5G-EPICENTRE

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

This is a postprint version of the following accepted article:

Apostolakis, K. C., Margetis, G., Stephanidis, C., Duquerrois, J. M., Drouglazet, L., Lallet, A., Delmas, S., Cordeiro, L., Gomes, A., Amor, M., Díaz Zayas, A., Verikoukis, C., Ramantas, K. & Markopoulos, Ioannis. (2021, June). 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)* (pp. 235-240). IEEE.

DOI: 10.1109/EuCNC/6GSummit51104.2021.9482425

Cloud-Native 5G Infrastructure and Network Applications (NetApps) for Public Protection and Disaster Relief: The 5G-EPICENTRE Project

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***Abstract*—5G will lay the foundations for the mainstream broadband wireless technology of the next decade, a leverage toward ensuring the efficiency, effectiveness and adaptability of everyday high-demanding operations, such as those in Public Protection and Disaster Relief. The ITU considers LTE-Advanced systems and 5G as a mission critical PPDR technology able to address the needs of MC intelligence, providing support for MC voice, data and video services as an IMT radio interface. In this paper, we introduce 5G-EPICENTRE, an innovation action funded by the EC under the Horizon 2020 research framework, which aims to deliver an open, federated 5G end-to-end experimentation platform specifically tailored to the needs of PPDR software solutions. The envisioned platform will allow SMEs and developers a lower entry barrier to the PPDR market, enabling them to build-up and experiment with their solutions in a cost effective way. The 5G-EPICENTRE platform will be based on an open Service Oriented Architecture and will accommodate open access to 5G networks' resources, acting this way as an open source repository for PPDR 5G Network Applications (NetApps). The purpose of the federated platform is to provide sufficient resources to cover the entire range of the 3 ITU-defined service types (i.e. eMBB, mMTC and URLLC) and to deliver secure interoperability capabilities beyond vendor-specific implementation.**

I. Introduction

Advancements in 5G technologies will yield new and exciting business opportunities in several markets, including manufacturing, the creative industries and media, automated mobility and public safety. Recent market organizations studies forecast the latter to grow almost five-fold within the next 5 years, as 5G is expected to unlock significant benefits to PPDR software vendors. There could not be a more appropriate time for this transformation to take place, as the PPDR community generally lags behind in technology adoption (e.g. old TETRA being equivalent to 2G, slow adoption of video, broadband, AI, AR/VR, etc). From a network perspective, probably the most important benefit is the cost reduction of network roll-outs, pertaining to costs for commercial off-the-shelf (COTS) hardware and mainstream radio equipment, which will increase capacity and performance for a range of emergency service purchasers (from both public and private sectors). Although from a business perspective public safety constitutes a niche market regarding ICT stakeholders, it is safe to forecast that the 5G-enabled digitalization revenues for ICT players in the public safety market will increase as a result of widespread 5G adoption, thus paving the way for a wider exploitation of the field by the ICT industries that are going to invest in the PPDR domain. However, such investments will require significant CAPEXs, and the investment level can be beyond the capacity for Small and Medium-sized Enterprises (SMEs) who, especially at entry level, can usually only invest moderate amounts towards 5G enabled deployments.

5G-EPICENTRE is an EU-funded innovation action project that aims to lower the barriers to 5G adoption (and as a result, market entry) for SMEs to conduct rigorous experimentation of their products and applications aimed at the public safety market, through the provision of an open, federated, end-to-end experimentation facility. Over the course of three years, the 5G-EPICENTRE consortium partners will achieve several key objectives pertinent to that goal, by i) federating multiple constituent 5G platforms evolved under previous 5G PPP Phase 2 and 3 projects into an advanced, user-friendly, zero-touch orchestration single point of control; ii) implementing a repository of network functions and applications to address requirements pertaining to the most common PPDR experimentation environments; and iii) working towards the cloud-native transformation of both facilities and network functions in support of the transformational technologies, such as Multi-access Edge Computing (MEC). The project will further devote resources into demonstrating value of its results to stakeholders, i.e. key and emerging players in the public safety market. It hence aims to accelerate the widespread adoption of low-entry 5G virtualized experimental environments, along with vertical-specific network functions configured especially to fit the needs of the modern-era first responder. This paper aims at introducing the project overall scope and motivations and attempts to demonstrate key areas where 5G-EPICENTRE is expected to deliver significant contributions. The proposed overall concept of the project is illustrated in Figure 1.

The remainder of this paper is organized as follows: Section II presents the existing infrastructure and testbeds in the 5G-EPICENTRE federation, while Section III outlines the project's ambition with respect to delivering a federated 5G experimental facility for PPDR-specific vertical applications. Section IV presents challenges and a roadmap for the project to deliver on cloud-native transformation of the 5G-EPICENTRE underlying testbeds. Section V delves deeper into Virtual Network Function (VNF) containerization at the network edge, critical for the delay-sensitive components that many of the 5G-EPICENTRE PPDR use case scenarios will involve. Section VI presents a brief overview on VNF chain placement, re-routing and re-mapping, along with steps to be taken along the project implementation to accommodate end-user mobility and highly varying traffic dynamics characteristic in large event and disaster scenarios. Section VII presents how the project aims to leverage Artificial Intelligence for achieving cognitive experiment coordination and life-cycle management, while Section VIII deals with the innovative, information-rich platforms planned for 5G experiment KPI visualization. The paper concludes with a short discussion on the project ongoing activities and future work in Section IX.

II. 5G-EPICENTRE RESOURCES

To achieve its ambitious goal, 5G-EPICENTRE will bring together resources from four geographically dispersed, end-to-end private 5G platforms deployed in the contexts of previous EC calls, which support key 5G KPIs (related to capacity, speed, latency, reliability, density of users, location accuracy, service creation time and network management), as well as allow cross-site orchestration and experimentation for PPDR solution vendors to validate NetApps reliant upon those KPIs. Leveraging on such open, evolutionary 5G networks across the continent, 5G-EPICENTRE will undertake the necessary development of new features, with particular emphasis being placed on the requirements presented by applications targeting PPDR operational frameworks. This 5G-EPICENTRE experimentation infrastructure will result from federation of the following 5G testbeds: the 5G-VINNI experimental facility located in Aveiro, Portugal [1]; the 5GENESIS Málaga platform [2]; 5G Berlin in Germany [3]; and the CTTC 5G end-to-end experimental platform [4].

III. 5G FEDERATED INFRASTRUCTURE FOR PPDR

In terms of network capacity and coverage, MC communication systems, including those addressing PPDR requirements, are probably those with the most demanding requirements. Devices available to first responders today are getting significantly "smarter", are equipped with multiple sensors and provide a wide range of communication capabilities and modalities, including voice, real-time ultra high-definition (UHD) video streaming, high resolution image exchange and even bio-signals communicating the emergency responder's physical condition. As such, requirements for ultra-high throughput and extremely low latency become even more pronounced, as new and more efficient means for emergency crews to respond to catastrophic natural or man-made events are being introduced, based on the capabilities of those equipments.

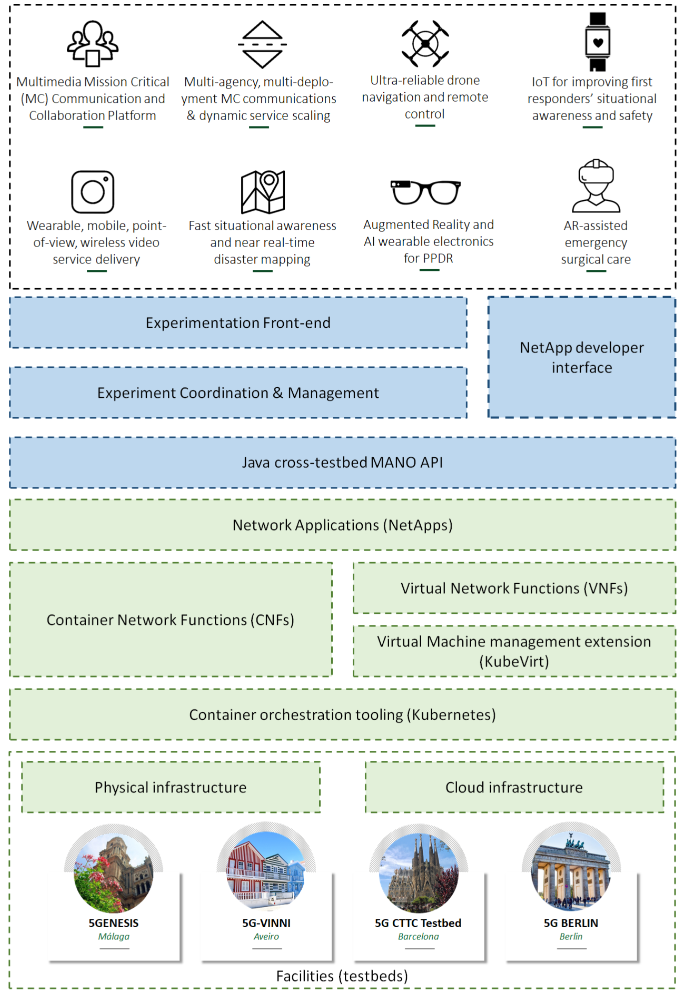

Fig. 1. 5G-EPICENTRE proposed approach. The top part of this diagram showcases indicative experimenter applications. Blue items correspond to the 5G experimentation facility architecture while Green items demonstrate the means by which the underlying testbed resources will support Cloud-native transformation.

To address the ever-growing list of requirements, innovation has relied on the rigorous experimentation of proposed solutions in near-real and operational environments. This in turn has led to a significant amount of experimentation testbeds being unveiled to the scientific and business communities over the last several years. However, the sheer amount of facilities has introduced an additional challenge for experimenters, who are suddenly required to identify the testbed that best matches their experimentation requirements, and might lead to the selection of sub-optimal facilities [5]. To alleviate this shortcoming, federation of multiple network testbeds has been proposed, aiming at integrating different technologies and resources by virtually unifying infrastructure across multiple sites [6]. However, heterogeneity of the underlying testbed infrastructures along with differences in the software frameworks used for management and orchestration introduce a whole new set of challenges to overcome [7]. As a result, extensions are developed into the testbeds to be federated, utilizing interfaces defined by the federation consortia [8]. There are a number of EU-funded projects that aim to address testbed federation in heterogeneous and multi-domain scenarios [9]. Among the most prominent, Fed4FIRE and its successor Fed4FIRE+ represent the largest federation of testbeds on this side of the Atlantic [10]. Of particular interest to experimentation with 5G technology, the SoftFIRE federated virtualization platform is a noteworthy endeavor [9].

The 5G-EPICENTRE project will undertake to federate 5G testbed infrastructures and resources across the EU, aiming at sufficiently addressing the particular nature and demands of communication solutions targeted at emergency and disaster management applications. In this respect, sufficient resources will be made available to provide the facility with the capacity to support use cases within all three ITU-defined 5G enabling service types (Enhanced Mobile Broadband - eMBB, massive Machine Type Communications - mMTC and Ultra-reliable low-latency communication - URLLC). The project ambitiously targets a multi-purpose, multi-service interoperable experimentation infrastructure, that can support extremely demanding bandwidth MC applications and services (e.g. MC video, data, intelligence, etc.), providing a reliable environment wherein solution vendors can gain valuable insight and configure their solutions to the maximum benefit of emergency response agencies and authorities across several operational frameworks (e.g. in their day-to-day activities, during the aftermath of a catastrophic event or disaster, etc.).

IV. Cloud-native transformation of the 5G core

Along with 5G New Radio (NR) access, the 5G Core network (comprised of functions such as the authentication server, the session manager, the access and mobility manager and security) is critical to the 5G system architecture and a crucial component in delivering quality 5G services. Earlier incarnations of the 5G Core architecture mirrored those established for 2G, 3G and 4G in that they were point-to-point based. However since Release 15 of the 3GPP System Architecture for the 5G System, a services-based core architecture is fast becoming the new standard. Thus, the new model thus is able to overcome barriers associated with the prior model of development, such as an overabundance of service-tailored interfaces. These have been known to have a negative impact on network flexibility, with networks not being sufficiently robust against the introduction or modification of new network functions as well as being limiting in terms of addressing a wide range of end-user services.

Such an envisioned service-based core architecture will require several techniques being applied in unison, i.e. Network Functions Virtualization (NFV), Software-Defined Networking (SDN) and service-based interactions facilitated among control-plane functions [11]. This calls for a transformation of the 5G Core VNFs into a microservices-based model or, more precisely, desconstructing those VNFs into microservices that i) will be deployed on a shared cloud infrastructure; and ii) will accommodate microservices orchestration tooling. This effectively translates to the containerization of the 5G Core, and the gradual decoupling of network functions from virtual machines (VMs) in support of Containerized Network Functions (CNFs) over traditional VNFs [12].

While not mutually exclusive, containers do seem to provide substantial advantages over the use of VMs for the delivery of NFV solutions as they are more lightweight and consume much less memory and therefore can unlock superior performance of the core network [13] - though the benefits of VMs in terms of isolation are not to be overlooked. Early experimental results have further examined and validated the use of popular container virtualization technologies (such as e.g. Docker) and orchestration tools (such as Kubernetes - K8s) for implementing the new Core network architecture [14]. To overcome issues with adopting K8s as both a Virtual Infrastructure and VNF Manager as well as operator reluctance to embrace container orchestration tooling due to their reliance on monolithic VNFs that are hard to deconstruct into containers, various add-ons to the K8s platform have been proposed. Most prominently, KubeVirt has been singled out by the 5G-PPP Software Network Working Group as a solution to overcome those barriers as it allows existing VMs to run inside containers that are orchestrated and managed by K8s [15]. However, to this day, only a handful of initiatives have opted to take this path.

5G-EPICENTRE will utilize K8s orchestration tooling, identifying advantages in the scheduling of core CNF/VNFs on the optimal available infrastructure; on-demand scaling; and container-level isolation and health monitoring, where instances can be rapidly restarted in case of failure. Such a transformation will be targeted at fully virtualized core network environments (such as the one provided e.g. by the Málaga platform) so as to allow PPDR NetApps to be deployed within a fully virtualized, containerized 5G core network. Benefits to be gained include a significant enhancement to the performance of the core part of the mobile network, especially considering the diversity of PPDR service types and applications requirements. Hence, experimenters will benefit from both superior experimentation infrastructure as well as K8s support for automated operations.

V. CNFs as enablers for MEC

Narrowband professional mobile radio has been, and will probably continue to be, central to the capacity of emergency and disaster management organizations carrying out their life-preserving duties. However, wireless communications fuelled by the increasing capacities of mobile broadband networks have become a critical complement to MC radio. As a result of the proliferation of smart devices, PPDR agents have become empowered to take advantage of connected components (e.g. commodity smart phones, smart vehicles and purpose-built devices and accessories) and accelerate their adoption of smart technologies, particularly MC video and data, towards building "mission-critical intelligence". Such solutions are characterized by demanding requirements for ultra-reliability, extremely low latency and an unprecedented degree of mobility. These are operationalized through the Multi-access Edge Computing (MEC) concept, which envisions the collection and processing of data at the edge of the network, i.e. closer to the first responder on the field. This ensures that latency requirements are addressed, affording real-time performance to even excessive bandwidth-consuming applications, such as MC UHD video streaming. Through this paradigm, execution of VNFs at the network edge becomes a possibility.

In recent years, Lightweight Virtualization (LV) techniques (e.g. containers, unikernels, etc.) are being applied to NFV infrastructures, utilizing MEC as a vehicle toward efficient running of containerized applications on even low-spec edge hardware [16]. In particular, containers are forecast to eventually replace monolithic VM implementations and deliver significant performance enhancements [17]. After experimenting with LV toward delivering containerized VNFs to edge computing clients, Cziva et al [18], [19] found container implementations to benefit from faster instantiation times, low resource utilization, platform independence and a smaller footprint, which delivers a significant boost to mobility. In the context of MEC, containers have been heralded as superior to VMs with respect to the time it takes to deploy them, the tooling available for container life-cycle management, the capacity offered to scale in and out on demand, ease of linkage and support for microservices-based architectures [20].

Along with the aforementioned effort to containerize the 5G Core, 5G-EPICENTRE will migrate MC services and applications from the remote cloud to the network edge to deliver significant boosts in communication delay reduction and network bandwidth alleviation. Toward this end, the decomposition of VM-based functions into "micro" CNFs that are not restricted by the particularities of NFV toolkits, frameworks or architectures will be explored, along with flexible allocation among the edge and the centralized core platforms (see Section VI, below). Through this means, it is expected that computational tasks will be optimally allocated among the terminal devices and network resources, achieving boosts in cost-saving, performance improvement and lessening the potential threat of devices overheating due to an overabundance of intensive computational tasks. This will enable experimenters to propose data-intensive applications for the PPDR domain, such as real-time, mobile Augmented Reality and Machine Learning solutions. The project will devote resources into the development of CNFs, and promote sharing via an open repository that aims to facilitate collaborative development and lead to ground-breaking innovation along with higher-quality services for PPDR agencies.

VI. Optimal distribution of VNF chains over the network Cloud and MEC infrastructure

By definition, VNFs virtualize functions carried out by dedicated hardware into software components, thus decoupling functionality from hardware. This comes with a number of advantages, among which flexibility, scalability and optimized use of resources are the most prominent. Through a process known as Service Function Chaining (SFC), VNFs are chained together to form an end-to-end sequence of actions required by a specific user. Such VNF chains are also known as Network Applications, or NetApps for short.

Because the network traffic is steered through these chains, the optimal placement of NetApp chain nodes to the most appropriate locations is an active topic of interest in NFV literature as it pertains to an improved capacity to service a variety of requests and deliver high Quality of Service (QoS) and Quality of Experience (QoE) for the entire network [21]. Moens and De Turck [22] provided one of the earliest formulations of the VNF placement problem inspired by application placement efforts in data centers and clouds. Addis et al [23] further elaborated the concept into VNF chain routing optimization, i.e. identifying optimal placement of VNFs over NFV Infrastructure clusters, coupled with optimal assignment demands routed through those NetApp chains, with consideration for the particularities of the network (e.g. capacity, compression/decompression, latency, node sharing capacity).

As specified in the previous Sections, the NFV community is steadily switching over to cloud-native implementations, enabling VNFs to be more flexibly placed over the network using LV technologies to extend the network cloud infrastructure in accordance with the MEC initiative. This perplexes the VNF chain placement problem: as NVFs can now be placed closer to the end users, it would make sense to execute the entire NetApp chain at the network edge, but the limitation of available resources introduces the need to instead strategically select which VNFs to execute at the Cloud (where more resources are available), and which to instantiate at the network edge, in close proximity to the end users' devices [24]. The problem has since been an active topic of research as it may unlock network performance via better utilization of resources and minimize service interruption phenomena. This is better understood in the work of Zheng et al [25], who address VNF chaining coupled with proactive video caching (which they realize as a NetApp chain) by utilizing MEC to enable caching of video content closer to the end users, and hence increasing perceived QoS. In cases where unpredictable network states caused by e.g. high user mobility or varying network traffic dynamics are to be expected, re-assessing the current optimal placement and re-routing VNFs to newly discovered optimal locations has been proposed as an effective solution [26].

Due to the pronounced nature of LV and MEC as key technological enablers behind the overall 5G-EPICENTRE vision, a significant portion of the project resources will be devoted to the exploration of algorithms for optimal NetApp chain node placement. This is expected to maximize the amount of resources to be reliably executed close to the first responders. As PPDR scenarios are characterized by mission-critical requirements, delay-sensitive traffic and extremely high degree of mobility of end users, dynamic recalculation of VNF optimal placement will be considered to gain the most out of the combined network Cloud and MEC infrastructure in terms of QoS and QoE.

VII. AI-driven experiment coordination and life-cycle management

Advancements in Artificial Intelligence (AI) have allowed the technology to become increasingly useful in IT infrastructure management, monitoring, scaling and security. AI enables automation of application-level traffic routing, can make accurate predictions on resource demand, can monitor application condition, identify anomalies and patterns and rapidly analyse huge amounts of data in anticipation of future events. The embedded use of AI (in the form of Machine Learning/Deep Learning algorithms) in infrastructure and operations is often referred to under the term 'AIOps' (Artificial Intelligence for IT Operations). AIOps therefore can have a role in 5G infrastructure management, deployed in support of critical functions, such as network slicing and application awareness, in order to achieve 'cognitive network management' [27], e.g. realizing "self-aware, self-configuring, self-optimization, self-healing and self-protecting" networks.

5G-EPICENTRE will deploy AIOps tooling in support of the envisioned 5G experimentation platform management, enabling dynamic adaptation to accommodate a diverse range of QoS and QoE requirements. This will be operationalized through intelligent components for experiment coordination and life-cycle management. With respect to the former, the virtual infrastructure will intelligently schedule experiments, autonomously monitor availability of resources, determine which experiments will be ran on top of the infrastructure (including concurrent execution, if resources permit) and identify which VNF containers to be instantiated during experiment execution. With respect to life-cycle management, AIOps tooling employed will cognitively manage and decommission network resources by specifying the network slices to be deployed and communicating with the layers below so as to ensure that experiment services are properly coordinated and executed. In addition, a 5G traffic simulator will emulate varying network traffic dynamics.

VIII. Beyond-desktop 5G KPI visualization

5G-EPICENTRE will define sophisticated experimentation scenarios and KPIs for the evaluation of the proposed experimentation infrastructure, especially those that relate to evidence of faster services' creation time through minimal containerized network function image sizes.

In order to navigate large amounts of data and make sense out of large-scale data analysis, graphical presentation methods are required that go beyond the representational capacity of conventional tools, such as bar graphs or pie charts. Several desktop dashboard tools (e.g. DataWrangler, OpenRefine, Quadrigram, etc.) exist today for communicating insights to users. As smart devices become more and more part of people's everyday business lives, data insights visualization requirements open new avenues for smaller screen surfaces, multi-sensory interfaces, tangible interaction and even immersive viewing experiences powered by portable virtual and augmented reality technology. The latter present entirely new worlds for making sense out of Big Data, enabling data visualization designers to take advantage of the superior human capacity for perception and cognition [28]. This means that new graphical elements can be used to translate data into a visual stimulus, where several affordances, such as spatial position, shape, colour [29] and even physics-based, can be utilized to trigger the human capacity to recognize patterns and unique ability to think outside of the box. A large variety of HMD-based and stereo-projection systems have been explored in the scientific literature so as to recognize their potential for data visualization, including Computer-Aided Virtual Environments (CAVE), HMD hardware (e.g. Oculus Rift, HTC Vive, etc.) [30], holographic displays (e.g. Microsoft HoloLens) [31], mobile and hybrid systems, and the combination of smart surfaces to create high-resolution immersive multi-wall display systems [32].

5G-EPICENTRE will explore large scale analytics' insights and 5G experiment KPI exploration, visualization and interaction using a wide range of smart surfaces, ranging from desktop environments to coherent interfaces using multiple interactive surfaces. The goal will be to deliver visualization tools that will connect analytics and graphics along with interaction modalities and affordances provided by the various output devices targeted. These systems will utilize intelligent multimodal interaction, ensuring seamless confluence of diverse computing platforms, unobtrusive monitoring and sensing (e.g., via computer vision), and producing advanced, immersive and tangible visual representations of KPI and anomalies' information. 5G-EPICENTRE will devote significant work toward facilitating Usability via User Experience Design in order to "develop and adapt today's visualization methods for tomorrow's devices" [32].

IX. Conclusion

In this paper, the 5G-EPICENTRE overarching goals and key ambitions have been presented, providing insight into key project activities to take place over the course of the next three years. 5G-EPICENTRE ambitions to address emerging topics in NFV, with lightweight containerization and the embracing of cloud-native, microservices-oriented architectures playing a prominent role in delivering on the project milestones and objectives. We presented our goal to leverage container virtualization technologies and orchestration tooling toward unlocking performance enhancements delivered by a fully-containerized 5G Core network architecture. We further elaborated on the potential to implement LV to facilitate MEC, along with the flexible allocation of lightweight containerized network functions among the core and edge resources. In addition, we have elaborated on the means by which the project will aim to unite the resources of four heterogeneous 5G testbeds in federation; the deployment of artificial intelligence in experiment monitoring and life-cycle management via AIOps tooling; and novel means of experiment insight discovery through innovative visualization techniques leveraging a variety of hardware platforms.

As a next step toward realizing these goals, the 5G-EPICENTRE consortium will specify in detail a service-oriented architecture driven by meticulously elicited requirements from invited end-users, i.e. SMEs and PPDR market players, who will experiment with the platform during 2022 for verifying its functionalities against the defined specifications. The platform will then be opened to third-parties external to the project consortium in mid 2023, in the interest of evaluating the technologies proposed with external stakeholders to gather additional insight with the targeted real users.

5G-EPICENTRE activities and key milestones will be documented in the project website at www.5gepicentre.eu.

Acknowledgment

This project has received funding from the EU's Horizon 2020 innovation action program under Grant agreement No 101016521 (5G-EPICENTRE project). This paper reflects only the authors' view and the Commission is not responsible for any use that may be made of the information it contains.

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