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

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Unification architecture of cross-site 5G testbed resources for PPDR verticals

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***Abstract*—A significant amount of fifth-generation (5G) experimentation facilities and testbeds have been proposed in the scientific literature over the past five years, each characterized by its unique setup of resources and control frameworks. Given the wide set of often contradicting requirements presented by the various classes of 5G use cases, the 5G-EPICENTRE project focuses on the provision of a truly open, multi-site 5G experimentation facility specifically tailored to the needs of public safety solution providers, which will leverage on, and extend the capabilities of 5G testbeds developed in, or resulting out of the 5G-PPP Projects (Phase 1-3). At its heart, 5G-EPICENTRE will encompass best practices derived from Cloud-Native implementations, providing a platform for automating and streamlining 5G experiment deployment inside flexible, easily reproducible environments packed in lightweight software containers. 5G-EPICENTRE will focus on the provision of an innovative, open and interoperable platform that aims to act as both a testbed, as well as a federation of existing 5G testbeds. Through an augmentation of experimentation facilities, 5G-EPICENTRE will define the necessary information models to interconnect testbeds partaking in the federation through simplified APIs, and will facilitate the orchestration of their resources to optimally service the needs and requirements of PPDR-centric applications.**

I. Introduction

Public Protection and Disaster Relief (PPDR) envelops a variety of organisations and agencies, all with a common goal of protecting the general public and the environment, particularly in cases of natural or man-made disasters [1]. PPDR operations include not only the personnel deployed on the field to administer first response to incidents, but also dispatchers and operators stationed in emergency control centers (ECC). Such facilities are equipped with several information and communications technology (ICT) systems designed for efficient communication, coordination and control between ECCs and deployed field operators. Particularly in response to disastrous events (such as earthquakes, floods, etc.), effective cross-discipline PPDR communications play a crucial role in carrying out duties and saving as many lives as possible. Given the diverse functions in which PPDR agencies engage, along with the various environments and domains (e.g., the urban or rural area, critical facilities, etc.) in which these disciplines operate, equipment characteristics and communication needs and requirements may vary significantly. Hence, PPDR software solution providers required to conduct rigorous experimentation before their entry into the highly competitive public safety ICT market are tasked with identifying an optimal experimentation facility. Finding a testbed that best suits their needs and application requirements can become a significantly time-consuming affair, given the many different options available.

The 5G-EPICENTRE project represents a convergence of key enabling technologies that are essential to lowering the entry barrier of the emergency and disaster management market in the foreseeable future [2]. This is achieved by allowing newcomers and smaller players keen on penetrating the market to rapidly deploy and extensively experiment on demand with new solutions under various network conditions, thus gaining the opportunity to improve their offerings in a timely manner, and address a wider range of public safety organisations and their requirements. Furthermore, 5G-EPICENTRE aims to deliver solutions that are based on cloud-native microservice-oriented architectures, thus gaining a significant competitive advantage through its support of interoperability between heterogeneous experimentation components via lightweight virtualisation technologies (i.e., software containers) and common orchestration tooling. As a validation step of this federated infrastructure, 5G-EPICENTRE brings 8 different PPDR use-cases of distinct nature to comply with the variety of needs in the industry.

In this paper we present the 5G-EPICENTRE vision of federating 5G testbed infrastructures into an open, interoperable experimentation platform. We present relevant projects regarding 5G federated testbeds within the EU, and describe an overview of the envisioned experimental facility building blocks that comprise the final platform to be delivered. The paper proposes a services-based architecture approach for 5G-EPICENTRE to achieve the aforementioned goals, aiming at accommodating a microservice-based model through the decomposition of virtual network functions (VNFs) into

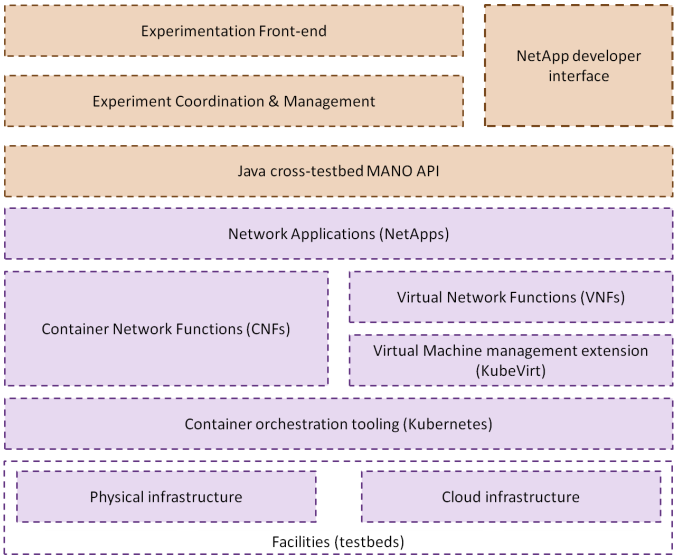

Fig. 1. 5G-EPICENTRE make-up of 5G facility framework (orange) and modified testbed infrastructure components (purple).

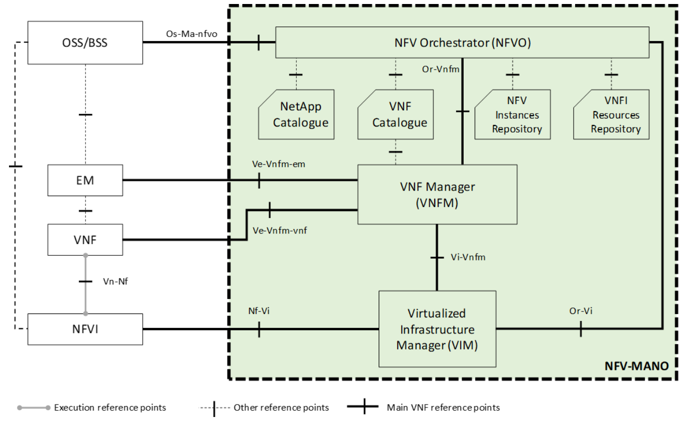

Fig. 2. NFV-MANO reference architectural framework (Adapted from [11]).

containerised, or cloud-native network functions (CNFs) [3], which can be deployed on a shared cloud infrastructure, and which are compatible with modern-era orchestration tools, like Kubernetes [4]. The described 5G-EPICENTRE architecture is expected to allow flexible integration of both new and existing building blocks, particularly the individual 5G components coming from each of the four geographically dispersed testbed platforms participating in the federation (5GENESIS Málaga platform, 5G-VINNI Aveiro facility, CTTC 5G Testbed, 5G Berlin).

II. Related work

In recent years, there has been a strong activity in the development of 5G testbeds for supporting research in mobile technologies [5]. In this section, particular focus has been placed on 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 [6]. One of the earliest initiatives, the Fed4FIRE project, proposed the use of standardised federation interfaces on top of heterogeneous testbed software frameworks [7], eventually leading to the largest federation of testbeds in Europe. More recent approaches are characterised by the requirement that individual facility sites partaking in the federation be built to accommodate specific features dictated by a unified reference architecture.

In the context of the 5G-VINNI project, such an 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 [8]. In this way, network slices can be hosted in one or more geographically dispersed facilities. A similar blueprint is being developed in 5G EVE [9], where several facilities are unified in the federation employing an interworking framework enabling cross-site network slicing. Furthermore, 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 [10]. It thus unifies heterogeneous physical and virtual network elements under a common coordination framework exposed to experimenters, while enabling E2E slicing and experimentation automation.

Similarly, 5G-EPICENTRE aims to leverage federation of heterogeneous 5G testbeds developed under previous 5G-PPP phases to realise 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 functional components to deliver a novel 'testbed of testbeds' supporting a 5G experiments-as-a-service (ExaaS) model. Capitalising on containerisation technologies, the purpose of 5G-EPICENTRE is to fully realise the potential of combining 5G and edge computing paradigms in an open service-oriented architecture (SoA), which aims to gather together technologies in the areas of software-defined networking (SDN), network functions virtualisation (NFV), cloud-native applications, and edge computing, so as to fully realise new business opportunities for PPDR communication service providers.

III. The 5G-EPICENTRE Approach

Conceptually, the 5G-EPICENTRE architecture represents a combination of a novel 5G experimentation facility framework and the modified combined testbed infrastructures of the four geographically dispersed platforms, as can be seen in Figure 1. To that end, some elements of the 5G-EPICENTRE architecture are 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 Management and Orchestration (MANO) components. This is supported so that each platform's infrastructure can maintain its independence whilst ensuring interoperability with the other platforms, particularly in the MANO capabilities necessary for deploying and running a

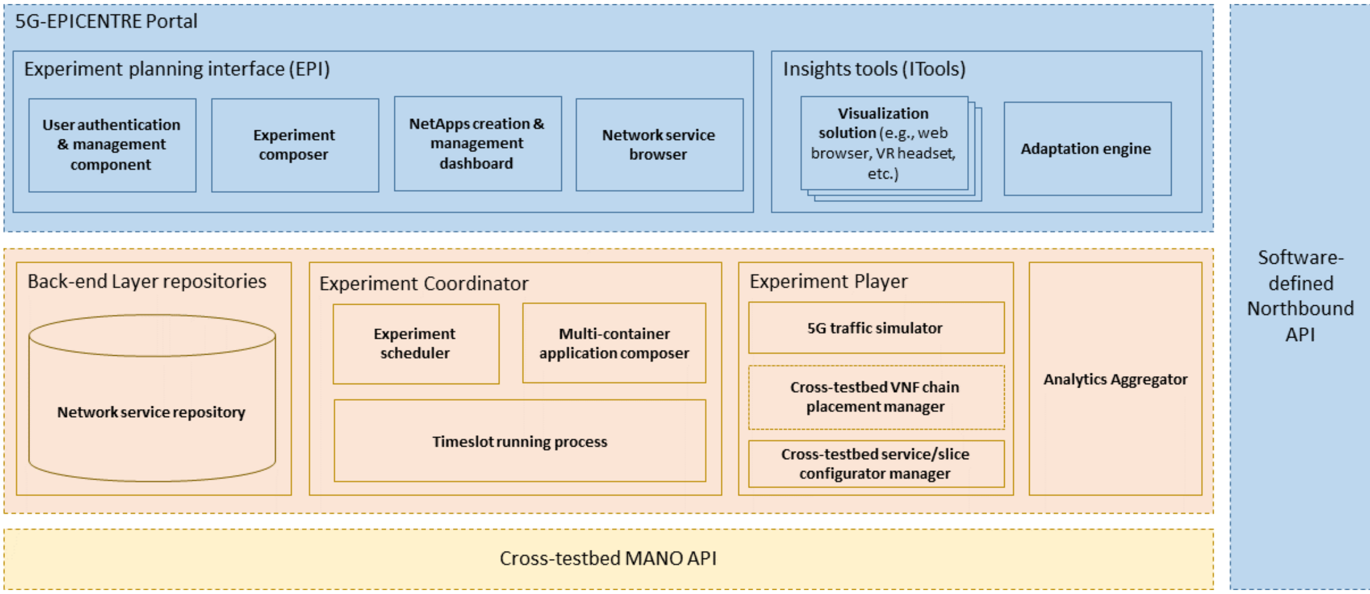

Fig. 3. 5G-EPICENTRE experimentation facility framework. Blue components correspond to 'Front-end Layer' elements. Orange components correspond to 'Back-end Layer' elements. Yellow components finally correspond to the 'Federation Layer'.

variety of experimenter applications on top of the NFV infrastructure. In this respect, each platform should accommodate a means to orchestrate and manage deployment and operation of VNF E2E service chains referred to as network applications (NetApps) on top of 5G infrastructures.

To that end, the NFV-MANO high-level architectural reference framework defined by the ETSI Industry Specification Group for NFV [11] is accommodated by the underlying 5G-EPICENTRE platforms. The base information elements involved in the NFV-MANO system are summarised in Figure 2. This evolution to cloud native involves deployment of network functions in the cloud in the form of microservices containers, introducing several advantages to ETSI-compliant NFV-MANO systems [12]. Over the course of the 5G-EPICENTRE project, we aim at maintaining elements that can continue to serve their purpose when applying the transformation to cloud-native NFV, introducing augmentations where necessary, and replicating those across all four testbed platforms to accommodate the shift to cloud-native solutions.

IV. Experimentation Facility framework

The 5G-EPICENTRE vision, as specified in the previous section, results from the development of functional components of an E2E 5G experimentation facility framework, whose conceptual architecture is shown in Figure 3. This model accommodates a segmentation of the envisioned architecture on a vertical axis, adopting a layered design that allows the facilitation of the development of the various proposed solutions and functional blocks. The corresponding layers of this axis from top to bottom are the 'Front-end'Layer, the 'Back-end' Layer, and the 'Federation' Layer. The main technological components comprising this framework are described in the following paragraphs. Each Layer implements all necessary security measures, thus comprising a horizontal security and privacy framework that caters to the security requirements of the entire architecture from top to bottom. This aims at configuring secure network policies to deal with the larger attack surface resulting from the shift toward edge VNF containerisation. In this respect, 5G-EPICENTRE takes advantage of service mesh architectures to enforce such policies over the entirety of the network.

A. *Front-end Layer*

On the 'Front-end' Layer, the 5G-EPICENTRE facility framework hosts functional components related to facilitating the interaction between the platform and targeted end-users, i.e., experimenters and network function developers. Its aim is to effectively address how these actors can utilise 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 need in terms of network resources (e.g., data, storage, bandwidth, etc.), and receive insights on what each of the federated testbeds can deliver. It is comprised of:

- The Experiment Planning Interface, where experimenters are able to create and run their experiments leveraging the 5G-EPICENTRE infrastructure. Apart from programming application demands, this collection of components provides: i) services for easily creating new experiments and choosing when and where to run them (Experiment Composer); ii) user authentication and management; iii) an AppStore-like browsing experience for the VNFs and NetApps hosted on the platform's open-source repositories; and iv) a graphical NFV prototyping & composition platform (NetApps' creation & management dashboard)

supporting the definition of novel NetApps using the available VNFs and orchestration of the experimental environment using the underlying testbed resources, similar to the Containernet dashboard described in [13].
- The Insights Tool, an analytics visualisation dashboard to determine the success of a range of network services, providing both beyond-desktop visualisation features (via advanced graphics visualisation dashboards and simulation engines targeting an array of heterogeneous devices) along with a rule-based adaptation engine for meaningfully personalising the visual output with a dual emphasis on improving both the visualisation process and overall system usability. The engine is based on an ontology-based reasoner for adapting the visual information, taking into consideration the content to be displayed as well as the context of use, utilising the framework described in [14].

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, is realised.

B. 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 defines the synergies that these components should implement, e.g., all necessary data the system has to provide, as well as how these data are 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. [2]. The base components comprising this layer include:

- The Network Service Repository of NetApps and micro-VNFs and CNFs, together with their northbound interface, towards the catalogue browser and southbound interface towards the cloud-native VNF manage, (see Section V) constitutes a safety storage for the services. The main function of the repository is to store the list of available VNFs/CNFs or NetApps (and relating the latter with the chains of VNFs/CNFs), as well as the constraints of each element to be run over different infrastructures or sites.
- The Experiment Coordinator, which coordinates the life-cycle of experiments, ensuring that the required testbed(s) resources are available, and that the configuration to be sent to the orchestrator in the infrastructure is generated. It is comprised of three sub-components, namely the Experiment Scheduler, which determines the placement of the experiment to effectively schedule its execution; a Timeslot Running Process, which monitors availability of resources to determine experiment execution; and a Multi-Container Application Composer, which is used to define the user application environment and the services needed to run the experiment, producing a configuration file that enables the Experiment Player (see below) to run all necessary services together.
- The Experiment Player, which effectively runs the entire experiment and manages the entire life-cycle of the users' applications. At its core lies a cross-testbed service & slice configurator manager, which manages the orchestration of the necessary resources so as to optimise the NFV infrastructure for each experiment, and also handles all network service events, such as starting, monitoring and termination of the experiment, even across testbeds. A cross-testbed VNF chain placement manager efficiently manages and monitors optimal placement of NetApp chain nodes for experiments spanning multiple testbeds, while a 5G traffic simulator, which is fed by a monitoring system in the Analytics Aggregator (see below), handles the creation of artificial network traffic in order to simulate different 5G network conditions.
- Finally, an Analytics Aggregator is used to aggregate the analytics data generated from the different testbeds (see Section V) to the Front-end Layer, storing the data to make them available to the Insights Tool (see previous paragraph) in order to make them available for visualisation.

C. Federation Layer

The 'Federation' Layer handles cross-testbed orchestration of network services and resources so as to ensure an optimal experiment environment. It implements a cross-testbed MANO API, which allows access to the facilities federated under 5G-EPICENTRE by wrapping different aspects of each individual testbed API under a unified information model. This component defines and develops a set of common and standardised interfaces that intelligently combines the underlying testbed hardware and software components to enable the creation of new, virtual components that provide enhanced capabilities. Key objectives of these interfaces are: i) to allow testbeds to federate without losing control of their individual resources; ii) enable the calibration of individual testbed components from a singular control point; iii) allow experimenters to combine the available resources to achieve different experimentation conditions of varying scale and diversity; and iv) ensure these configurations are easily repeatable by supporting reproducible experimentation conditions.

V. Infrastructure Layer

The 'Infrastructure' Layer includes the individual 5G testbed infrastructural elements, including the hardware required for the realisation of each individual 5G platform. This layer acts as an abstraction of the heterogeneous 5G radio deployment and network architecture configurations that characterise 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. Figure 4 describes a common frame of reference for

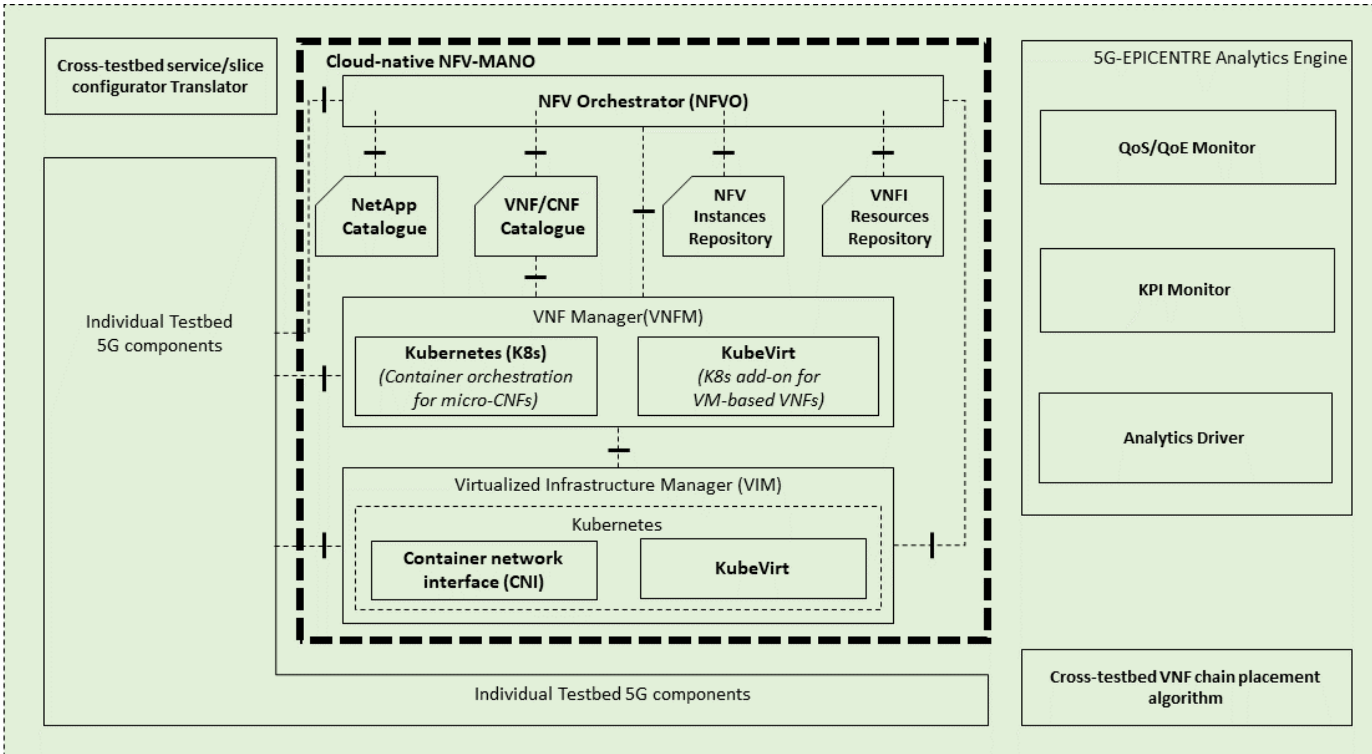

Fig. 4. 5G-EPICENTRE Infrastructure Layer reference frame with ETSI NFV-MANO architecture amplification for cloud-native NFV. Reuse of individual 5G testbed components are sought after to ensure administrative independence of each platform, with highlighted 5G-EPICENTRE augmentation (cloud-native NFV MANO) and components (Analytics Engine, cross-testbed service & slice configurator translator, cross testbed VNF chain placement algorithm) being replicated across all four testbeds to ensure interoperability via open interfaces.

the augmentation of the individual testbeds into the 5G-EPICENTRE federation.

As already mentioned, the 5G-EPICENTRE architecture aims to smoothly integrate testbeds into federation and, where necessary, facilitate the reuse of existing components to support administrative independence of the platform outside of 5G-EPICENTRE activities. The 5G-EPICENTRE project devotes more time and effort on the adaptation, reconfiguration and evaluation of these components, refining and developing all necessary functional blocks into a microservice-based architecture. Hence, the goal is to smoothly evolve the existing NFV-MANO architectures in each testbed currently built on hypervisor-based virtualisation environments, supporting the deployment of VNFs as virtual machines (VMs), where the virtualised infrastructure (VI) manager (VIM) is mostly based on VM orchestration tools, such as OpenStack and VMWare. The end result is a Kubernetes-based orchestration system for automating VI and VNF/CNF deployment, scaling and management. To complement Back-end Layer cross-testbed management components, two functional blocks are replicated inside each testbed facility. Hence, a VNF chain placement is installed at each testbed site, responsible for offloading and redirecting traffic between the cloud and edge resources available. Further, a slice manager translators component provides a translation layer that adapts the requests received from the Back-end Layer cross-testbed service & slice configurator manager to the specific infrastructure in each testbed.

Finally, a 5G-EPICENTRE Analytics Engine is installed at each site, containing all necessary components towards validating KPIs and assessing metrics related to the quality of service and quality of experience (QoS/QoE), continuously analysing experiment parameters to determine whether targets set by the experimenters are met. This includes:

- An Analytics Driver component, which receives input data from the individual 5G testbed components and cloud-native NFV-MANO and pre-processs the data in order to i) extract relevant data for KPIs calculation; ii) extract relevant data for QoS/QoE analysis; and iii) forward them to the other analytics components.
- A KPI Monitor component, which continuously computes all prescribed experiment KPIs using data provided by the Analytics Driver. Additionally, it stores computed values in order to track KPIs' evolution.
- A QoS/QoE Monitor component, which continuously analyses received data to perform anomaly detection. Periodically it performs in-depth analysis (i.e., pattern discovery, clustering, etc.) in order to improve the overall system performance. Moreover, it stores computed values in order to track QoS/QoE parameters evolution. Finally, it provides relevant data to the Analytics Aggregator and notifies any detected anomalies to the Analytics Aggregator.

VI. Discussion

From a technical standpoint, 5G-EPICENTRE will pursue the unification of multiple constituent 5G testbeds toward delivering an experimentation infrastructure that will provide sufficient resources for the deployment and carrying out of PPDR experiments. Having the capacity to combine virtual resources into new components that deliver greater capabilities will enable 5G-EPICENTRE to sufficiently address highly varying sets of requirements with respect to the various application service types for PPDR use cases.

To achieve this goal, the architecture encompasses a shift toward Cloud-Native network function orchestration to reap the benefits that containers bring, such as faster instantiation, lower resource utilization and smaller footprint of containerized microservices. Container virtualization technologies, such as Docker, and container orchestration tooling such as Kubernetes, are prime candidates for implementing the proposed shift in NFV MANO. In this respect, many works underline the use of Kubernetes as both a Virtual Infrastructure and a Virtual Network Function Manager. This is expected to enable 5G-EPICENTRE's capacity to capitalize on transformational technologies, such as Multi-Access Edge Computing (MEC).

The foreseen (theoretical) benefits of the proposed architecture are manifold. For one, the performance of the network will be sufficiently enhanced due to the adoption of containerization and automated operations technologies. In addition, functional components within the 5G-EPICENTRE architecture address the capacity to orchestrate VNFs closer to the end users, hence the notion of flexibly allocating NetApp chain nodes between cloud and edge resources will be fully taken advantage of. Finally, due to the analytics modules being replicated across all testbeds participating in the federation, a consistent output that can satisfy KPI and anomalies' reporting requirements elicited by key 5G-EPICENTRE stakeholders (experimenters and network function developers) can be ensured.

VII. Conclusion and future work

In this paper, we presented the 5G-EPICENTRE reference architecture toward the integration of tools for cross-site network slice management, automated service function control, experiment life-cycle management and KPI monitoring, all supported through a 5G experimentation facility framework acting as a single point of control. As a testbed federator, 5G-EPICENTRE will pursue interoperability between each of its underlying testbed's diverse, multi-vendor 5G network hardware, so as to harmonize and align technologies and standards native to each testbed facility. Toward this end, specifically, NetApp developer interfaces for interoperability will be employed in cross-testbed service orchestration, ensuring an additional layer of interoperability is provided.

The proposed framework is complemented by a reference implementation for Cloud-Native NFV-MANO, which will support the deployment of the 5G-EPICENTRE microservice-based model (e.g. deconstructing VNFs into microservices, that can be deployed on a shared Cloud infrastructure) as well as compatibility with modern-era orchestration tools (Kubernetes). The overall aim will be to facilitate the flexible integration of both new and existing building blocks.

The presented architecture will serve as a guide for the development activities taking place in the context of the 5G-EPICENTRE project, toward the implementation of the functional building blocks and their eventual integration into the preliminary and final experimentation facility. Following the project's evolutionary approach, this architecture will be revised and updated as needed throughout the lifetime of the project, thus taking into account updates on user requirements as well as feedback from the development, integration and testing of both individual components and the integrated experimentation platform prototype.

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References

[1] R. Ferrus and O. Sallent, *Mobile Broadband Communications for Public Safety: The Road Ahead Through LTE Technology*. John Wiley & Sons, 2015.

[2] K. Apostolakis, G. Margetis, C. Stephanidis, J.-M. Duquerrois, L. Drouglazet, A. Lallet, S. Delmas, L. Cordeiro, A. S. Gomes, M. Amor, A. Diaz Zayas, C. Verikoukis, K. Ramantas, and I. Markopoulos, "Cloud-Native 5G Infrastructure and Network Applications (NetApps) for Public Protection and Disaster Relief: The 5G-EPICENTRE Project," in *2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit): Vertical Applications and Internet of Things (VAP) (2021 EuCNC & 6G Summit - VAP)*, Porto, Portugal, Jun. 2021.

[3] R. Cziva and D. P. Pezaros, "Container Network Functions: Bringing NFV to the Network Edge," *IEEE Communications Magazine*, vol. 55, no. 6, pp. 24–31, 2017.

[4] M. Gawel and K. Zielinski, "Analysis and Evaluation of Kubernetes Based NFV Management and Orchestration," in *2019 IEEE 12th International Conference on Cloud Computing (CLOUD)*. IEEE, 2019, pp. 511–513.

[5] L. Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia, "Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead," *Computer Networks*, vol. 182, p. 107516, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1389128620311786

[6] L. Yala, M. Iordache, A. Bousselmi, and S. Imadali, "Testbed federation for 5g experimentation: Review and guidelines," in *2019 IEEE Conference on Standards for Communications and Networking (CSCN)*. IEEE, 2019, pp. 1–6.

[7] T. Wauters, B. Vermeulen, W. Vandenberghe, P. Demeester, S. Taylor, L. Baron, M. Smirnov, Y. Al-Hazmi, A. Willner, M. Sawyer *et al.*, "Federation of Internet experimentation facilities: architecture and implementation," in *European Conference on Networks and Communications (EuCNC 2014)*, 2014.

[8] M. Xie, W. Y. Poe, Y. Wang, A. J. Gonzalez, A. M. Elmokashfi, J. A. P. Rodrigues, and F. Michelinakis, "Towards Closed Loop 5G Service Assurance Architecture for Network Slices as a Service," in *2019 European Conference on Networks and Communications (EuCNC)*. IEEE, 2019, pp. 139–143.

[9] M. Gupta, R. Legouable, M. M. Rosello, M. Cecchi, J. R. Alonso, M. Lorenzo, E. Kosmatos, M. R. Boldi, and G. Carrozzo, "The 5G EVE end-to-end 5G facility for extensive trials," in *2019 IEEE international conference on communications workshops (ICC workshops)*. IEEE, 2019, pp. 1–5.

[10] H. Koumaras, D. Tsolkas, G. Gardikis, P. M. Gomez, V. Frascolla, D. Triantafyllopoulou, M. Emmelmann, V. Koumaras, M. L. G. Osma, D. Munaretto, E. Atxutegi, J. S. d. Puga, O. Alay, A. Brunstrom, and A. M. C. Bosneag, "5GENESIS: The Genesis of a flexible 5G Facility," in *2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, 2018, pp. 1–6.

[11] "GS NFV-MAN 001 V1.1.1 Network Function Virtualisation (NFV); Management and Orchestration," ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV), Group Specification, Dec 2014.

[12] Y. Chen and A. Bernstein, "Bridging the gap between etsi-nfv and cloud native architecture," in *Proc. SCTE/ISBE Fall Tech. Forum*, 2017, pp. 1–27.

[13] M. Peuster, J. Kampmeyer, and H. Karl, "Containernet 2.0: A Rapid Prototyping Platform for Hybrid Service Function Chains," in *2018 4th IEEE Conference on Network Softwarization and Workshops (NetSoft)*. IEEE, 2018, pp. 335–337.

[14] G. Margetis, S. Ntoa, M. Antona, and C. Stephanidis, "Augmenting natural interaction with physical paper in ambient intelligence environments," *Multimedia Tools and Applications*, vol. 78, no. 10, pp. 13 387–13 433, 2019.