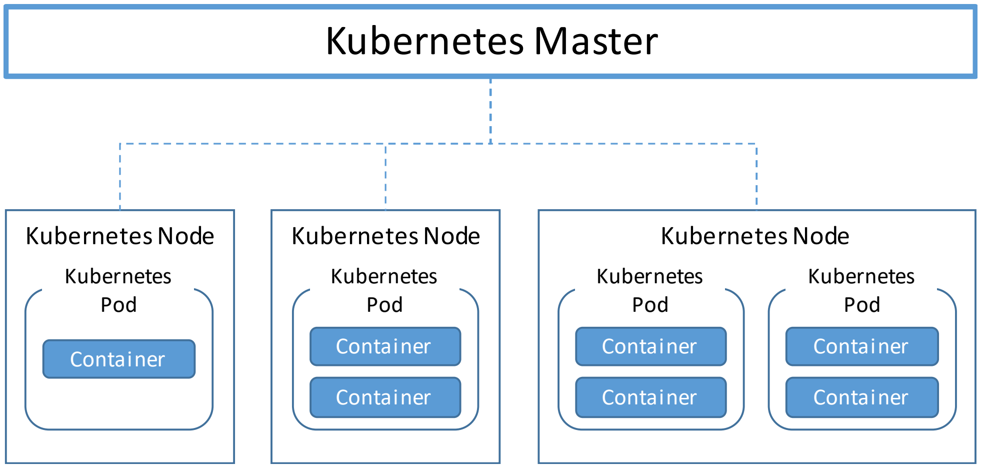

Figure 19: Kubernetes high level master node system architecture.

Because of this extensible architecture, K8s is a MANO-compliant platform can be mapped to the functions of the ETSI NFV-MANO architecture into a single, yet extensible solution. According to the NFV Release 4 FEAT17 [7], the de-facto standard solution analogy for the above terms correspond to K8s nodes and services, as specified in the Table below (Table 11).

Table 11: Mapping of [6] terms to de-facto standard solutions.

Component/Functionality	Analogy
CIS	K8s services exposing the Container Runtime Interface (CRI), Container Network Interface (CNI) and Container Storage Interface (CSI).
CIS instance	K8s worker node.
CISM	K8s master node.

Extensibility in K8s is ensured via plugins, which enable a K8s cluster to adapt to the needs of any work environment. For instance, a Container Network Interface (CNI) plugin is used to setup network connectivity between pods on different nodes, allowing them to communicate with one another.

Within 5G-EPICENTRE the goal will be to smoothly evolve the existing NFV-MANO architectures in each testbed into a K8s-based orchestration system for automating VI and VNF/CNF deployment, scaling and management.

[3] https://kubernetes.io/

This will be achieved by extending K8s with the appropriate plugins for extending its functionality. An important such extension toward the cloud-native transformation, adaptation, reconfiguration and evaluation of the test-beds should facilitate support for MANO of both container-based and VM-based VNFs. This would facilitate backward compatibility, making it easier to map the NFV-MANO functional model augmented with CISM functionality to K8s. The latter supports such mixed VM-container workloads through the KubeVirt VM management add-on[4], which essentially enables the launch of both containers and VMs on the same cluster, or even the same node, using the same networks and same storage infrastructure (Figure 20). Recent evidence by the 5G-PPP supports this technology as a potential disruptor in the NFV-MANO architecture [1].

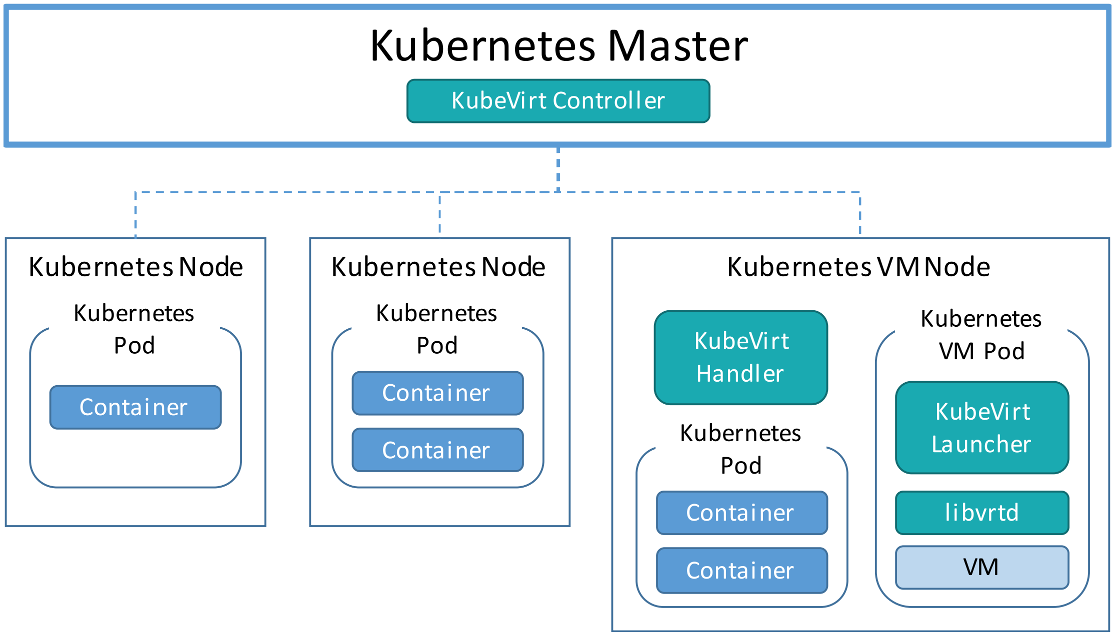

Figure 20: KubeVirt components for orchestrating/managing VM-based workloads alongside container-based workloads.

Taking the above into account, Figure 21 describes an early common frame of reference for the augmentation of the current NFV-MANO block by adding support to manage both network functions and virtual infrastructure on Kubernetes, essentially instigating embedding CISM functionality inside both/either the VIM and the VNFM. An updated RP between the between the CNF and VNFM (**Ve-Vnfm-cnf**) is expected to fulfil the same exchanges as Ve-Vnfm-vnf (see previous Section), albeit utilizing K8s and KubeVirt add-on for management and control of both CNFs and VM-based VNFs (running inside regular pods managed by K8s alongside container pods) respectively.

3.4.3 Cloud-native VNF architecture

The ETSI GS NFV-SWA 001 [5] describes a high-level internal architecture of a VNF. In principle, a VNF consists of one or more VNF Components (VNFCs), each occupying a single VM and providing appropriate links (by means of the SWA-2 interfaces) to the other VNFCs so as to deliver the desired functionality of the VNF. The VNF block further exposes well-defined interfaces toward the NFVI (Vn-Nf, providing the VNF with access to a slice of the NFVI resources), the VNFM (Ve-Vnfm-vnf, providing the VNF with lifecycle management by the VNFM) and EM (SWA-4, enabling the EM to communicate with the VNF). VNFs can be linked together by means of SWA-1 interfaces to form a network service, service function chain or NetApp. This RA is iterated in Figure 22.

This Section aims at providing a high-level overview of how the shift to cloud-native or containerized NFs (CNFs)

[4] http://kubevirt.io/

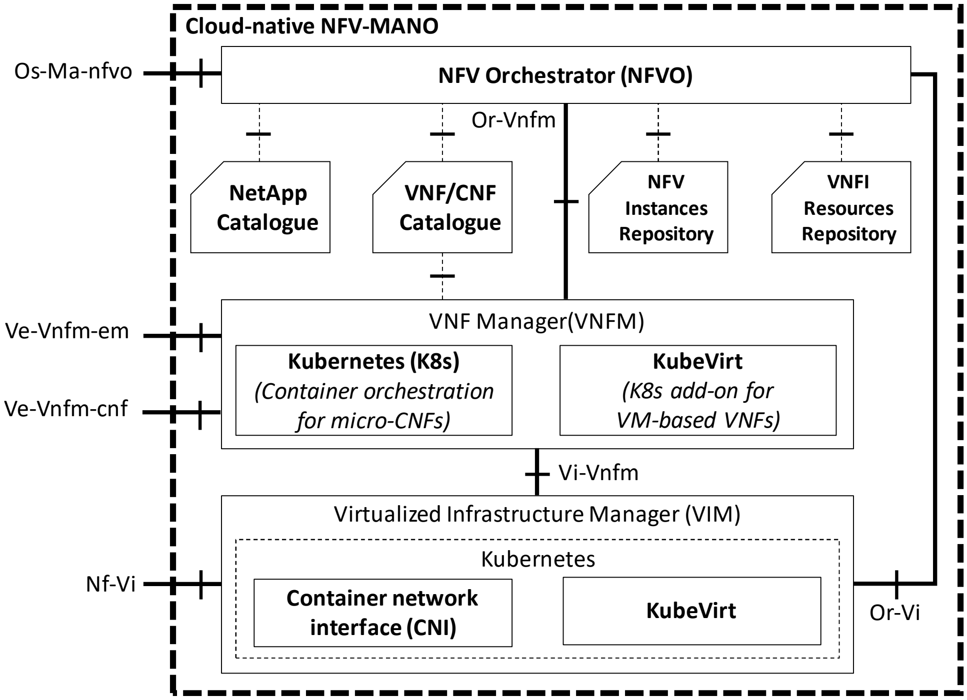

Figure 21: CISM functionality embedded in the ETSI NFV-MANO RA via Kubernetes and add-ons (KubeVirt, CNI). The figure focuses on the portion of NFV-MANO architecture relevant for the architectural impacts. Figure adapted from [4].

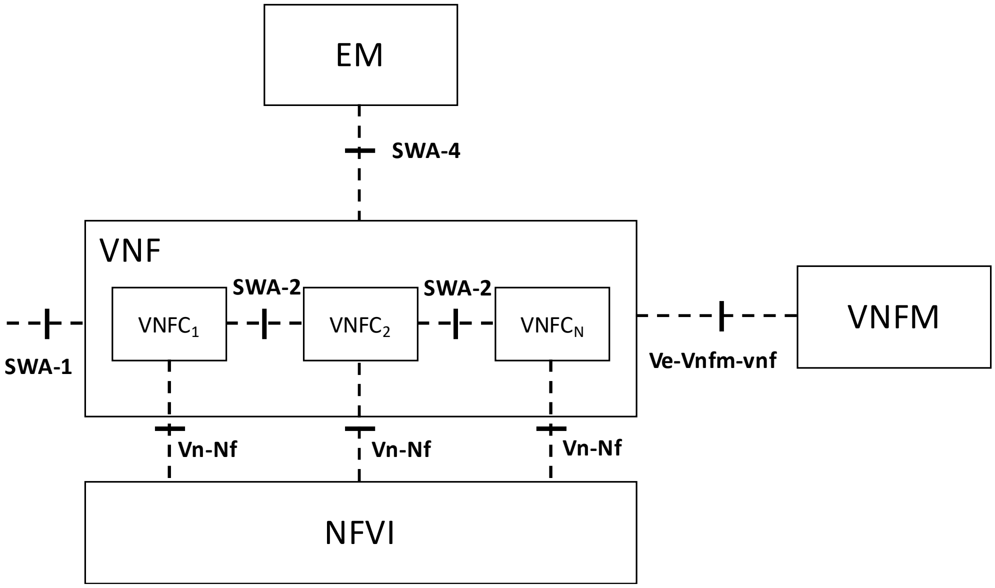

Figure 22: Internal functional architecture of VNF, adapted from [5].

will be accommodated. In addition, an overview of hosting CNFs alongside legacy VNFs will be provided to facilitate developments in the context of WP2 through WP4.

3.4.3.1 Micro-VNF/CNF architectural enhancements

As specified in the previous Section, 5G-EPICENTRE is based on the augmentation of the current NFV-MANO block to which it will integrate support to manage NFs and VI using a container engine (Kubernetes) enhanced with the appropriate add-ons to accommodate VM-based VNF implementations dictated by the Figure 22 specification. This will impact the NFV-MANO architecture specification [4] in the following manners:

- It will require infrastructure for the network services to be deployed as containers in a hybrid cloud environment (both public and private clouds), thus accommodating a Cloud-native NFVI (CNFVI). It will contain the hardware needed for compute, storage and networking along with a containerization layer on top of which CNF containers can be spun up [2].
- It will require VNFCs to be realised in a microservices-based approach, foregoing the 1:1 correspondence between VNFC-VM and yielding instead a one-to-one microservice to container analogy to form a CNF Component (CNFC).

These impacts, along with the considerations for cloud-native NFV-MANO elaborated in the previous Section are highlighted in Figure 23. Internal implementation of microservices-based VNFs is a responsibility assigned to the function developer, and consists of identifying the CNFCs from a microservices perspective (either by developing NFs that correspond to generic functionality that a wide range of CNFs should support , or decomposing existing VNFs into smaller units [3]), and specifying well-defined interfaces for facilitating communication among CNFs by means of the SWA-2 interface (Figure 23).

3.4.3.2 Reference implementation NFV ecosystem in Kubernetes

In order to accommodate the hybrid deployment envisioned within 5G-EPICENTRE, VNF/CNF orchestration and lifecycle management should accommodate both VM-based monolithic VNFs as well as CNFs. The addition of the KubeVirt add-on to the K8s orchestration engine enables treatment of such VMs as K8s-managed resources in a similar way to container resource management across the same K8s cluster, as shown in Figure 20.

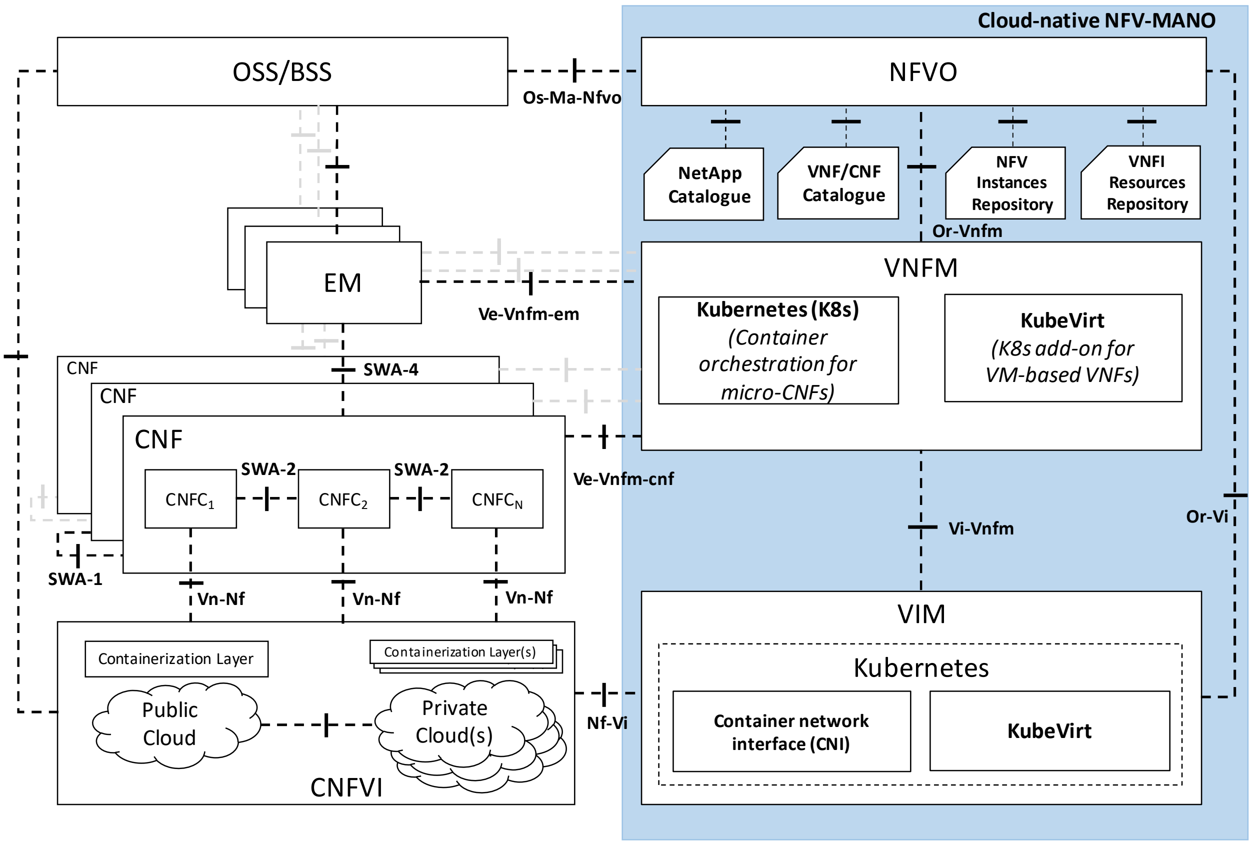

Figure 23: Cloud-native implications for NFV-MANO RA.

Utilizing this information, a reference implementation of the functional augmented NFV-MANO RA depicted in Figure 23 can be seen in Figure 24. CNFs are broken down into CNFCs each hosted in a container on a K8s Pod assigned to a worker node. Similarly, legacy VNFs utilize K8s VM pods running the *virt-launcher* and *virt-handler*

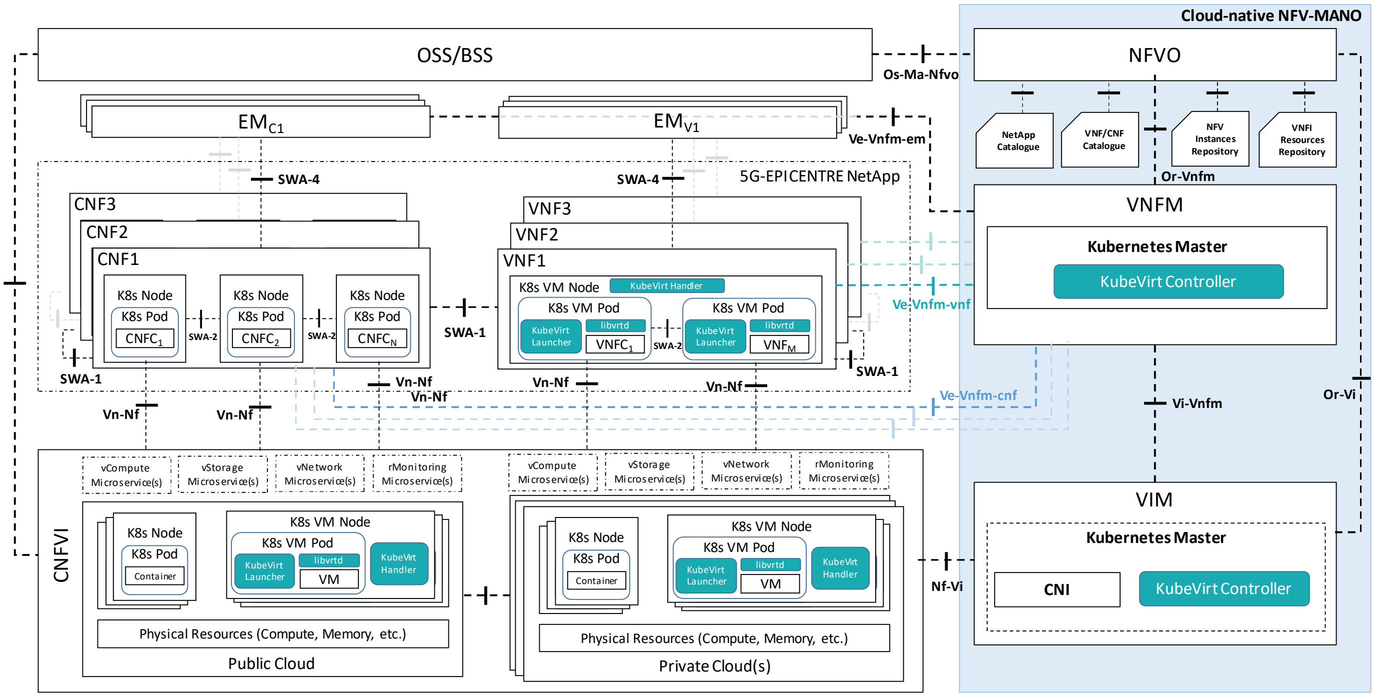

Figure 24: Reference implementation architecture proposal for cloud-native NFV-MANO with K8s and KubeVirt add-on.

KubeVirt components along with an instance of *libvirtd* to manage the lifecycle of the VM process. The K8s master, as the access point responsible for managing scheduling and deployment of the CNF/VNF containers is assigned to the VNFM block, storing the state and configuration of the entire cluster. The VNFM further incorporates the *virt-controller*, which is responsible for creating and scheduling the VM pod.

On the CNFVI side, a container cloud platform is deployed, responsible for management and capability virtualization of the underlying (public/private cloud) hardware resources, exposing resource management and software microservice support capabilities for the upper layer. The VIM, centred around K8s and KubeVirt add-on, provides the necessary container resource management for managing compute, network, storage and resource utilization in support of the service-based architecture evolution of the upper-layer NetApps and NFs.

3.5 5G-EPICENTRE architecture specification

3.5.1 High-level 5G-EPICENTRE architectural framework overview

Conceptually, the 5G-EPICENTRE architecture represents a combination of a novel *5G facility framework* and the modified combined testbed infrastructure of the four geographically dispersed platforms, complete with their own hardware and software components (Infrastructure Layer). As a result of deliberation among consortium partners under different roles (*e.g.* testbed owners, technology developers and experimenters) during the architecture workshops, it was decided to for some elements of the 5G-EPICENTRE architecture to be replicated across all four testbeds toward ensuring synchronisation and harmonisation of the different platforms partaking in the federation, most prominently the cloud native NFV components, as can be seen in Figure 25. 5G-EPICENTRE envisions for its underlying testbed infrastructure to maintain its administrative independence while ensuring interoperability with the other platforms, particularly in the management and orchestration (MANO) capabilities necessary for deploying and running the experiments of both first and third-party experimenters. In this respect, each platform should accommodate a means to orchestrate and manage deployment and operation of NetApps on top of 5G infrastructures.

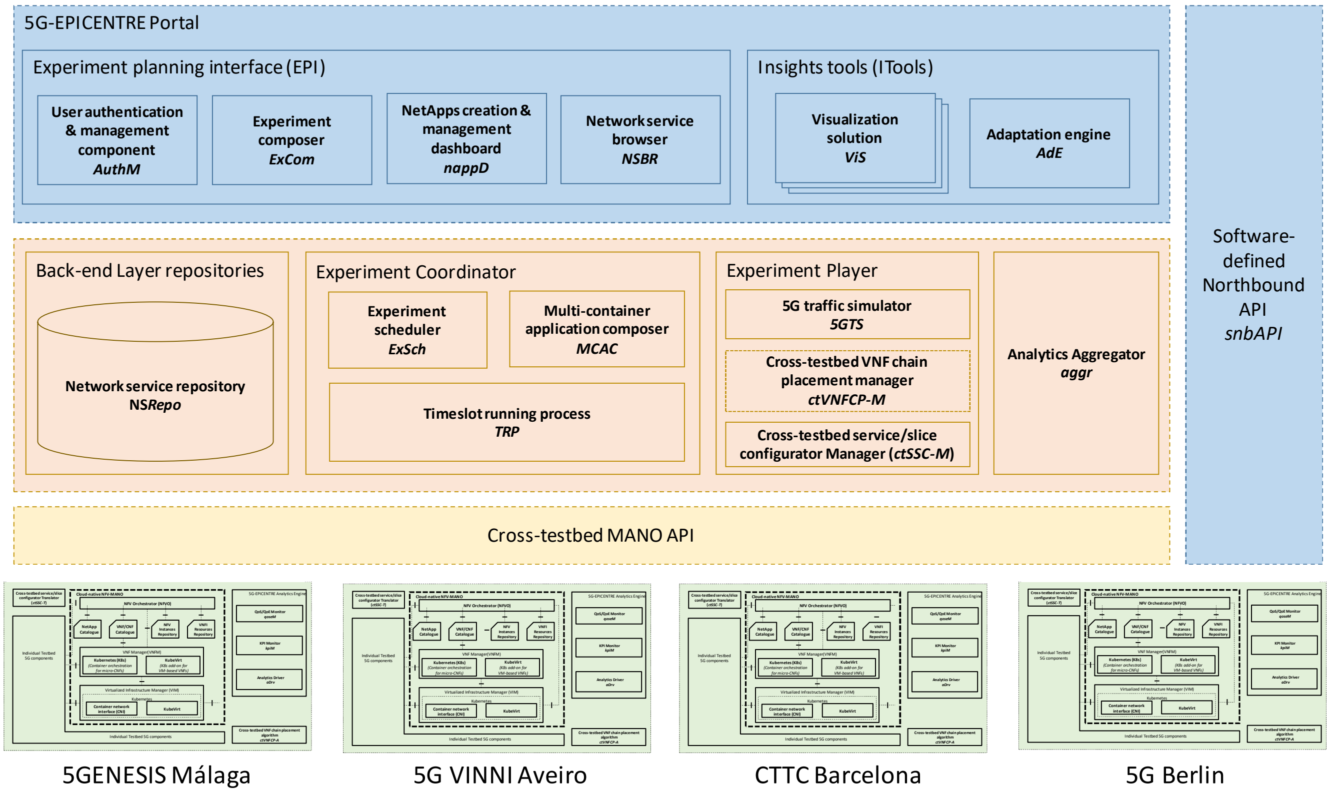

Figure 25: 5G-EPICENTRE overall functional architecture component diagram.

The architecture diagram shown in Figure 25 retains the architectural layers specified in the conceptual model presented in Section 3.2, namely the '**Front-end layer**', '**Back-end layer**', '**Federation layer**' and '**Infrastructure layer**'. The first three layers constitute the entities comprising the *5G facility framework*, which will be presented in more detail in the following Section (Section 3.5.2) The latter layer corresponds to the individual 5G testbed infrastructural elements, including the hardware required for the realizing of each individual 5G platform. It will be described in Section 3.5.3.

Each Layer will implement all necessary security measures, thus comprising a horizontal security and privacy framework that will cater to the security requirements of the entire architecture from top to bottom. This will aim at configuring secure network policies to deal with the larger attack surface resulting from the shift toward edge VNF containerization. In this respect, 5G-EPICENTRE will take advantage of service mesh architectures to enforce such policies over the entirety of the network.

As already mentioned, the 5G-EPICENTRE architecture aims to smoothly integrate testbeds into federation and wherever necessary, facilitate the reuse of existing components to support administrative independence of the platform outside of 5G-EPICENTRE activities. 5G-EPICENTRE will devote more time and effort on the adaptation, reconfiguration and evaluation of these components, refining and developing all necessary functional blocks into a microservices-based architecture. This includes the enhancement of the existing NFV-MANO architectures in each testbed in accordance to the guidelines in Section 3.4.2, and particularly, the cloud-native NFV-MANO architecture depicted in Figure 21.

3.5.2 5G-EPICENTRE facility framework

The 5G-EPICENTRE facility framework is a centralised, single point of entry for the four testbeds below. It consists of three architectural Layers specified in the previous Section, namely the 'Front-end', 'Back-end' and 'Federation' Layers. These are described in the following sub-Sections.

3.5.2.1 Front-end layer

On the 'Front-end' Layer, 5G-EPICENTRE is composed of functional components related to facilitating the interaction between the platform and targeted end-users, *i.e.*, experimenters and network function developers. It aims to effectively address how these actors can utilize the front-end of the platform to build up and experiment with their solutions. Hence, this layer includes the 5G-EPICENTRE portal, a web-based user interface where actors can define the experiment environment, migrate their applications, specify what they will need in terms of network resources (*e.g.*, data, storage, bandwidth, *etc.*), and receive insights on what each of the federated testbed can deliver. In addition, using a RESTful software-defined northbound application program interface (API), interconnection between user-defined applications, with the services and applications running over the network, will be realized. The functional blocks residing in this Layer are summarized in Table 12 below:

Table 12: Front-end Layer functional components.

Front-end Layer functional blocks		
Component No. (corresponding to Table 9)	**Component**	**Section**
1	Experiment composer	3.5.4.1
2	User authentication and management component	3.5.4.2
3	Network service browser	3.5.4.3
4	NetApps creation & management dashboard	3.5.4.4
5	Adaptation engine	3.5.4.6
6	Graphics and visualization dashboards	3.5.4.7
7	2D/3D simulation engine	3.5.4.7
8	Software-defined Northbound API	3.5.4.10

3.5.2.2 Back-end Layer

The 'Back-end' Layer incorporates several key functional components of the platform, implemented as a single entry point into the orchestration, with each testbed platform being treated as a point-of-presence. This layer will define the synergies that these components should implement *e.g.*, all necessary data the system has to provide, as well as the means by which this data is accessed. It further indicates the high-level classification of the 5G-EPICENTRE functional components according to their contribution to the main objectives of the 5G- EPICENTRE project, *i.e.*, automated infrastructure management, strategic placement of NetApp chain nodes over the Cloud and edge infrastructure resources, *etc.* Components in Back-end Layer will be a point of entry for experimenters to specify network slice details realized in the testbeds below, meaning each testbed must provide its own reusable components (*e.g.*, network slice manager) for handling the commands obtained by the platform Back-end Layer. The functional blocks residing in this Layer are summarized in Table 13 below:

Table 13: Back-end Layer functional components.

Back-end Layer functional blocks

Component No. (corresponding to Table 9)	Component	Section
9	Network service repository	3.5.4.11
10	Experiment scheduler	3.5.4.12
11	Timeslot running process	3.5.4.12
12	Multi-container application composer	3.5.4.12
13	Cross-testbed VNF chain placement manager	3.5.4.13
14	5G traffic simulation engine	3.5.4.14
15	Cross-testbed service/slice configurator manager	3.5.4.15
16	Analytics aggregator	3.5.4.17

3.5.2.3 Federation Layer

The 'Federation' Layer handles cross-testbed orchestration of network services and resources so as to ensure an optimal experiment environment. The functional blocks residing in this Layer are summarized in Table 14 below:

Table 14: Federation Layer functional components.

Federation Layer functional blocks		
Component No. (corresponding to Table 9)	**Component**	**Section**
17	Cross-testbed MANO API	3.5.4.18

3.5.3 Infrastructure Layer

The 'Infrastructure' Layer acts as an abstraction of the heterogeneous 5G radio deployment and network architecture configurations that characterize each testbed, with individual platforms' 5G components stemming from a variety of EU and nationally funded research and innovation activities at sufficiently high maturity levels. As can be seen in Figure 25, this Layer is comprised of four augmented testbed platforms (TB).

Within the scope of the present document, an augmented testbed platform corresponds to an administratively independent testbed platform that implements and hosts the 5G-EPICENTRE Infrastructure Layer components summarized in Table 15, together with applying the cloud-native transformation principles reported in Section 3.4.2 for the simultaneous support of both VM-based and Cloud-native network functions. This facilitates compliance of the platform with the ETSI standards in terms of supporting the NFV-MANO interfaces and functional blocks. Figure 26 describes a common frame of reference for the augmentation of the individual testbeds into the 5G-EPICENTRE federation.

Table 15: Infrastructure Layer functional components.

Infrastructure Layer functional blocks

Component No. (corresponding to Table 9)	Component	Section
18	Analytics driver	3.5.4.19
19	KPI monitor	3.5.4.20
20	QoS/QoE monitor	3.5.4.21
21	VNF chain placement algorithm	3.5.4.13
22	Cross-testbed service/slice configurator Translator	3.5.4.15

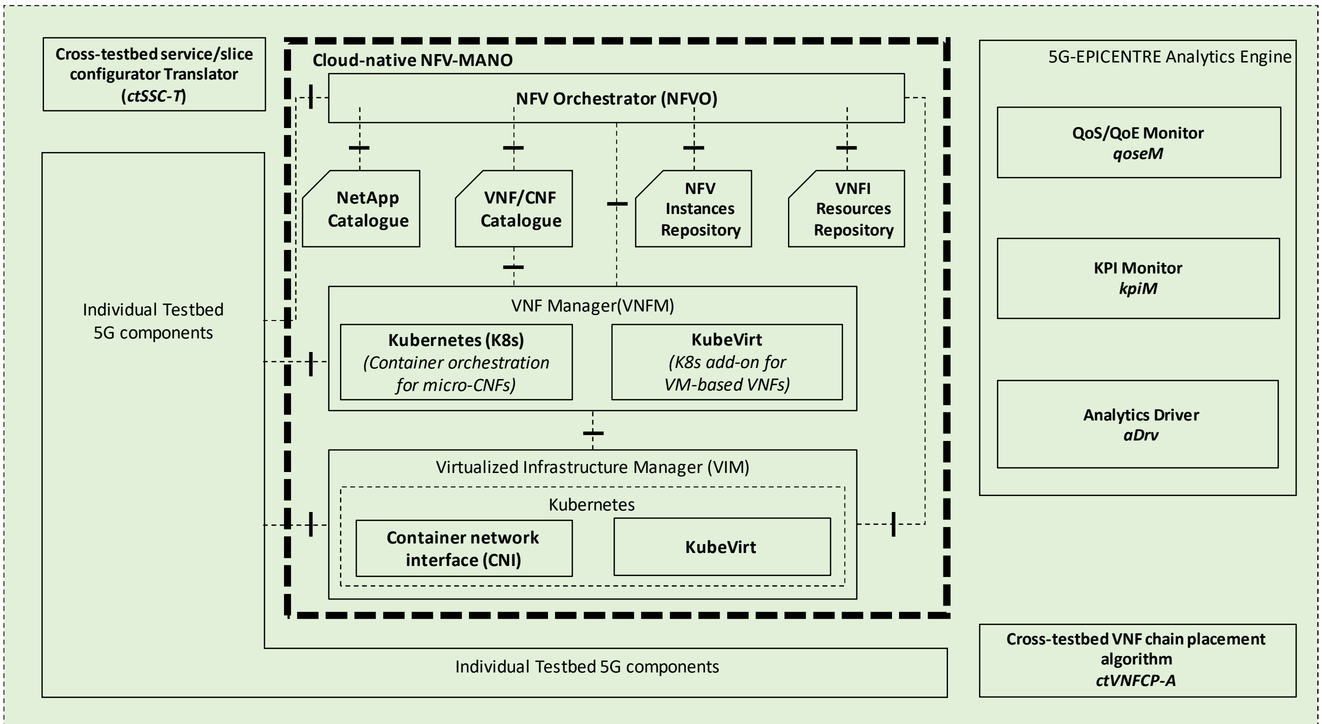

Figure 26: 5G-EPICENTRE Infrastructure Layer reference frame.

3.5.4 Functional view

In this Section, the functional entities of the 5G-EPICENTRE architectural framework (as depicted in Figure 25), their responsibilities, and interactions with other components will be elaborated. This Section aims to represent the functional blocks specified in accordance to the design methodology elaborated in Section 3.3 provided at a *functional* level, implying no specific implementation. Hence, the following Sections will focus on detailing the main components of the 5G-EPICENTRE platform, presenting their main functionalities and well-represented responsibilities, thus providing a comprehensive overview of the overall architecture functional view. An updated reference *implementation* of the 5G-EPICENTRE architecture will be reported in the follow-up version of this deliverable (D1.4: *"Experimentation requirements and architecture specification final version"*). All component descriptions present in this Section are derived from the templates used for bottom-up design specification, as presented in Section 3.3.3.

3.5.4.1 Experiment composer (ExCom)

The Experiment composer (ExCom) is responsible for allowing experimenters to easily define new experiments leveraging the 5G EPICENTRE infrastructure, providing information on what their execution will require in terms of network resources (*e.g.* data, storage, bandwidth, *etc.*), and receiving information on what each testbed can deliver so as to make a request on when and where to run their configuration.

The following list represents a non-exhaustive set of capabilities provided by the ExCom, exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities or other external tools and applications (for instance, web-based APIs and interfaces).

- Provide platform users with the means to define and describe their experiments, thus generating an experiment descriptor template that can be consumed by the Experiment coordinator block (Section 3.5.4.12) for the management and scheduling of queued experiment requests (creating, planning and executing an experiment).
- Provide an interface with the VNF/CNF and NetApp browser so as to capacitate platform users to select from the available catalogues of CNFs/VNFs and NetApps to compose an optimal experimentation environment.
- Consume user authentication data in the form of a template toward restricting access to experiments' and experimenters' data to authorized users only in the interest of experiment data privacy protection. In addition, role-based access control (RBAC – see also Deliverable D1.5: "Security-by-design toolkit") shall be ensured to support personalized services for the various roles/profiles of the 5G-EPICENTRE platform users that require access to the platform capabilities and APIs.
- Expose an interface to the experimental capabilities of the platform (for instance, network topology) for controlled programmability, thus providing platform users the ability to identify and configure particular experimental properties provided by the platform components. These shall be exposed to other 5G-EPICENTRE platform components by means of the experiment descriptor.
- Expose an interface to notify platform users about the status of an experiment.
- Provide the means to retain, explore and/or erase data on specified experiments, by storing and deleting experiment data, and enabling browsing of exemplar experiment descriptors.
- Provide an interface experience that is easy to understand and use, including a quick start guide on how to create an experiment, as well as the means to help a user to learn how to use it.

3.5.4.2 User authentication and management block (AuthM)

The user authentication & management component (AuthM) main responsibility is to manage data related to roles/profiles of the users of the 5G-EPICENTRE platform. More specifically, the AuthM is bestowed the following responsibilities:

- it provides an authentication mechanism in order to allow users to login and start a session, implementing a mechanism for user registration.
- it provides persistent storage mechanism for user preferences that can be utilized from other 5G EPICENTRE components (*e.g.*, adaptation engine – see Section 3.5.4.6).
- it enforces security policy based on the RBAC approach where each user, based on their role, will have restricted access only to the 5G EPICENTRE part they are authorized to use.

The component hence manages the roles of the different user types of 5G-EPICENTRE users. User roles specified at this time include:

- Experimenters, who can create and run experiments over the 5G EPICENTRE Infrastructure.
- Function Developers, who develop and maintain VNFs/CNFs for the project.
- NetApp Developer, who develop and maintain NetApps for the projects.

- Testbed owners, who own the underlining testbeds and can test various aspect of the platform against their testbed.
- Administrator, who will be able to validate user and manage the underlying infrastructure.

The following list identifies a non-exhaustive set of functionalities assigned to the AuthM, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- Validation and authorization of user authentication requests, which may impact the way requests for accessing platform services and experiment descriptors are handled (granting of the requested permissions shall be governed by security policies).
- User profile management, exposing interfaces for platform usage information (*e.g.*, by the adaptation engine, see Section 3.5.4.6) and the persistence of metadata about users in the form of key/value pairs constituting user profile data (exposed in the form of a template) needed by the different 5G-EPICENTRE components implementing RBAC processes.

3.5.4.3 Network service browser (NSBR)

The Network service browser (NSBR) is a combined NetApp and VNF/CNF browser responsible for implementing browsing capabilities for platform users to view the different NetApps and VNFs and CNFs available through the 5G-EPICENTRE platform. In addition, it provides a point-of-entry for other 5G-EPICENTRE components and services to retrieve NetApp and VNF and CNF information.

The following list expresses a non-exhaustive set of functions performed by the NSBR, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- Expose a UI for AppStore-like marketplace browsing and searching, where users list VNFs and CNFs that can be incorporated into customer NetApps. This will provide APIs for selecting a VNF, defining customer-specific VNF configuration options (*e.g.*, its firewall rules or caching policies), *etc.*
- Provide an interface for CNFs and VNFs' descriptors in the form of a template, complete with information about their usage, configuration and software update/upgrade status.
- Expose a UI for AppStore-like marketplace browsing and searching, where users list the various customer NetApps for PPDR verticals. It will provide APIs for selecting a NetApp, defining customer-specific NetApp configuration options, as well as exposing details on the individual VNFs/CNFs in the service function chain.
- Provide an interface NetApps' descriptors in the form of a template, complete with information about their usage, individual VNF/CNF configuration options, *etc.*

3.5.4.4 NetApps creation & management dashboard (nappD)

The NetApps creation & management dashboard (nappD) constitutes a graphical NFV prototyping & composition platform, with the aim being to supporting the creation of novel and complex NetApps, allowing the chaining of both VM-based, KubeVirt-managed VNFs and K8s-managed CNFs in the same service function chain. The main responsibilities of the nappD are:

- To allow 5G-EPICENTRE platform users to create custom end-to-end network applications utilizing a graphical user interface (GUI) allowing them to drag and stitch together visual elements corresponding to 5G-EPICENTRE VNFs and CNFs exposed through the NSBR interface.
- Facilitate onboarding and verification of the specified NetApps in the platform via templates exposing the necessary configuration of the experiment environment to be scheduled for automated deployment, execution and monitoring by the Back-end Layer components.

The following list represents a non-exhaustive set of capabilities provided by the nappD, exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities or other external tools and applications (for instance, web-based APIs and interfaces).

- Provide interfaces for obtaining data (in the form of a template) on the available VNFs and CNFs hosted on the 5G-EPICENTRE platform, and realize visualization for users to drag and drop service function chain nodes into a graphical composition area to allow NetApps to be customized for each customer.
- Expose an Interface toward the ExCom, to pass on information (in the form of a template) about the VNFs/CNFs selected in the chain for the latter to automatically orchestrate the experimental environment (in the form of the appropriate experiment descriptor template) using the underlying testbed resources.

3.5.4.5 Experiment planning interface (EPI)

Within the scope of the present document, the Experiment planning interface (EPI) encompasses all Front-end Layer components (ExCom, AuthM, NSBR, nappD) that together provide functionality corresponding to visual representation for experiment definition via a GUI. The EPI may thus include additional (external to the aforementioned components) software and APIs for the provision of a web-based interface that experimenters can use.

3.5.4.6 Adaptation engine (AdE)

The main function of the Adaptation engine (AdE) is to support the experiments' results visualisation user experience with a dual emphasis on improving both the visualisation process and overall system usability. Its responsibilities therefore are twofold:

- It aims to support adaptive UIs, involving methods and tools to optimally improve the interactive visualisation experience, with runtime transformations which can utilize knowledge and information exploitable for the current interactive session.
- It will exhibit dynamic visual aspects, distributed presentations and interaction, multi-user involvement and many-platform sessions.

The following list identifies a non-exhaustive set of functionalities assigned to the AdE, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- It will configure appropriate experiment KPI visualization for a diverse range of output devices, accommodating specific aspects of the user profile along with user preferences (consumed in the form of a template), to meaningfully adapt user interfaces and visualizations.
- It will orchestrate the information flow taking into consideration user specificities, context and preferences in accordance to its internal information regarding the current user, the content to be displayed as well as the context of use.
- Store, maintain and process user information based on an ontology-based reasoner for adapting the visual information to ensure an optimal user experience.

3.5.4.7 Visualisation solutions (ViS)

5G-EPICENTRE visualization solutions (ViSs) will comprise advanced graphics and visualisation dashboards and simulation engines targeting an array of heterogeneous devices (such as mobile phones, laptops, tablets, desktop PCs, head-mounted displays, *etc.*) The main function of any given ViS is to provide sleek, intuitive and functional experiment data visualisations.

The following list expresses a non-exhaustive set of functions performed by any given 5G-EPICENTRE ViS, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities, or other external tools and applications (for instance, a 2D/3D simulation engine, such as Unity 3D[5]).

- Will obtain analytics/KPIs/network metrics/anomalies' information by means of an interface with the analytics aggregator component residing in the Back-end Layer (see Section 3.5.4.17) and translate it into visualization formats and outputs that can easily be interpreted by a human operator.
- Will produce advanced, immersive and tangible visual representations of KPI and anomalies' information supporting different visual, graphical elements differentiated through spatial position, shape, colour or physics-based affordances, *etc.*
- Provide rich and interactive dashboards using multiple visualization options (2D/3D) and (when possible) combining different input and output smart surfaces to create high-resolution immersive multi-screen display systems.
- Based on the capabilities of the output device, 360-degree advanced and tangible visual real-time representations could be supported.

Any ViS implemented within the context of the 5G-EPICENTRE project will be comprised of user interface and data visualizations that combine ease of use, speed and reliability of monitoring network performance/QoE, providing visuals that make the data story cleaner and concise for easy comprehension. The ultimate goal is to help users fully understand complex information and uncover insights, potential anomalies and objectives.

3.5.4.8 Insights tools (ITools)

Within the scope of the present document, the Insights Tools (ITools) encompasses all Front-end Layer components (AdE and the different implementations of the ViS archetype specified in Section 3.5.4.7) that together provide functionality corresponding to visual representation of experiment results and network metrics via a GUI. The ITools may thus include additional (external to the aforementioned components) software and APIs for the provision of web-based interfaces, cross-platform play and other components or libraries that experimenters can use for experiments' insights visualisation.

3.5.4.9 5G-EPICENTRE portal

Within the scope of the present document, the 5G-EPICENTRE Portal encompasses both EPI and ITools components that together provide functionality corresponding to the interfacing of the 5G-EPICENTRE platform with experimenters. The full functionality of the Portal hence spans both the definition of new experiments, as well as the real time information provision about their execution status.

3.5.4.10 Software-defined northbound API (snbAPI)

The software-defined northbound application programming interfaces (snbAPI) will be utilized to enable the automatic communication between the testbeds at the bottom-end of the architecture and the NetApps at the top of the platform. This functionality will serve as an enabler for configuration of the network. The snbAPI is meant to serve as a second entry point to the 5G-EPICENTRE federated platforms (the other being the 5G-EPICENTRE Portal), enabling end-user applications to directly expose their needs and requirements (*e.g.*, data, storage, bandwidth, *etc.*) to the Back-end and/or Federation Layer in order for the 5G-EPICENTRE platform to orchestrate and deliver those resources in a dynamic fashion. Hence, it will be an alternative path for accessing the testbeds from the NetApps.

The following list represents a non-exhaustive set of capabilities provided by the snbAPI, exposed by means of interfaces consumed by the 5G-EPICENTRE functional entities residing at the Back-end and Federation Layers, as

[5] https://unity.com/

well as the external applications consuming those interfaces to facilitate orchestration of application-specific resources.

- It will expose integration methods toward the components that need to integrate with the snbAPI to achieve interexchange of information with end-users' applications, notifying those components in the event the communication between the endpoints is achieved or has failed.
- It will provide a consistent, common design template for information data models to define the message exchange file format for information sent over the snbAPI, along with the exact fields, field types and the frequency of exchanges between the integration end points. This will be in the form of a configuration request (including a number of parameters) from an application to the network.
- It will allow the communication between the testbeds and NetApps: i) collectively, via the cross-testbed MANO API (Section 3.5.4.13); and ii) individually at each testbed, exposing a template describing a form of a service level agreement for the configuration of an application to the network.
- It will support APIs defined as RESTful HyperText Transfer Protocol (HTTP) services, following Representational State Transfer (REST) conventions and architectural style.

3.5.4.11 Network service repository (NSRepo)

The Network service repository (NSRepo) is a 5G-EPICENTRE NetApps repository that constitutes a safety storage of all NetApps and their constituent micro-VNFs/CNFs and metadata. Moreover, it supports a northbound interface towards the NSBR and the nappD, and a southbound interface towards the cross-testbed MANO API for facilitating exchanges with the testbeds' VNF managers. Therefore, the main function of the NSRepo is to store the list of available NetApps and VNFs/CNFs, as well as the constraints of each element. The repository will contain all the necessary image files and descriptors[6].

The following list represents a non-exhaustive set of capabilities provided by the NSRepo, exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities:

- The internal relational database will facilitate the storage of the relationship of NetApps with their constituent VNFs/CNFs (*e.g.*, as foreign keys of the micro-VNFs and micro-CNFs in the NetApp list) that will be provided by the NetApps creation & management dashboard.
- It will support message exchange with the cross-testbed MANO API component, and optionally individual testbeds' NFV-MANO block for the onboarding of NetApps.
- It shall store any relevant metadata regarding the limitations of each service with respect to NFVI, as well as include enforcement configurations (if any). It will hence support each VNF/CNF having isolated limitations like the infrastructures to run over, the minimum required slice or the location of the service workspace (*e.g.* address of docker registry, location of docker-compose, *etc.*).
- It will support information exchange with the NSBR by means of northbound interface operations exposing limitation of each NetApp with each site or NFVI, or at least include the available ones for each NetApp, along with enforcement configurations (if any) like the required minimum slice.

Figure 27 provides a macroscopic overview of the repository, and the impact that each action has in components and layers below.

3.5.4.12 Experiment coordinator (ExCoord)

Within the scope of the present document, the Experiment coordinator (ExCoord) encompasses all 5G-EPICENTRE facility functionality corresponding to experiment scheduling and production of the necessary experiment

[6] The interface split between the rest of the infrastructure and the repository could vary depending on the selected method, but it may well be reasonable to think that all the northbound interface is directly connected to the repository.

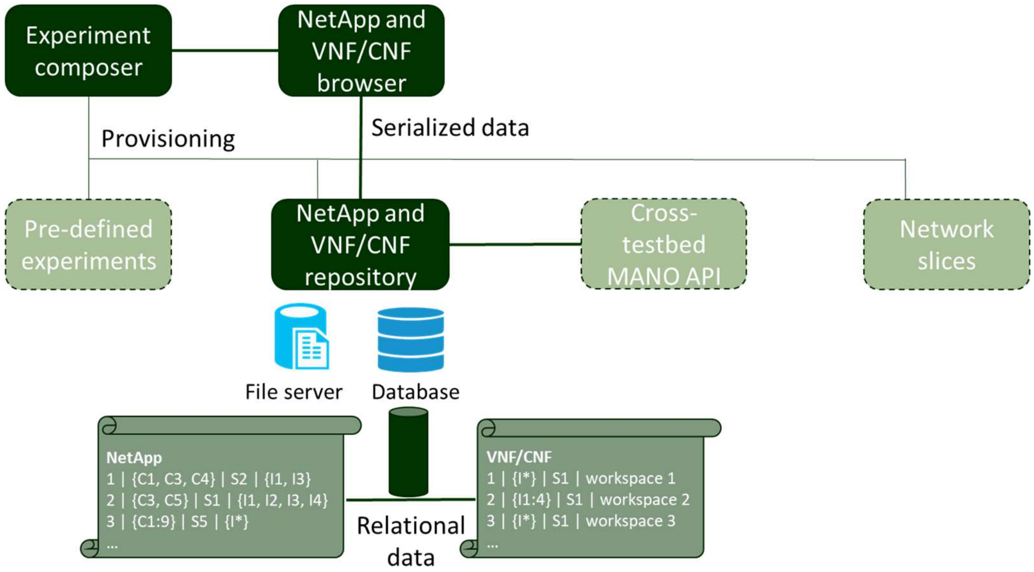

Figure 27: Back-end layer repository overview with example.

configuration files during experiment execution. Hence, the ExCoord is responsible for receiving experiment execution requests from the ExCom (which contain a description of the experiment's requirements and general configuration), and deliver commands and configurations for both the components of the Experiment Player, which are in charge of handling the fine-grained interactions with the testbed components below. Despite functioning as a singular application, ExCoord includes three functional sub-blocks assigned specific duties and internal features, as shown in Figure 28:

- Experiment Scheduler (ExSch).

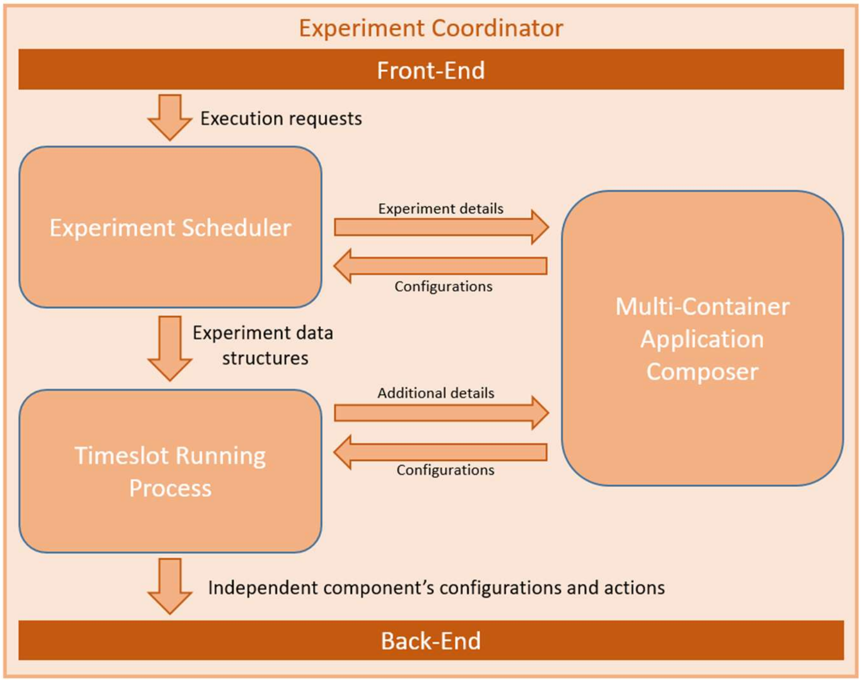

Figure 28: Experiment coordinator functional elements and interface concept.

- Timeslot Running Process (TRP).
- Multi-Container Application Composer (MCAC).

These functional elements reside within the same ExCoord application, and communication between them is foreseen to be facilitated through a shared memory space. However, each provides distinct capabilities and interfaces consumed by other 5G-EPICENTRE functional entities. The following list represents a non-exhaustive set of capabilities provided mapped onto each of the three identified functional entities of the ExCoord:

- Handling the reception of the experiment execution requests and creating the data entities required for managing the experiment life-cycle by means of the ExSch consuming the experiment execution requests from the Front-end Layer, containing an experiment descriptor template.
- Generating the configuration of the different components that are involved in the experiment execution as part of the functionality provisioned by the MCAC block.
- Overseeing the experiment execution as part of the functionality provided by the TRP block, initiating the different processes or experiment stages whenever required.

3.5.4.13 Cross-testbed VNF chain placement block (ctVNFCP)

The Cross-testbed VNF chain placement block (ctVNFCP) is responsible for the efficient offloading and redirection of traffic flows on VNF service chains (*i.e.*, the NetApps) between Cloud and edge resources available. It is divided into two components:

- The cross-testbed VNF chain placement manager (ctVNFCP-M) D located in the Back-end Layer (as part of the Experiment Player). Its main responsibility is to determine the appropriate testbed for the VNF chain placement.
- The cross-testbed VNF chain placement algorithm (ctVNFCP-A) is a functional block to be replicated inside each testbed facility at the Infrastructure Layer. Its main responsibility is to determine the specific VNF chain node placement selections for the VNFs instantiated in the referenced testbed infrastructure.

The following list represents a non-exhaustive set of capabilities provided by the ctVNFCP functional blocks elaborated above, exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities:

- Offloading and redirecting network traffic between the Cloud and edge resources available, with the intent to deliver significant improvements to the NetApp QoS/QoE. This will be accommodated by means of the dynamic re-calculation of optimal placement of the NetApp chain nodes to accommodate changing network dynamics and mobility support/ Functionality will be assigned to the ctVNFCP-A at the testbed level.
- It will efficiently manage and monitor the optimal placement of NetApp chain nodes for experiments spanning multiple testbeds by means of functionality provisioned by the ctVNFCP-M.
- It exposes appropriate interfaces toward 5G-EPICENTRE functional blocks and testbed entities to receive data on experiment execution and traffic/mobility simulation.

3.5.4.14 5G traffic simulation engine (5GTS)

5G Traffic simulator (5GTS) is responsible for handling the creation of artificial network traffic in order to simulate different 5G network conditions. It coordinates the work of multiple probes deployed in different parts of the testbeds[7], sending the required parameters to each probe in order to simulate different network conditions during the experiments. The concept is illustrated for clarity in Figure 29.

[7] These probes could be created specifically for the system, or be adapted based on existing tools (for example, by creating a wrapper that adds compatibility with the system). For the purpose of this document, these probes are considered part of the system.

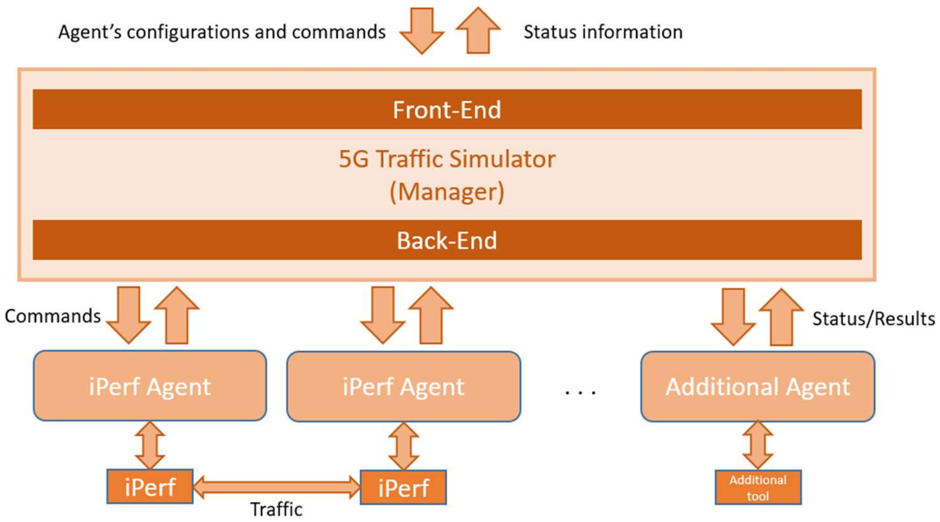

Figure 29: 5G traffic simulation engine functional elements and interface concept.

The following list represents a non-exhaustive set of capabilities provided by the 5GTS, exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities:

- It exposes a REST API that allows the configuration of the different network conditions. This API will be used by the Experiment Coordinator and/or Experiment Player during the execution of an experiment
- It concurrently manages and coordinates the usage of multiple agents (*e.g.*, iPerf) in separate points of the testbeds in the network, to generate the requested traffic conditions based on received configurations and commands.

3.5.4.15 Cross-testbed service/slice configurator (ctSSC)

The Cross-testbed slice monitor/configurator (ctSSC) component is responsible for coordinating the creation of slices in the different testbeds, while providing monitoring capabilities during the lifecycle of the slices. It is divided into two components:

- The cross-testbed manager (ctSSC-M) is a centralised functional block located in the Back-end Layer (as part of the Experiment Player). It is responsible for receiving instructions for the deployment of network slices in the different testbeds, and for providing a single endpoint from which the status of the slices can be monitored. It is further responsible for communicating with the Slice Manager Translator in each testbed.
- The Slice Manager Translators (ctSSC-T) are distributed functional blocks replicated for each testbed and thus are located in the Infrastructure Layer. They provide a translation layer that adapts the requests received from the ctSSC-M to the specific infrastructure in each testbed.

Figure 30 describes a common frame of reference for the internal architecture of the ctSSC.

The following list represents a non-exhaustive set of capabilities provided by the ctSSC functional blocks specified above, exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities:

- It consumes data related to slice deployment instructions and configurations via an exposed interface toward the functional blocks within the Experiment coordinator (at the start of the experiment lifecycle) or the other functional blocks within the Experiment player (during the experiment lifecycle).
- It forwards these requests to the Infrastructure Layer, generating the commands and settings required for deploying slices in each testbed's infrastructure and adapts the responses from the specific components in each particular testbed (by means of the functionality provided by the ctSSC-T).

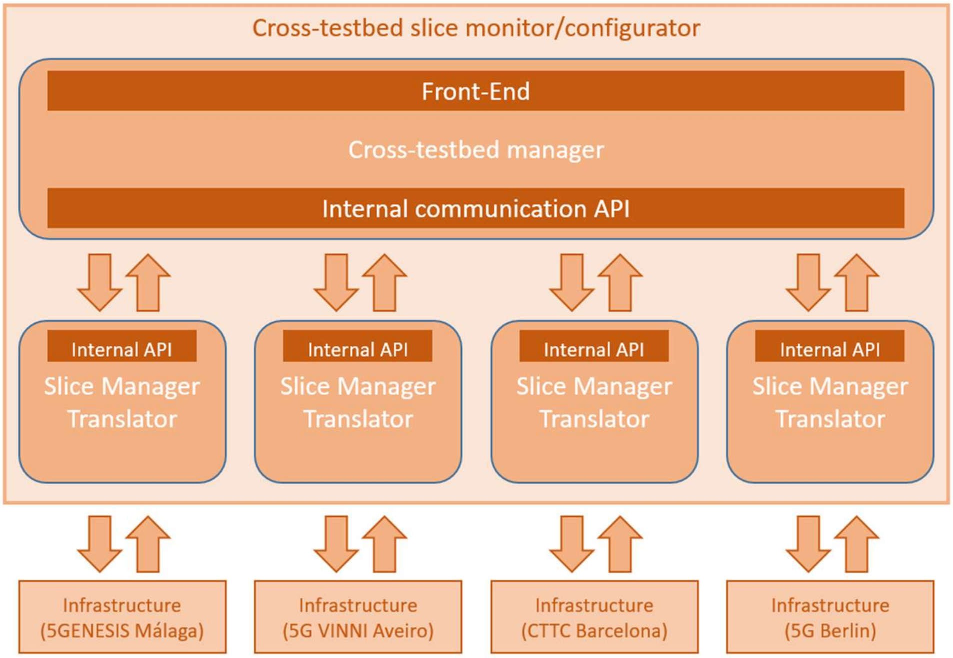

Figure 30: Cross-testbed service/slice configurator functional elements and interface concept.

- It utilises the responses from the testbed components in the ctSSC-M to concurrently manage the deployment and monitoring of multiple network slices.

3.5.4.16 Experiment player

Within the scope of the present document, the Experiment player encompasses all functional blocks that together provide functionality corresponding to the execution of an experiment (or concurrent experiments) from start to completion. It is thus comprised of the 5GTS, ctSSC-M and vnfCPM functional blocks described in Sections 3.5.4.14, 3.5.4.15 and 3.5.4.13 respectively.

3.5.4.17 Analytics aggregator (aggr)

The main responsibility of the Analytics aggregator (aggr) is to aggregate the analytics and performance data generated from the different testbeds in the Infrastructure Layer to the visualisation components residing in the Front-end layer. In more detail:

- it receives input data from the internal Analytics Engine modules installed at each individual testbed at the Infrastructure Layer and aggregates their information to produce accurate reports on network performance.
- it stores the data to make them available to the ITools in order to provide them for visualization.
- it notifies values corresponding to anomalous conditions or trends to the ITools components.

The following list expresses a non-exhaustive set of functions performed by the aggr, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- Measurements collection and notifications obtained from the KPI Monitor and QoS/QoE Monitor. To this end, the module exposes a "southbound analytics API" to facilitate the exchange of calculated measurement results coming from the underlying Infrastructure Layer.
- Forwarding of performance measurement results and faults/events information relative to virtualised resources to the ITools by means of northbound interface operations exposing a suitable API ("northbound analytics API").

3.5.4.18 Cross-testbed MANO API (ctMANO)

The cross-testbed MANO API (ctMANO) main responsibility is to expose common and standardized interfaces toward the other functional entities of the architecture so as to allow access to the facilities federated under 5G-EPICENTRE by wrapping different aspects of each individual testbed API under a unified information model. More specifically, the ctMANO handles responsibilities related to:

- allowing testbeds to federate without losing control of their individual resources or independence;
- enable the calibration of individual testbed components from a singular point of control;
- provision the capability to combine available resources to achieve different experimentation conditions of varying scale and diversity;
- ensure these configurations are easily repeatable by supporting reproducible experimentation conditions.

The following list expresses a non-exhaustive set of functions performed by the ctMANO, that are exposed by means of interfaces consumed by the other 5G-EPICENTRE functional entities.

- Forwarding NetApp and VNF descriptors onto the individual testbeds' NFV-MANO blocks to orchestrate services, facilitating a two-way communication with the experiment lifecycle components for monitoring and management.
- Forwarding slice creation information in order for the testbeds to orchestrate resources over the infrastructure layer, intelligently combining the underlying testbed hardware and software components to enable the creation of new, virtual components that provide enhanced capabilities for experimentation.
- Facilitating any communication needed between the functional blocks residing at the 5G-EPICENTRE facility framework and the distributed components replicated across the four testbed infrastructures.

3.5.4.19 Analytics driver (aDrv)

The Analytics driver (aDrv) is responsible for collecting information in the form of input data from the Infrastructure Layer (*e.g.*, the individual testbed 5G components as well as the augmented Cloud-native NFV-MANO functional block) and will pre-process the data in order to forward them to the other analytics engine components for Machine Learning (ML)-based analysis. These metrics could be related to network performance (*e.g.*, latency, usage, bandwidth, resource consumption), performance of container management actions (*e.g.*, service creation time) and to KPIs of the Experiments.

The following list expresses a non-exhaustive set of functions performed by the aDrv, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- Collection of measurement results coming from the individual testbed 5G components, VNF Chain Placement Algorithm and Cloud-Native NFV-MANO.
- Pre-processing of raw data for the components dealing with the extraction of network KPIs and aggregated measurements.

3.5.4.20 KPI monitor (kpiM)

The KPI Monitor (kpiM) has two main responsibilities:

- To continuously compute all prescribed experiment KPIs using data provided by the aDrv and forward output measurements on computed KPI values to the aggr component.
- To store computed values in order to track KPIs' evolution.

The following list presents a non-exhaustive set of functionalities provided by the kpiM, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- Analysis of input data from the infrastructure exposed by the Analytics Driver functional block in order to monitor metrics for experiment KPI validation, provided that such KPIs' requirements are listed in the VNF/CNF deployment template descriptor.
- Provide output data to the Analytics Aggregator by invoking a RESTful API provided by the latter, by means of the "Analytics Southbound API" exposed via the cross-testbed MANO API.

3.5.4.21 QoS/QoE monitor (qoseM)

The Quality of Service / Quality of Experience (QoS/QoE) Monitor (qoseM) functional block is bestowed the following responsibilities:

- It is responsible for continuously analysing the pre-processed data received from the aDrv with the primary aim being to perform anomaly detection.
- It has a responsibility to periodically perform in-depth analysis (*i.e.*, pattern discovery, clustering, *etc.*) in order to monitor the overall system performance.
- It is tasked with storing computed values in order to track QoS/QoE parameters evolution.
- It will forward relevant data to the Analytics Aggregator block, as well as notify any detected anomalies to that component.

The qoseM is comprised of ML components that will be trained on what constitutes 'normal' operation with one or multiple experiments running concurrently on the 5G-EPICENTRE platform. This will enable the system to flag conditions in which anomalies are detected.

The following list identifies a non-exhaustive set of capabilities provided by the qoseM, that can be exposed by means of interfaces consumed by other 5G-EPICENTRE functional entities.

- Analysis of input data from the infrastructure exposed by the Analytics Driver functional block in order to monitor metrics for end-to-end QoS and QoE KPIs, provided that such KPIs' requirements are listed in the VNF/CNF deployment template descriptor.
- Perform close to real-time analysis for the detection of anomalous situations, exposing the results corresponding to anomalous network conditions or trends (*e.g.*, via a notification template) towards the Analytics Aggregator, by invoking a RESTful API provided by the latter ("Analytics Southbound API") exposed via the cross-testbed MANO API.

3.5.4.22 5G-EPICENTRE analytics engine

Within the scope of the present document, the Analytics engine encompasses all Infrastructure Layer components (aDrv, kpiM, qoseM) that together provide functionality corresponding to determining proper or anomalous functioning of the network and container orchestration. Its main responsibility is to produce KPIs based on ML processing analysis. Hence, the 5G-EPICENTRE analytics engine should be installed at each site, containing all necessary components towards validating KPIs and assessing metrics related to the QoS and QoE, continuously analysing experiments' parameters to determine whether targets set by the experimenters are met. This functional block should support the 5G-EPICENTRE objective for retaining the functional independence of the platform it is installed on, and therefore should work with both raw data generated by the infrastructure, or other types of metrics exposed by onboarded monitoring platforms (such as *e.g.*, Prometheus[8]).

3.5.5 Information view

The architectural information view of 5G-EPICENTRE is derived from defining the necessary interconnections between the specified functional architecture components elaborated in the previous Section. The means by which these interrelationships will be addressed is with the use of reference points (RPs). RPs hence take the form of "placeholders" for identifying peer-to-peer relationships between the architectural functional blocks,

[8] https://prometheus.io/

which will provide guidance toward identifying standardized, or specifying new or extended interfaces to facilitate interaction between those components. Toward this end, the producer-consumer paradigm will be followed in which a functional block can be a producer of data, a consumer of data or both. In this way, a mapping of interfaces to 5G-EPICENTRE RA RPs can be drawn, in which the interface describes the functions a producer block in the RP exposes to a consumer block connected to that same RP.

Given the early incarnation of the 5G-EPICENTRE project, this Section of the current document aims at providing a description of the reference points (RPs) between the 5G-EPICENTRE functional blocks, as well as between the 5G-EPICENTRE functional blocks and components external to the specified reference architecture. Its aim is to describe the logical properties, leading to producer-consumer behaviours, rules and principles of the defined system that aim to clarify how the 5G-EPICENTRE platform behaves to deliver specific features of interest through the interconnection between its functional blocks.

An early specification of identified interfaces corresponding to the RPs defined in this Section will be elaborated as part of the integration planning activities reported in D4.1: *"Integration plan and framework"* due in M12. Updated versions of those interfaces will then be specified in the updated version of this deliverable (D1.4: *"Experimentation requirements and architecture specification final version"*), describing the final system architecture resulting from two years of project implementation and architecture refinement activities.

Figure 31 presents an overview of the 5G-EPICENTRE architectural framework specified in Section 3.5.1 with RPs that declare exchange of information between functional blocks within the architectural framework, as well as those between 5G-EPICENTRE components and potential external entities. The following paragraphs describe these RPs in terms of the producer-consumer exchanges they should facilitate.

3.5.5.1 Authm-Excom

This reference point represents data exchanges between the AuthM and ExCom functional blocks. It aims to support the following functions:

- User authorization/validation using authentication data with credentials (*e.g.*, access token) from the ExCom and the generation of an authentication response by the AuthM.
- User role and permission assignment evaluation during login transaction initiated by the ExCom.
- Enforcement of RBAC authorization policies for ExCom APIs, facilitating the permissions assigned to the user for those APIs.

3.5.5.2 Nsb-Excom

This reference point represents data exchanges between the NSBR and ExCom functional blocks. It is used for information retrieval about the available VNFs/CNFs and NetApps, along with all necessary metadata, in order for the experimenter to be able to configure the requested services and parameters of the NFs in the experiment/NetApp composition to later include those NFs in the experiment deployment process.

3.5.5.3 Excom-Exsch

This reference point represents data exchanges between the ExCom and ExSch functional blocks. It aims to support experiment execution requests from the ExCom, exposed via a RESTful API. More specifically, it should support the consumption of experiment parameters (in the form of an experiment descriptor) by the Experiment Scheduler functional block received via a POST request.

3.5.5.4 Nsrepo-Nsb

This reference point represents data exchanges between the NSRepo and NSBR functional blocks. It aims to support the following functions:

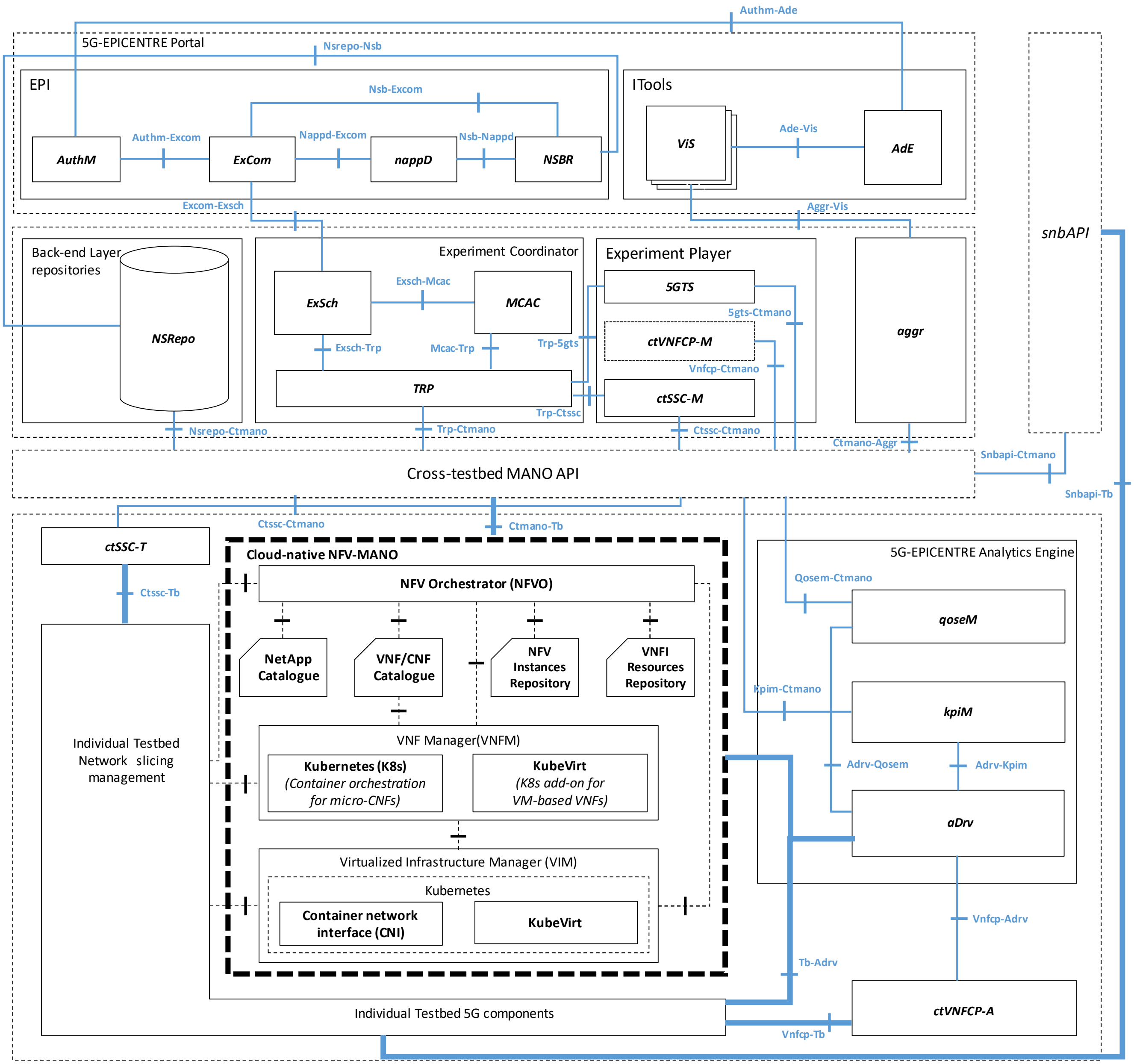

Figure 31: 5G-EPICENTRE architectural framework with reference points (in blue). RPs drawn in bold represent targets for further elaboration and development between existing, reusable testbed platform components and 5G-EPICENTRE functional blocks.

- Enabling the NSBR to request a list where all available VNFs/CNFs and/or NetApps for end-users are recorded from the NSRepo, and receive the list in a serialized format. It should support message exchange of database query responses as serialized files, triggered by VNF/CNF queries incoming from the vcnfB, and providing a serialized file with query response.
- VNF/CNF modification data (*e.g.*, updated VNFs and CNFs that are available in the 5G-EPICENTRE platforms) toward applying specified modification for a VNF/CNF entry in the repository.

3.5.5.5 Nsb-Nappd

This reference point represents data exchanges between the NSBR and nappD functional blocks. It is used for the retrieval of available data about the CNFs and VNFs from the NSBR to the nappD for prototyping of custom NetApps using chain nodes from those VNF/CNF elements.

3.5.5.6 Nappd-Excom

This reference point represents data exchanges between the Nappd and Excom functional blocks. It is used for information retrieval about the selected VNFs/CNFs in the NetApp chain, along with all necessary metadata, in order to define the experiment descriptor for onboarding and validating the custom NetApp by orchestrating the necessary NFs and slice resources during the experiment deployment process.

3.5.5.7 Authm-Ade

This reference point represents data exchanges between the AuthM and AdE functional blocks. It aims to support the following functions:

- User authorization/validation using authentication data with credentials (*e.g.*, access token) from the AdE and the generation of an authentication response by the AuthM.
- User role and permission assignment evaluation during login transaction initiated by the AdE.
- Enforcement of RBAC authorization policies for AdE APIs, facilitating the permissions assigned to the user for those APIs.
- Exposure of user profile and preferences data associated with the user token from the AuthM for the configuration of the visualisation output controlled by the AdE in accordance to the user-specific parameters.

3.5.5.8 Ade-Vis

This reference point represents data exchanges between the AdE and ViS functional blocks. It is used for personalised orchestration of the information flow during visualisation of experiments' outputs, taking into consideration user specificities, context, and preferences.

3.5.5.9 Snbapi-Ctmano

This reference point represents data exchanges between the snbAPI and ctMANO functional blocks. It is used for enabling end-user applications to directly expose their needs and requirements to the 5G-EPICENTRE testbeds in the event more than one platforms are involved in the execution of an application test.

3.5.5.10 Snbapi-Tb

This reference point represents data exchanges between the snbAPI and individual networking and NFV-MANO components in the 5G-EPICENTRE augmented testbed platforms. It is used for enabling end-user applications to directly expose their needs and requirements to a single (specified) 5G-EPICENTRE testbed in the event a single platform suffices for the execution of an application test.

3.5.5.11 Nsrepo-Ctmano

This reference point represents data exchanges between the NSRepo and ctMANO functional blocks. It is used to facilitate a southbound interface between the VNF/CNFs in the repository and a VNF Manager on the cloud-native NFV-MANO block on one or more 5G-EPICENTRE augmented testbed platforms.

3.5.5.12 Exsch-Trp

This reference point represents data exchanges between the ExSch and Trp functional blocks. It aims to support exchange of experiment data and structures from the ExSch to the TRP.

3.5.5.13 Exsch-Mcac

This reference point represents data exchanges between the ExSch and MCAC functional blocks. It aims to support exchange of experiment details and configurations between the two components.

3.5.5.14 Mcac-Trp

This reference point represents data exchanges between the Trp and Mcac functional blocks. It aims to support the following functions:

- Forwarding of details during runtime of the experiment from the TRP toward the MCAC toward the configuration of additional components in the testbeds (if needed).
- Delivery of the general configuration of underlying components and actions from the MCAC toward the TRP, which translate to Commands and configurations for the components of the Experiment Player and the underlying testbeds

3.5.5.15 Trp-Ctmano

This reference point represents data exchanges between the TRP and ctMANO functional blocks. It is used for forwarding the Kubernetes configuration to be sent to the Cloud-native NFV-MANO block in each individual testbed platform for the execution of an experiment.

3.5.5.16 Trp-5gts

This reference point represents data exchanges between the TRP and 5GTS functional blocks. It aims to support the following functions:

- It is used for forwarding commands and configurations established in the ExCoord toward the Experiment Player for controlling the 5G traffic simulation agents through a management interface.
- Deliver status information back to the TRP for experiment lifecycle management.

3.5.5.17 Trp-Ctssc

This reference point represents data exchanges between the TRP and ctSSC-M functional blocks in the Back-end Layer. It is used for forwarding commands and configurations established in the ExCoord toward the Experiment Player for 5G slice configuration, to allow the system to be able to coordinate the parallel execution of multiple experiments in the different testbeds.

3.5.5.18 5gts-Ctmano

This reference point represents data exchanges between the 5GTS and multiple probes deployed in different parts of the testbeds to simulate the network traffic condition based on received configurations. This is implemented by means of the ctMANO functional block. It aims to support the following functions:

- Configuration of the traffic measurements to be generated by the different agents.
- Communication of the current status of the agents

3.5.5.19 Ctssc-Ctmano

This reference point represents data exchanges between the ctSSC (both –M/-T blocks) and the ctMANO functional blocks. It aims to facilitate exchange between the ctSSC-M and ctSSC-T via the ctMANO on slice deployment instructions and configurations via an exposed REST API. More specifically, it aims to support the ctSSC-M in providing status reports for each deployed slice.

3.5.5.20 Ctssc-Tb

This reference point represents data exchanges between the ctSSC-T and specific components in each particular testbed. It aims to support the ctSSC-T generating the commands and settings required for deploying slices in each testbed's infrastructure.

3.5.5.21 Vnfcp-Ctmano

This reference point represents data exchanges between the ctVNFCP-M and ctVNFCP-A through the ctMANO functional block. It aims to support the ctVNFCP-M generating the commands required establishing re-deployment of NetApp chain nodes in the ctVNFCP-A.

3.5.5.22 Aggr-Vis

This reference point represents data exchanges between the aggr and ViS functional blocks. It is used for provision of aggregated data to the ITools functional blocks comprising the ViSs. The dedicated interface will be implemented as a REST API implementing an analytics northbound API, which will expose a JSON payload for forwarding notifications on KPI and QoS/QoE values corresponding to anomalous conditions or trends as JSON objects.

3.5.5.23 Ctmano-Tb

This reference point represents data exchanges between the ctMANO and individual networking and NFV-MANO components in the 5G-EPICENTRE augmented testbed platforms. It aims to support the following functions:

- Provision of slice creation data to the designated testbed regarding an experiment's execution requirements.
- Provide NetApp and VNF descriptors generated from the NSRepo to the NFV-MANO VNFM block in each testbed.

3.5.5.24 Ctmano-Aggr

This reference point represents data exchanges between the ctMANO and aggr functional blocks. It aims to support an analytics southbound API that enables the aggr to receive data from the KPI Monitor and QoS/QoE Monitor functional blocks running on each individual testbed, with the purpose to provide the computed KPIs and QoS/QoE parameters via a JSON payload.

3.5.5.25 Tb-Adrv

This reference point represents data exchanges between individual networking and NFV-MANO components and the aDrv installed in the 5G-EPICENTRE augmented testbed platforms. It aims to support a communication interface of the aDrv with the individual testbed 5G components via an asynchronous message queue (*e.g.*, AMQP or similar), supporting (raw) data coming from the TB networking components (*e.g.* slice manager) and cloud-native NFV-MANO block.

3.5.5.26 Vnfcp-Adrv

This reference point represents data exchanges between the vnfCP and aDrv functional blocks installed in the 5G-EPICENTRE augmented testbed platforms. It aims to support a communication interface between the VNF Chain Placement algorithm and the aDrv functional block via an asynchronous message queue (*e.g.*, AMQP or similar) supporting dynamic re-localisation of VNFs in response to varying network traffic dynamics and user mobility at the Cloud and MEC resources, toward calculating improvements delivered in the QoS and QoE.

3.5.5.27 Adrv-Kpim

This reference point represents data exchanges between the aDrv and kpiM functional blocks installed in the 5G-EPICENTRE augmented testbed platforms. It aims to support a communication interface between the KPI monitor and the aDrv functional block via an asynchronous message queue (*e.g.*, AMQP or similar) to capacitate the former to compute KPI values starting from input data coming from the latter in the form of JSON objects.

3.5.5.28 Adrv-Qosem

This reference point represents data exchanges between the aDrv and qoseM functional blocks installed in the 5G-EPICENTRE augmented testbed platforms. It aims to support a communication interface between the QoS/QoE monitor and the aDrv functional block via an asynchronous message queue (*e.g.*, AMQP or similar) to capacitate the former analyse input parameters coming from the latter in the form of JSON objects.

3.5.5.29 Kpim-Ctmano

This reference point represents data exchanges between the kpiM and ctMANO functional blocks. It is used for the provision of output data from an individual instance of the KPI Monitor installed in any one of the 5G-EPICENTRE augmented testbed platforms to the Analytics Aggregator (centralized instance of the functional block inside the 5G-EPICENTRE facility framework), invoking the REST API provided by the Analytics Aggregator (Ctmano-Aggr, Section 3.5.5.24).

3.5.5.30 Qosem-Ctmano

This reference point represents data exchanges between the qoseM and ctMANO functional blocks. It is used for the provision of output data from an individual instance of the QoS/QoE Monitor installed in any one of the 5G-EPICENTRE augmented testbed platforms to the Analytics Aggregator (centralized instance of the functional block inside the 5G-EPICENTRE facility framework), invoking the REST API provided by the Analytics Aggregator (Ctmano-Aggr, Section 3.5.5.24).

3.5.5.31 Vnfcp-Tb

This reference point represents data exchanges between individual networking and NFV-MANO components and the vnfCP functional block installed in the 5G-EPICENTRE augmented testbed platforms. It is used for collecting information on the parameters of the experiment and use of network resources, needed to re-evaluate placement of NFs between the Cloud and MEC resources available.

3.5.6 Deployment view

The 5G-EPICENTRE architecture deployment view is used to define the physical environment for the deployment of the system across virtual and real machines (processing nodes, each with a list of hardware requirements, dependencies and constraints), as well as any runtime dependencies. Its goal is to define:

- what hardware/physical components will be used to execute the software;
- where those hardware components will be deployed;
- how and why to assign each software block to a hardware element;

Hence, the deployment view is meant to describe how the 5G-EPICENTRE software will be deployed into the available hardware, and how it will interact with that hardware to deliver the platform's functionality. For illustrative purposes, it will be elaborated by means of a deployment diagram.

Given the early stage in the development of the 5G-EPICENTRE experimental facility, deployment considerations will be elaborated in the updated version of this deliverable (D1.4, M24), where the entirety of nodes and artefacts (*e.g.*, executables, libraries, scripts, *etc.*) participating in the final execution of the system will be specified in detail.

3.5.7 Security and privacy framework

The 'Holistic Security and Privacy Framework' caters to the security requirements of the entire architecture from top to bottom, thus following a holistic approach. At the top, it features the Northbound Security solutions, which deal with issues such as access control via Single sign-on, credential authentication mechanisms and malicious intent detection (*i.e.* use of ML to detect if an API request contains a cybersecurity at-tack/injection). At the Back-end, DevOps Security solutions are deployed, aimed at protecting the underlying host OS that runs containers and functions against malicious escape and breakout attempts into other targets on the same host, or on the shared infrastructure, achieved by means of VM-level Container Isolation. Further, this Security Layer implements functions for overload prevention and management beyond resource virtualization, to be aware of and adapt to real resource limitations, as well as deal with protective mechanisms pertaining to i) traffic encryption, to protect sensitive/confidential information, such as *e.g.* police and/or patient data; and ii) mobility management, to track highly mobile network users and allow networking services to be available to them on the move. The Southbound Security solutions involve the protection of the physical hardware and communications by means of: i) vulnerability scanning, to identify, classify, prioritize, remediate, and mitigate exploitable weaknesses (such as *e.g.* open ports); and breach mitigation and response, to defend against internal and external leaks (*e.g.* Ransomware). The final security layer aims to protect the 5G testbed Infrastructure itself, and encapsulates all of security protocols, software and storage implementations.

The proposed security and privacy framework is composed of three key elements: a security engine, a policy engine, and an AI engine. The security engine encapsulates all the security protocols, software, and storage implementations for the different layers of the architecture, including mechanisms for protecting the physical hardware and communications, vulnerability scanning and breach mitigation response. The policy engine centralizes the configuration of the policies enforced at the network and container levels. Finally, an AI engine will be researched to assist with security and policy enforcement. For instance, it will help to identify anomalous streams based on the observability of the network traffic and support the corresponding enforcement of automated response policies and actions.

At the same time, a cloud-native framework approach aims to support data observability and traffic filtering by enforcing different types of policies at the application and network levels. To accomplish that goal, this approach includes the usage of security by design techniques, as well as network and container-level isolation strategies and a service mesh design pattern at the core of the security framework. These elements, when combined, become key elements to secure the overall infrastructure and properly monitor, mitigate, and respond to security incidents.

4 Conclusions

This document outlined two main contributions from 5G-EPICENTRE WP1 Tasks 1.2 and 1.3. The first one concerns the requirements elicitation process and analysis, which has led to a first break-down of the 5G-EPICENTRE experimentation facility functional and non-functional requirements from a system-level perspective. The second concerns the specification of the first version of the 5G-EPICENTRE platform architecture, complete with a description of the design process followed by the architecture specification team. The final version of these findings will be included in the updated version of this document due M24 (D1.4).

In order to define the version of the architecture specified in this document, a phased approach was followed in which technology exploration (*e.g.*, the collection of information from relevant projects) and surveying of relevant standards (particularly to identify implications of the cloud-native approach proposed by 5G-EPICENTRE onto the NFV-MANO blocks specified in the ETSI documentation) play a significant role in the architecture design steps. Hence, a number of components and subcomponents, belonging to the set of partners' assets, were identified and considered necessary for the 5G-EPICENTRE platform. In addition, missing components and corresponding functionalities were identified as well. Each partner presented their functional blocks' role, capabilities, and whenever necessary, their internal architecture, functionalities, and interaction with other main components. Following this approach, the 5G-EPICENTRE architecture was defined and documented. Three different views are targeted, namely, functional, information and deployment view, with the latter being introduced in this document to take deployment aspects into consideration at an early stage in the project. The full deployment consideration however will be outlined in the updated version of this deliverable to be published with D1.4 "Experimentation requirements and architecture specification final version".

This first version of the architecture was defined in the period M1-M6. In particular, the overall architecture was carefully reviewed by taking into account inputs from the technical work packages (*i.e.*, WP2, WP3 and WP4), the requirements from T1.2 (available in Section 2 of this document) and the use cases (UCs) from T1.1 (available at in D1.1). The updated version of this document will contain a revision of components descriptions as well as an update of the overall architectural viewpoints (Functional Viewpoint, Deployment viewpoint and Information viewpoint).

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Annex I: Electronic survey – Questionnaire

5G-EPICENTRE Requirements Questionnaire (T1.2)

Fields marked with * are mandatory.

1 Informed consent

Key contact details:
ELLINIKI ETAIRIA TILEPIKOINONION KAI TILEMATIKON EFARMOGON AE (FORTHNET)

Survey coordinator / contact details:
Dr Ioannis Markopoulos, Head Innovation & Project Management Department, Tel. +302106602104, email: jmarkopo@forthnet.gr

Key information about the Project:
Project Coordinator: AIRBUS DS SLC
Funding Program: Horizon 2020
Website and contacts: https://www.5gepicentre.eu/. info@5gepicentre.eu

Description of the research project

LTE-Advanced systems and 5G are key technologies for future mission-critical public protection and disaster relief (PPDR) services. Contributing to this field, as well as lowering barriers to 5G adoption, the EU-funded 5G-EPICENTRE project will develop based on a Service oriented Architecture, following the current best DevOps practices (containerization of micro-services), an open, end-t-end, experimentation 5G platform that focuses on software solutions that serve the needs of PPDR. It aims at facilitating adoption of current services to capitalize on 5G networks advanced capabilities as well as to provide a solid ground for the proliferation of such services. The project will pave the way providing concrete experiments and libraries of PPDR oriented VNF chains and Netapps. Through this platform, SMEs and developers will be able to learn about the latest 5G applications and approaches for first responders and crisis management and build up and experiment with their solutions. 5G-EPICENTRE aims at establishing an environment that bridges the development and operation worlds for PPDR services capitalising on current and upcoming 5G network opportunities.

The project lasts three years (running from January 2021 to December 2023) and is funded by the European Commisiion (contract no. 101016521), within the context of the Horizon 2020 programme.

The project partners are:

- AIRBUS DS SLC
- ELLINIKI ETAIRIA TILEPIKOINONION KAI TILEMATIKON EFARMOGON AE
- ALTICE LABS SA
- FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
- IDRYMA TECHNOLOGIAS KAI EREVNAS
- UNIVERSIDAD DE MALAGA
- CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA
- ISTELLA SPA
- ONESOURCE CONSULATORIA INFORMATICA LDA
- IQUADRAT INFORMATICA SL
- NEMERGENT SOLUTIONS S.L.
- EBOS TECHNOLOGIES LIMITED
- ATHONET SRL
- REDZINC SERVICES LIMITED
- OPTOPRECISION GMBH
- YOUBIQUO SRL
- ORAMAVR SA

Purpose of the study and of data collection:
This study aims at collecting the views, requirements, comments, and proposals of participants with regard to 5G-EPICENTRE platform in order to obtain information on useful features from a sufficient sample of potential platform end-users (in this case, the SMEs and PPDR service providers).

Personal data:
Your identity data (full name, contact details) will not be collected for the purposes of the study.

Data processing / confidentiality:
In the context of the study, only the personal data that is absolutely necessary for conducting the relevant research will be collected and processed through the "pseudonymization" process. Your participation in this study will remain confidential and your identity will not be stored by any means along with your replies or screenshot data. Your personal data will receive a code number and the digital list linking your name to that number will be stored in a secure, locked digital file. When the data is used, your name will not be displayed under any circumstances. The participants' data are protected and kept safe throughout the Project. After the completion of the Project, the list linking your name to the code number of your data will be deleted. The data processing and analysis will be carried out by the processing coordinator of this study as well as by processing coordinators of the partners. The results of the study may be published in scientific journals and conferences in an anonymous form.

Participation (benefits / motives):
Your participation in the present study is on voluntary basis. No financial reimbursement is provided for the participation in the present study.

Right to refuse or withdraw:
As participants volunteering in the study, you are free at any time and until the end of the study to refuse to participate, or withdraw your participation / consent for the data collected in the study. There are no risks of adverse consequences for withdrawing participation and you do not need to justify your decision. In this case your personal data will be destroyed.

You can withdraw your consent to this study at any time, in writing to Dr Ioannis Markopoulos (see contact details at the beginning of this document).

Use of your views in other research activities:
Following the analysis of your views, your views might be included in a piece of work submitted to the European Commission and scientific research papers. These results will be anonymized and will therefore not include your name. Any of these data that are not used in the reporting of results will be destroyed when they are no longer needed, and, in any case, five years after the end of the project in order to be able to fulfil reporting obligations to the European Commission (whichever is sooner).

Potential risks:
The 5G-EPICENTRE consortium foresees no physical or psychological risks which could materialise from your participation in this research activity.
You will not be pressured or coerced into participating in this research activity. You are free to leave at any point, with no negative consequences.

Applicable regulations:
The protection of natural persons in relation to the processing of personal data is a fundamental right. The law provides specific rights for natural persons (data subjects) and sets specific obligations for those who keep and process such data (controllers). All applicable EU and national legal frameworks and guidelines on the protection of personal data, as derived from the application of the "General Data Protection Regulation (EU 679/2016)", are being considered in this study.

Rights of participants:
In accordance with principles of research ethics and EU data protection regulations, you have rights regarding how your personal data is processed.

You have the right to be informed about your personal data collected in and for the purposes of this study and to have access to them, and the right for these data to be in a portable and easily accessible form. You also have the right to request that your personal data be corrected, updated or deleted, the right to have the processing restricted, and the right to object, with the reservation of any exceptions provided for in existing European and national legislation. We acknowledge also to you, that in accordance with the aforementioned Regulation, you have the right to file a complaint to the corresponding national Data Protection Authority (complaints@dpa.gr).

We aim to fulfil all requests. In accordance with data protection legislation, some requests may be rejected.

Who to contact if you have questions or you want to exercise your rights.

In order to exercise your rights or you have any questions, as far as this study is concerned, you may contact Dr Ioannis Markopoulos (jmarkop@forthnet.gr) or send your requests at DPO@forthnet.gr

Informed Consent:
By submitting this form you hereby declare that:

You agree to participate in this study, in the context of the Project 5G-EPICENTRE – “5G ExPerimentation Infrastructure hosting Cloud-nativE Netapps for public protection and disaster RElief”.

You have been explained in writing through this information sheet: the purpose of the study, the respective activities and your rights. you are participating voluntarily and understand that you can withdraw from the research activities without repercussions, at any time by the end of the study, and have your data deleted. you are satisfied that the assurances of responsible and strict data governance, given by the 5G-EPICENTRE project, will be upheld. you understand that your personal data are kept and treated as confidential as far as this research program is concerned. you know and understand that your personal data will be kept in a secure environment and that the data controller, as well as any data processors, will take all the necessary and appropriate measures to protect the security, and in particular the confidentiality and integrity, of personal data, according to data protection legislation and the relevant guidelines. You agree with the publication of the results of this study in anonymous form and with the publication of selected screenshots for the promotion of the study in mass media, and / or scientific publications aimed at informing the public and / or the scientific community.

Consent to participate:

- Yes
- No

2 Questionnaire

1.1 Name of your organisation:

1.2 Please specify your sector

- Public: (*e.g.* public service with PPDR services' needs)
- Private: (*e.g.* 5G Operator, PPDR services implementer, experimentation facilities providers, *etc.*)
- Academic
- Regulatory
- Other

1.3 If other, please specify:

1.4 Please indicate the approx. size of your organization (no of employees):

- 1-50
- 51-250
- 251-1000
- more than 1001

1.5 Which is the main country of your current workplace?

1.6 Which of the following roles describes you best (multiple answers allowed)?

- Business
- Strategy
- Technical
- Domain Expert

1.7 Please describe the role of your organisation (multiple answers allowed)

- PPDR service buyer
- PPDR service user
- Application/service provider
- Telecommunications network operator
- Standardisation body/regulator
- Other

1.8 If other please specify:

1.9 Please indicate your management level (multiple answers allowed)

- Executive officer (*i.e.* CEO, CTO, CFO, COO *etc.*)
- Operating officer (*i.e.* General manager, Plant manager, Regional manager, and Divisional manager *etc.*)
- Administrative officer (*i.e.* Office manager, Shift supervisor, Department manager, Foreperson, Crew leader, Store manager, Project leader *etc.*)
- Professor
- Engineer
- Researcher
- Other

1.10 If other please specify:

1.11 Please indicate your years of business experience

- None
- Less than 2 years
- 2 to 5 years

- 5 to 10 years
- 10 to 20 years
- 20+ years

1.12 If other please specify:

1.13 Are PPDR services limited by current networks/solutions? (1: totally disagree, 5: totally agree)

1.14 Please explain which KPIs/PPDR service aspects are limited by current networks

1.15 Do you currently test the PPDR services you develop/procure in operational environments/experimentation facilities? (1: totally disagree, 5: totally agree)

1.16 Please explain your domain of PPDR services focus (Law enforcement, Emergency Medical Services, Command & Control, *etc.*)

1.17 Please explain the benefits of using the 5G-EPICENTRE experimentation facility (multiple answers allowed):

- Test KPIs
- Test performance in near operational environment Test compliance to standards
- Test performance in extreme conditions (simulated)
- Collaborate with other providers to create a value chain (*e.g.* VNF implementers, application implementers, equipment providers, *etc.*)
- Provide the ability to the end user to run their tests
- Provide the ability to the operators to test onboarding/operating of the service
- Provide the ability to define the business collaboration model between the involved parties
- Other

1.18 If other please specify:

1.19 Please describe the functions that the experimentation facility should provide (multiple answers are allowed):

- Friendly user interface guiding to perform test cycle processes
- Service onboarding/parametrisation functionality
- VNF/Netapps repository and ability to use
- Other services repository and ability to use
- Network resources repository and ability to use
- Slices parameters definition
- Ability to test in various 5G releases
- Ability to define test cases and KPIs
- Traffic generator
- Visualisation of KPIs measure and automated analysis vs required performance/advanced reporting
- Standards compliance inspection
- Security inspection and security breach test
- Interference inspection
- Simulate extreme operation condition (physical and digital)
- Scaling ability inspection
- Service setup latency
- Other

1.20 If other please specify:

1.21 Please describe the services that the experimentation facility should provide (billing, scheduling, training, *etc.*):

1.22 Please describe what the experimentation facility should avoid:

1.23 Should the experimentation facility support cross-domain experiments?

- Yes
- No
- Don't know

1.24 What are your expectations regarding network slices' configuration during setup phase (*e.g.*, regarding maximum uplink/downlink capacity, prioritisation of flows, security schemes)?

- Don't mind, 5G-EPICENTRE experts should perform network slice configuration
- Need to be able to fine tune parts of the network slice by invoking appropriate NETAPPs (*e.g.*, for RAN, Core Network, *etc.*)
- Need to be able to manage the lifecycle of the involved VNFs and fine tune their operation
- Need to be able to manage the virtual machines hosting the VNFs, as well as manage and fine tune these VNFs
- Don't know

1.25 How do you envisage the reservation of experimentation facilities' resources for conducting iterations of experiments over time?

- ○ Online tools for resource booking should be provided by each experimentation facility infrastructure
- ○ Online tools for resource booking should be provided by 5G-EPICENTRE portal as a "one-stop-shop" for all experimentation facilities
- ○ Resource booking should be done offline by contacting the individual experimentation facilities' administrators
- ○ Don't know

1.26 How do you expect the 5G-EPICENTRE experimentation facility infrastructure to support the analysis of results from experiments?

- ○ No tools are expected from the experimentation facility for analysing the required data of the experiments' results
- ○ Standard 5G-EPICENTRE reports should be created
- ○ Custom reports should be supported by 5G-EPICENTRE
- ○ Don't know

1.27 What are your expectations regarding security schemes at run-time?

- ○ Don't mind, 5G-EPICENTRE experts should manage security schemes
- ○ Need to be able to define standards security schemes
- ○ Need to be able to customize security schemes
- ○ Don't know

1.28 What are your expectations regarding cross-layer privacy framework?

- ○ Don't mind, 5G-EPICENTRE experts should manage cross-layer privacy framework
- ○ Need to be able to configure cross-layer privacy framework
- ○ Don't know

1.29 Please describe your use case:

1.30 Please describe the experimentation facility usage business & remuneration model:

1.31 Would you like us to contact you to further discuss your view on the experimentation facility?

- Yes
- No

1.32 If yes please provide the following details: name, tiltle, organisation, prefered contact details (tel./email/skype, *etc.*):

Annex II: Interviews guidelines

The interview should be structured around the same questions we had in the questionnaire but we have to have an open discussion trying to deep dive into the interviewee answers by requesting clarifications or examples when he/she responses for a company process, data exchange, applications needed, *etc.*

We would like to find what could make organizations use the 5G-EPICENTRE experimentation facility and which the key functionalities that the experimentation facility should have are.

At the end of the day, we would like to find out the reasons that could drive organizations and employees within these organizations, making the 5G-EPICENTRE part of their everyday business like being yet another utility.

The proposed duration of each interview is approximately 30 minutes.

Annex III: Interviews

In the following the interviews' summaries and related information reside:

Interview 1

Affiliation: Network Operator (manager with 20+ experience in PPDR service provision)

Key comments:

During the completion of the 5G-EPICENTRE survey/interview from the Network Operator, the interviewer recorded the following comments of the interviewee.

1. During the last 20 years or so, PPDR Services are offered through networks based on the ETSI Standard TETRA or through competing systems TETRAPOL (France) and P25 (USA). Such digital systems are used in public safety, emergency medical services (ex, ambulances), transportation (airports, METRO, highways, railways), refineries, mining sites, *etc.* The main service offered is PTT Voice Group calls with central dispatching. **It is imperative that any new system for PPDR services should match the reliability and the availability of PTT service in these systems currently in operation.**

2. **The availability** in the current systems like TETRA is assured by deploying autonomous networks, completely independent from 2G/3G/4G mobile networks that may overload and fail during emergencies and natural catastrophes. In new 4G/5G networks, the service availability should take advantage of novel implementations for call prioritization and network slicing.

3. **Till now, the service reliability** in efforts to provide PTT through 4G networks is extremely limited and typically inappropriate for PPDR service providers. This conclusion stems after we have tested PTT transmission through "best effort" grade service (for instance, in the MOTOROLA WAVE network platform). The latency levels in the current mobile telecom networks is also a problem.

4. Besides voice, the next big interest from PPDR service providers **seems to be Push-to-Video**, especially between a first responder (or a talk-group member in distress) and a dispatcher. This is where the bandwidth of a 5G network would be at hand.

5. We realize that a 5G network implementation for PPDR could offer cross domain communications. However, at a business level, that would demand complex deals among large Network Operators, which would only proceed if they were technically well-defined in the Standard and required by a National Regulator.

Interview 2

Affiliation: IoT company (CTO, with 20+ experience in the telecommunications sector)

Key comments:

During the completion of the 5G-EPICENTRE survey/interview from a Greek IoT Company, the interviewer recorded the following comments of the interviewee.

1. The current status in the IoT market is dominated by LPWAN technology systems operating in the ISM unlicenced frequency band. The technologies utilized are LoRa & LoRaWAN (mainly), as well as SigFox, UNB, *etc.* Specially, LoRa has developed an extensive ecosystem of low-power sensors and APPs. The emerging 5G technologies are expected to broaden the market, with products that will take advantage *of low latency and high bandwidth characteristics*. However, there is still a long way to go. New zones for 5G IoT devices are being allocated by the Regulators worldwide, to facilitate wave propagation in robust networks. Operation in that 5G frequency zones, in addition to the use of a 5G Operator core and RAN resources, will introduce extra costs to IoT implementations. Last but not least, a novel ecosystem with new 5G devices is still to evolve.

   Following the above, an SME considers that a platform for testing, like the 5G-EPICENTRE, may play a significant role **in accelerating the development of such 5G ecosystem, allowing developers to evaluate new APPs (relative to performance indicators and resource utilization) in a controlled experimental environment that complies with the latest 5G Standard.**

2. The business model for the 5G-EPICENTRE usage should take into account the size of the experimenter company. It is advantageous for all stakeholders to flexibly allow SMEs to experiment with novel APPs and devices, so that the 5G ecosystem grows. During an introductory phase, using a few resources in the platform could be relatively cheap or even free of charge. A subscription could be more appropriate once a firm demands facility usage above a certain level or for an extended period of time.

3. On a technical note, the interviewee mentioned that PPDR services, as well as APPs for the public sector and/or public safety, typically involve sensitive user information data. As AI software gradually takes over certain operations of the management layer mixing them to those in the control layer, it is imperative that a platform like 5G-EPICENTRE assures cross-layer privacy. In fact, it would make a very strong argument for a tested PPDR service, if the platform could provide the appropriate framework, and then assess and prepare clear reports for the experimenter SME on the issue.

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Interview 3

Affiliation: Network Operator/Cloud Services Operator (more than 20 year experience)

Key comments:

During the completion of the 5G-EPICENTRE survey/interview from the Network Operator/Cloud Services Operator, the interviewer recorded the following comments of the interviewee.

> As Cloud Services Operator the aim is to deploy Value Add services in order to augment the ecosystem and identify new revenues stream.
>
> A testbed like 5G-EPICENTRE's is envisaged that it will offer services to:
>
> - SMEs to deploy and test services
> - SMEs to collaborate in order to chain their services to provide greater end to end functionalities
> - Network Operators to test services performance, compliance to standards, *etc.*
> - Standardization bodies

Such a testbed should:

- Provide adequate network abstraction policies, alternatives, *etc.*
- A user friendly user portal for all stakeholders
- A VNF/NETApp library.
- Federation with other testbeds especially on the VNF/NETApp library level can be considered as a plus
- Tools to define the end to end experiment lifecycle according to the test owner needs (test scheduling, resources allocation, KPIs measurement, analysis of results, identification of problematic areas, reporting, billing, *etc.*).
- The admin interface is significant as well
- Security, IPR protection and GDPR compliance are significant issue
- AI should be considered in the results analysis
- Traffic generators and PPDR oriented scenarios simulation should be included in the testbed as well.

Interview 4

Affiliation: VR Medical Education R&D Researcher

Key comments:

The following comments come from an R&D researcher, specializing in VR medical Education, from a Greek company.

The current state and usage of PPDR services is quite limited, especially in Greece, mainly due to the low network coverage and the lack of cloud and edge servers that are geographically close. If one had to use a server located in USA, for example, or in a remote place in Europe, there would be a dramatic decrease of the Quality of Experience or even inability to properly provide PPDR related services.

A second limitation of that current 4G protocols and services regards the horizontal scalability and therefore the number of concurrent users allowed per application while maintaining latency below a desired threshold. The development of 5G network and services such as the ones described in the 5G-EPICENTRE seem to address such problems and provide solutions that can be exploited by a variety of companies. To be more specific, the innovations of this project may alter the landscape of AR/VR Medical Education as we know it. By offloading the performance intensive processes to a close enough edge server, one could use much cheaper untethered HMDs, with lower specs, to perform AR/VR medical operations on the site of the disaster. The 5G network will allow such processes to be done in real-time with low latency. Since the HMD will only stream content, it will only consume minimal energy, increasing the portability of the overall procedure and allowing multiple operations per charging.

Of course, the success of the whole 5G-EPICENTRE projects depends both on the creation of the appropriate architecture that will enable certain features as well as the adaptation of the existing applications to properly take advantage of them. For example, the platform must provide useful KPI related results, such as latency, in suitable format that will allow fast (maybe on-the-fly) diagnostics that will dictate the correct tweaking of the preferences of the application instance on the edge towards amending potential problems. Also, with an efficient dissection of monolithic applications into multiple components - microservices, the number of concurrent users can exceed the limitations of the current state-of-the-art. However, this dissection must be done in such a way that intercalls between components do not hinder the overall user experience by creating latency issues beyond a threshold.

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Interview 5

Affiliation: MCX Vendor

Key comments:

During the completion of the 5G-EPICENTRE survey/interview from the MCX vendor, the interviewer recorded the following comments of the interviewee.

1. **Easy service deployment**. One of the main problems we face today as PPDR communications providers is the difficulty to integrate over mobile network operators**.** We have two main options: (i) to have a framework agreement with a MNO or MVNO, where we can deploy our service with assured / agreed service guarantees; (ii) to deploy OTT. For the M(V)NO, the problem is similar: it is not easy for them to expose their network capabilities to different service vendors, thus they are usually limited to one vendor. The 5G network slicing paradigm promises to modify this complex ecosystem, enabling more open and flexible service deployment models. As MCX technology vendor, we are interested on learning and testing how we can deploy our service over a network slice and how we can interface with the MNO's infrastructure to manage and handle the QoS of the different calls.

2. **Specific 5G anchors.** It is not easy to find in the market a proper 5G testbed with the required 5G SA interfaces, *e.g.* N5. We'd like to have access to a platform where we can develop and test our implementations.

3. **Wide area testing.** Beyond testbed equipment, it is even more relevant to access wide area testbeds where we can experiment with different coverage and mobility patterns, resembling the typical daily operations of the first responders.

Interview 6

Affiliation: Software/application developer

Key comments:

How do your professional interests match the objectives of 5G-EPICENTRE?
5G in general promises a technological breakthrough that will forever change the way networked applications are developed. It unlocks endless possibilities with respect to what you will be able to achieve with an Internet connection.
In my professional life, I have developed many applications for smart devices and harnessing the power of connectivity, especially for the demanding cases of networked VR and AR is extremely interesting to me. I look forward to see how 5G-EPICENTRE will enable VR/AR applications in the domain of public safety to provide seamless, almost instant delivery of information even in congested network conditions. In particular, AR applications are expected to benefit by being able to offload computationally-intensive processes onto cloud and edge resources. In this respect it will be interesting to see how 5G-EPICENTRE developments impact latency and rendering, and as a result, frames-per-second (FPS). Recent literature suggested that latency of 20ms or higher becomes noticeable, while anything over 50ms cannot be tolerated in the context of AR/VR. Hence, I am extremely interested to see what 5G-EPICENTRE can offer in this respect. The implications are very relevant in other domains as well, such as in cultural applications, games, media and education.

What is unique about 5G-EPICENTRE?
5G-EPICENTRE represents an attempt to move pas monolithic VM-based implementations and fully embrace lightweight virtualization and container technology. According a recent survey on the Phase 2 and Phase 3 5G-PPP projects, Cloud-native transformation is slowly gaining ground but still faces barriers, as well as a reluctance for adoption. Therefore, only a handful of projects utilize container orchestration tooling, such as Kubernetes for VNF orchestration. 5G-EPICENTRE represents a coordinated effort to demonstrate the benefits of containerization in terms of KPIs such as instantiation time, resource utilization, platform independence and high mobility, which are essential in the context of PPDR.

What do you see as the biggest challenge for 5G-EPICENTRE?
The biggest challenge lies with the federation of the testbeds. 5G-EPICENTRE has been envisioned as a platform that unlocks countless opportunities for experimenters in terms of it allowing users to combine the underlying testbed hardware and software components and thus create new, virtual components that provide enhanced capabilities. This will require very careful design with respect to the cross-orchestration of the underlying testbed components.

Three key words to describe the overall impact of ***5G-EPICENTRE****?*
Robustness, reliability, performance.

Interview 7

Affiliation: Research Institution

Key comments:

Which is the motivation for using 5G in PPDR services (please respond per service type)

- Low latency and ultra high reliability (URLLC) and enhanced mobile broadband (eMBB) (high bandwidth) to ensure high reliability for critical missions

How can 5G features *e.g.* VNFs, NETAPPS, slices, *etc.* benefit PPDR services vs current technologies

- By using *e.g.* network slicing, a dedicated bandwidth will be reserved for the requested PPDR service, thus the reliability is ensured and much better than just a best effort service in the current technologies *e.g.* 4G. Special tailored PPDR services can be created by VNFs and Netapps, the 5G core can be optimized.

Which are the 5G KPIs that are essential for the PPDR services

- Latency (max. 1ms), Round trip delay (max. 10ms) and response times, reliability of connectivity (no dead zones) (99.9999%), high datarate (>10 Gbps)

What services a 5G operator should provide to PPDR service providers/application developers in order to ease on-boarding, testing and commercialisation of the service. Which is the need for network resources abstraction visibility.

- An API/interfaces for the developers and service providers, a requirements catalogue, eMBB and URLLC, a slicing configurator, orchestration software that can adjust the base stations in such a way to deliver network slices to the specific requested service.

Which is the business model of the collaboration

- No comment, we are a research facility

Which are the key features that the testbed should have (indicatively on-boarding process/UI, KPIs measurements and analysis tools, traffic generator, networks & UE emulations, upgradability to comply to forthcoming 5G releases, *etc.*)

- 5G release updates are necessary, traffic generators, analysis tools (internal or external), UE emulators should be processable by the network core (the core should be adjustable), a requirements catalogue from the specific testbed (*e.g.* to test products or for POCs and Use-Cases)

How do you envisage the testing process

- It will be an iterative testing process until it runs.

How do you envisage that an operator will utilise the testbed outcome (test results, *etc.*)

- The operator can evaluate his use-case or tested products from the test results

What type of security should be implemented for the PPDR services, considering the sensitivity of data.

- That is task of the use-case operator / product tester because he is interested in the results and knows best about his data.
- E2E encryption and other security measures on the software side

How do you envisage the evaluation process, in the scope of 5G features (VNFS, Containerization, MEC *etc.*)

- The KPIs will be measured and can be evaluated by the use-case operator and the testbed operator.
- The use-case or service request can be evaluated according to the implementation (*e.g.* containerization, *etc.*), in order to check for compatibility

Which ethical/legal issues can emerge, considering PPDR software solutions (*e.g.* User data Privacy -Anonymity -profiling)

- No comment, we are a research facility

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Interview 8

Affiliation: Mission Critical and PPDR expert (with 20+ year experience)

Key comments:

The comments of the interviewee concerned mainly the network performance requirements for Mission Critical and PPDR voice service.

MC and PPDR service provision require stringent performance in Survivability and Immediacy of voice call transfer. That is,

- the network should succeed to transfer a talk burst even under heavy coexisting traffic load (related or not to MC / PPDR service)
- the network should transfer the talk burst with low end-to-end delay that is critical to user experience.

In the LTE framework, the highest priority and lowest latency have been addressed in QCIs 65 and 69 for voice group calls. In 5G, there are additional tools and implementations (ex, more flexible network slicing) that should be tested in the 5G-EPICENTRE platform.

As for the end-to-end transfer, one should meet the following requirements:

- KPI 1: (Access time <200 ms, for the 95% of requests): Time between when a user requests to speak (typically by pressing a PTT on a hand-held device) and when this user gets a signal to start speaking
- KPI 2: (mouth-to-ear latency <250 ms, for the 95% of calls): Time between the transmission of a voice message to its playback at the corresponding receiving end.

The above numbers should be reconsidered if there is substantial signal delay in the backbone network.

Interview 9

Affiliation: Research Centre *(New generation networks (IMS, 5G) especially oriented to emergency and mission critical management in NFV and SDN environments)*

Key comments:

Which is the current state of the PPDR market and what does 5G technology bring?

PPDR agencies have traditionally employed private radio networks for mission critical communications. Mainly to ensure the security and privacy of communications. These networks cover the scope of the PPDR agency they serve.

These are generally local or regional agencies operated by a local telecommunications provider in charge of ensuring network continuity and availability. PPDR agency resources are organized hierarchically and require hierarchical communications, where working groups can be defined and communication prioritized depending on the hierarchy of the resource that is speaking. Voice has traditionally been the most effective and direct way to manage all distributed resources in service in a coordinated and efficient way. They are half-duplex communications, which means that when one resource speaks, the rest listen, as opposed to the full-duplex communications of telephony.

However, PPDR agencies demand to be able to exchange media data, mainly images and video, between the resources deployed in the field and the coordination or command centre. The environmental information provided by this data makes it possible to know at any time the real situation in which each deployed resource is, as well as the real scope of the incident they are dealing with.

Private radio networks have not been designed for the transmission of this type of information, which is why they must use non-secure, non-private public broadband networks to send media data.

The definition by 3GPP of MCPTT, MCDATA and MCVIDEO services within the LTE standard in versions 13 and 14, allows broadband network operators to offer the services demanded by PPDR agencies. These can be offered by the telecom operator itself or by specific MCX service providers.

As of yet, it is still too early to know what 5G networks offer compared to 4G networks. From the point of view of service indicators, an improvement in all indicators has been observed in 5G-NSA networks compared to the deployment of services in 4G networks. The 5G Standalone architecture includes a new network core design, which makes it possible to optimize the transmission of control and data information. The enabling technologies used have already been successfully validated on 4G networks. To the question of what 5G technology can bring compared to 4G technology, the answer would be more along the lines of robustness and management than in the new functionalities that the use of 5G networks can bring to a PPDR agency compared to the current 4G networks.

What role do test platforms such as 5G-EPICENTRE´s play in the current PPDR sector framework for research centres and SMEs?

5G-EPICENTRE […] acts as an infrastructure and service provider and can accommodate external providers to deploy its mission-critical services.

Inasmuch as 5G-EPICENTRE can be flexible to provide infrastructure and auditing services to service providers who want to test their products, 5G-EPICENTRE may be an alternative to having to deploy its own laboratory infrastructure. Flexibility, speed, service provisioning and quality of IT support will be critical to the success of this platform. Solution developers need agility in testing and flexibility to be able to test their solutions. If 5G-EPICENTRE is not well balanced, product stress testing can impact the rest of the platform users.

Its use as a demonstration infrastructure for end customers may be its niche market. I don't think a research centre would want to depend on an external test infrastructure during product development. But it is for end-customer testing, especially during the process of PPDR agencies converging from their existing networks to broadband networks. For a significant period of time the PPDR agency will need to be able to use both communications networks simultaneously in operation and production. This functionality will not be provided by any service provider's laboratory test network.

Which are the challenges for the deployment of back-tested applications in the market?

The biggest challenge is the network infrastructure itself. The auction of radio space means that the frequency bands for 5G operation are already allocated to mobile operators. These networks are not reliable and have not been designed to guarantee the availability and continuity demanded by PPDR agencies or IoT services, assisted navigation, virtual reality, *etc.* The biggest constraint to deployment is the telephone operators themselves. Although they are part of projects such as 5G-EPICENTRE, the transition to production of a solution with the SLAs required for this type of services can be complex.

The paradox can occur when the services meet the requirements of the end customers, the IT technology guarantees the deployment of the services in the terms demanded in the SLAs, and yet the 5G network operators do not have as many professional end customers to be able to provide the services. The investment that operators will have to make will have to be supported by business.

The market rules and it will be the end customers who will set the pace in telecommunications.

Interview 10

This is extracted from TCCA (The Critical Communications Associations) work group results. Not all of them are demonstrable within 5G-EPICENTRE, but it provides a good view of the expectations.

Key outcome:

Some 5G capabilities relevant to Critical Communications

• Mission Critical Services over 5G.

• 5G Multicast & Broadcast Services (5MBS): Enabling more efficient and effective usage of spectral resources for group-based communications – MCPTT, MCData, MCVideo – and support for high concentrations of Public Safety users operating in large groups within a small incident area.

• Device-to-Device Communications: Enabling the capability for Proximity Services (ProSe) and Vehicle-to-X (V2X) services, addressing device-to-device (D2D) communication use cases in environments with limited or non-existent network coverage.

• Network Slicing: Providing a customizable level of connectivity and priority for a plethora of critical applications, each with widely differing network service characteristics, yet carried over the same physical network.

• Enhanced Security: Further mechanisms to protect the integrity, confidentiality and availability of the network services and user data.

• Advanced Congestion Management: Improvements to support differentiation of mission-critical users and services during times of peak congestion – such as Access Identity and Prioritized Random Access Channel (RACH).

• 5G Non-Terrestrial Networks (NTN): Expanding coverage solutions to places with no terrestrial coverage and involving use of satellites as well as networks, or segments of networks, using an airborne or space borne vehicle for transmission, such as High-Altitude Platforms (HAPs) and Unmanned Aircraft Systems (UAS).

Some use cases enabled or further enhanced with 5G compared to 4G

• Situational Awareness: Understanding the nature of events in time and space is a key area where the introduction of broadband will play a pivotal role. Combining enhanced positioning capability in the X, Y and Z dimensions together with 10 to 100 times more connected devices per square kilometer, it will enable the possibility to collect and process a large amount of data from a wide variety of mobile-connected sources for real-time pattern matching and use big data technologies. In practice, this means connecting body-worn cameras and cameras in police cars to command centers to identify what is happening at an incident and to gain an overview of the situation as it unfolds. This will ultimately enhance user operations and planning for future emergency response.

• Video Surveillance and Analytics: In addition to cameras hosted in and around emergency services vehicles, cameras can also operate on remotely controlled drones or unmanned vehicles for a better awareness of urgent situations occurring in areas that human beings cannot easily access. Because 5G focuses on massive broadband, it will allow the number of cameras in specific hotspots to be increased where capacity is currently limited by 4G. In addition, higher resolution 4K, 360° cameras or thermal imaging cameras can be used for more precise visual insights.

• Remote Control and Monitoring: With the introduction of 5G NR, ultra-reliable and low-latency communications, new applications will pave the way to assisted driving and fully unmanned automated vehicles and keep the network reliable when multiple remote-control applications coexist in the same location. This phase will also be important for automating a fleet of high-speed drones with real-time centralized coordination that uses sensors, geo-fencing and/or video analytics to avoid collisions.

• Immersive Applications for First Responders: The introduction of mobile broadband with low latency combined with edge computing opens new possibilities for deploying command and control capabilities. Usage of augmented reality (AR) and virtual reality (VR) will reduce the amount of desk space used by multiple display screens and allowing emergency organizations to equip workers with wearable solutions like smart glasses to access data at the scene of event.

• User-Friendly Operations: The user of the device out in the field will be able to focus more on the task at hand, since the system will be reliable, responsive and easier to use than previous technologies, which are considered complicated. With the use of geofencing techniques, the system can place users in the same area in contact with each other automatically, *i.e.* without the user having to do anything on the device. The device will be easier to use and reliable to operate with or without wide area coverage.

• eHealth: The new level of performance provided by 5G networks will be an important enabler for major eHealth and telemedicine applications. Examples include the enhanced sensor of a user's vital signs before, during and after an incident; sensors on a user will trigger an alarm when no motion is detected, activating the user's camera (and other sensors) to help identify what is happening. Furthermore, it will empower moving ambulances to transmit life-critical data to hospitals, including high-definition real time video and the outputs of sophisticated medical equipment.

• 5G will enable massive Machine Type Communications (mMTC) designed to provide penetration for hundreds of thousands of devices per square kilometer, allowing Command and Control systems to monitor an almost unlimited number of sensors. This combined with new technologies such as AI and Big Data analytics, providing results in a relevant, consolidated and insightful format, will enable enhanced situational awareness and decision making.

• 5G infrastructure will deliver the possibility for device processing and data offloading, running applications much close to end user operations, leveraging edge computing techniques. This means that first responders can use advanced applications for data analytics and communications at the location of an event since processor capacity is deployed in the network, and where devices or tablets only need to act as clients.

• 5G will provide first responders with more opportunities to focus on the task. For instance, at a traffic accident, a drone from the first unit at the scene is setup, providing a good overview of the situation for the dispatch center, and helping to identify if more resources should be sent. The drone will provide a good view of the traffic situation, giving first responders information they need to prioritize saving lives.