Management of Mission Critical Public Safety Applications: the 5G ESSENCE Project

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***Abstract*— To address the limitations of legacy Public Safety (PS) solutions, as narrow bandwidth, high deployment cost and poor flexibility, the 5G cellular systems have been proposed. The architecture proposed by the 5G ESSENCE project is based on a cloud-enabled small cell infrastructure with a fully distributed orchestration architecture leveraging multi-access technologies in 5G. Furthermore, SDN and NFV are exploited, with MEC, to create flexible slices for dedicated mission critical public safety applications also at the edge of the network. This is shown by describing as the mission critical push-to-talk services have been implemented in a real testbed.**

Keywords—5G, cloud computing, NFV, orchestration, Public Safety, small cells, SLA.

I. INTRODUCTION

During emergency events, both natural and man-made, the commercial telecommunication networks may be impacted and not be able to offer services. For this reason, there is also a Public Safety (PS) communication network, which is used in parallel to commercial ones. Due to the need of ubiquity, this network is wireless, but dedicated frequencies and robustness are paid with small bandwidth and high costs of terminals and equipment. First responders and PS operators express the need to exchange data, images and video, not only voice. Therefore, the trend is to use both commercial and PS networks to exchange information [2]. 3GPP has started since 2006, in particular with Release 12, 13 and 14, to include functionalities related to mission critical applications as public safety in the mobile networks standards [3].

With its capabilities able to meet the requirements for massive number of connected devices (MMTC), ultra-reliable and low-latency communications (URLLC) and enhanced mobile broadband (eMBB), 5G is presenting itself as the ideal candidate for a mission critical and PS solution. Mobile edge computing (MEC), Software-defined networking (SDN), network function virtualization (NFV) , network slicing, cloud computing and seamless integration of different radio technologies [4] will furthermore empower 5G to use the common infrastructure for the commercial users to create safety networks within them [3][5].

This paper aims to present the 5G ESSENCE innovative project [6] and how the 5G ESSENCE architecture can support mission critical and public safety applications. 5G ESSENCE aims at supporting the requirement of the PS sector, i.e. which requires prioritized and high-quality services, by providing a highly flexible and scalable platform. This platform will be based on edge computing, small cells and on the implementation of end to end slicing, elastic resource allocation, operability of the service in emergency situations and high service Quality of Experience. In the proposed solution VNF are deployed and chained with the needed connectivity performance in the edge computing platform, to support partially computing intensive and delay constrained applications.

The paper is organized as follows: Section II describes the state of the art in PS networks including limitations; Section III describe the 5G ESSENCE solution, with both the overview of the general architecture and how this can be deployed for mission critical public safety services. Section IV explains how this solution is being implemented and validated in the project to realize critical PS services and finally section V summarizes the benefit of the solution and the future work.

II. STATE OF THE ART

Current solutions for mission critical applications include narrowband communication systems, such as terrestrial trunked radio (TETRA) and Tetrapol (TETRA for police) in Europe, and Project 25 (P25) in North America [1]. These traditional PS communication services provide advanced security features and functionalities, but cannot support the high data rates required for the increase of data traffic and the overall multimedia content transmission when it comes to mission critical applications. As the benefits of integrating mission critical communications towards commercial mobile broadband standards have been assessed and accepted by multiple authorities, the Long Term Evolution-Advanced

(LTE-A) mobile radio technology has become a reference technology and has been regarded as a possible technology for the next step of the evolution of the dedicated public safety systems [2]. These 4th generation networks support several enabling technologies for critical communications, including device-to-device (D2D) communications [7], group communications [8], direct mode communications (also referred to as proximity services, ProSe), mission-critical push-to-talk, video and data (MCPTT, MCVideo, MCData) and end-to-end security. Maintaining these communications in emergency situations such as natural disasters or accidents is the main challenge of public safety LTE networks [9].

Nevertheless, the original dedicated systems for public safety and other mission critical applications have been developed for different purposes and needs from the ones taken into account in the development of LTE-A and other commercial mobile networks. To this end, there is a big challenge in exploiting the infrastructure of the broadband commercial systems for providing reliable services for mission critical applications. The commercial networks lack of the high level security and reliability that mission-critical applications require, and for this reason, 3GPP has started addressing these requirements as part of the LTE evolution, with the first document concerning public safety published in 3GPP Release 11 [10].

A common technology for both commercial and dedicated public safety networks could offer many advantages and opportunities to both worlds. Sharing the network resources will reduce costs and deployment time while maintaining a single infrastructure supporting commercial and mission critical communications. The native support of (edge) cloud computing, SDN and NFV towards the concepts of network softwarization and slicing promote 5G as the ideal proponent in order to fully and flexibly address the needs of PS applications.

Some examples on how 5G networks can be exploited to realize mission critical PS services are presented in [3] and [5]. 5G ESSENCE offers orchestration and cloud enabled small cell infrastructure sharing, which is a new approach that has never been done before.

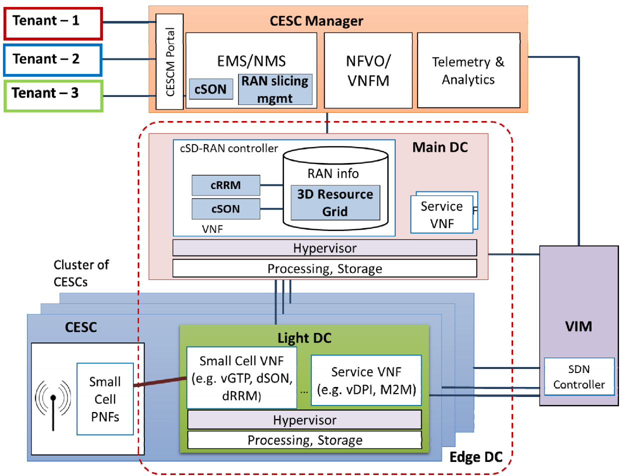

Fig. 1. 5G ESSENCE architecture.

The contribution in [5] focuses on the benefits of MEC-based architecture for mission-critical push-to-talk (MCPTT) services, by proposing a hierarchical distributed MCPTT architecture that allocates the user plane at the edge, while keeping the control plane (CP) centralized for synchronization and assistance purposes. The work in [3] studies and implements the use of commercial technologies for mission critical services for two important use cases: (i) first priority communication use case where authors apply dynamic QoS management to prioritize the MCPTT application by using policy and charging rules function (PCRF) in the core network; (ii) rapidly deployable network use case, where a distributed LTE network is implemented for the scenarios in which the legacy commercial network might be unavailable. However, 5G with enhanced capabilities can better support PS applications, as described next.

III. 5G ESSENCE SOLUTION

5G ESSENCE addresses the paradigms of edge computing and Small Cell as-a-Service (SCaaS) by fuelling the drivers and removing the barriers in the Small Cell (SC) market, forecasted to grow at an impressive pace up to 2020 and beyond and to play a “key role” in the 5G ecosystem. The main measurable objectives of 5G ESSENCE include:

- Full specification of critical architectural enhancements (as described in 5G PPP reference architecture [11]).
- Definition of the baseline system architecture and interfaces for the provisioning of a cloud-integrated multi-tenant Small Cell network and a programmable radio resources management (RRM) controller.
- Development of the centralized software-defined radio access network (cSD-RAN) controller to program the radio resources usage in a unified way for all CESCs (Cloud-Enabled Small Cells).
- Development of orchestrator’s enhancements for the distributed service management in a multi-tier architecture.

5G ESSENCE leverages knowledge, SW modules and prototypes from various 5G-PPP projects [12]. Building on these foundations, very ambitious objectives are targeted, culminating with the prototyping and demonstration of 5G ESSENCE system in three real-life use cases associated to vertical industries, i.e., edge network acceleration in a crowded event, mission critical applications, and in-flight communications.

A. 5G ESSENCE Architecture

5G ESSENCE targets the development and demonstration of an innovative architecture, capable of providing Small Cell coverage to multiple operators “as-a-Service”, enriched with a two-tier architecture: a first distributed tier for providing low latency services and a second centralized tier for providing high processing power for compute-intensive applications. To that end, 5G ESSENCE envisages to virtualize and to partition Small Cell capacity while, *at the same time*, it aims to support enhanced edge cloud services by enriching the network infrastructure with an edge cloud. 5G ESSENCE combines the MEC and NFV concepts with Small Cell virtualization in 5G networks and enhances them for supporting multi-tenancy and for increasing the network capacity and the available computational resources at the edge.

The proposed solution allows multiple network operators (tenants) to provide services to their users through a set of Cloud Enabled Small Cells (CESCs) deployed, owned and managed by a third party (i.e., the CESC provider). Fig. 1 shows a high level view of the envisaged architecture.

In the 5G ESSENCE architecture ([13]) the NFVI (Network Function Virtualization Infrastructure) spans across two tiers, Main DC and Light DCs, and this requires dealing with wide distribution and heterogeneity. The first tier, i.e., the Light DC hosted inside the CESCs, is used to support the execution of VNFs for carrying out the virtualisation of the Small Cell access. In this regard, network functions supporting traffic interception, GTP encapsulation/ decapsulation and some distributed RRM/SON functionalities are expected to be executed therein. VNFs that require low processing power, e.g., a Deep Packet Inspection (DPI), a Machine-to-Machine (M2M) Gateway, and so on, could also be hosted here. The connection between the Small Cell Physical Network Functions (PNFs) and the Small Cell VNFs can be realised through, e.g., the network Functional Application Platform Interface (nFAPI). The second cloud tier, i.e., the Main DC, will be hosting more computation intensive tasks and processes that need to be centralised in order to have a global view of the underlying infrastructure. This encompasses the cSD-RAN controller which will be delivered as a VNF running in the Main DC and makes control plane decisions for all the radio elements in the geographical area of the CESC cluster, including the centralised Radio Resource Management (cRRM) over the entire CESC cluster. As the geographic area of the cell cluster is at the edge of the 5G network, main and light DCs can be logically grouped together to form an edge DC. The legacy DC can be distinguished from the edge DC, being at the core of the cellular network.

The 5G ESSENCE system presents a high degree of dynamicity, due to the constantly changing behaviour of services and workloads to be supported by the radio and cloud infrastructure. From this perspective, a proper monitoring system able to adapt to the different supported scenarios is required. The data collected by the monitoring system is used for visualization purposes (for human consumption) and it is also provided to a set of analytics techniques capable of extracting insights from the data and, via feedback loop, enabling the realization of efficient resource allocation across the infrastructure, through the orchestration system. These are the functionalities provided from the 5G ESSENCE CESC Manager (CESCM).

The Orchestration module includes the Service Orchestrator (SO) and the Resource Orchestrator (RO) as part of Open Source MANO (MANagement and Orchestration) [14], in charge of configuring in one go, both the compute resources and the network resources, and the Virtual Infrastructure Manager (VIM) in combination with OpenStack [15], taking care of the computing resources, and OpenDaylight [16], taking care of flows, connections and communication between VNFs (and maybe other resources).

B. 5G ESSENCE for mission critical applications

As already stated, 5G ESSENCE common orchestration of radio, network and cloud resources is expected to fully meet the requirements of the PS sector. The objectives to properly support a PS application are the followings [17]:

- The priority access of first responders to the 5G ESSENCE enabled platform and more generally to a virtualised communication infrastructure
- The dimensioning and elastic resource allocation to first responders of radio, network and cloud resources in case of emergency
- The integration of first responders' deployable communications systems (macro base-stations, multi-RAT devices) to the 5G ESSENCE platform
- The hosting of Mission Critical (MC) applications and virtualised EPC (Enhanced Packet Core) to Edge DC for extremely low latency.

5G ESSENCE focuses on two MC services: MC Push-To-Talk (MCPTT), and MC messaging and localization services. The process of those services are as follows:

1. 5G ESSENCE platform owner provides the required network slices to different tenants
2. Allocation of data rates is made by the cSD-RAN controller in accordance with the cloud resources already allocated in the Edge DC by the VIM. In case of emergency, the CESC will add new resources taking into consideration the request, close-to-zero delay and maintaining the connection even if the backhaul is damaged. Moreover, 5G ESSENCE cSD-RAN controller will enforce the priority access of first-responders by extending the slices to the radio part thus creating the end-to-end slices that isolate those responders from other's parties' communications
3. In case that ICT infrastructure is damaged, the service operability is guaranteed by deploying the control plane at the edge. Therefore, when the backhaul connection is damaged, a new CESC is displayed to mitigate the damage in the macro base stations.

Fig. 2 shows the different components involved in the service of MCPTT. Eventually, an IP Multimedia Subsystem (IMS) can be implemented as a centralized subsystem attached to the EPC of each operator. Moreover, MCPTT server can be brought near to the user to achieve a distributed and scalable approach. As for the localisation and messaging service (FS), the proposed solution, called FeedSync, is based on a publish subscribe modular solution that works on top of the 5G ESSENCE leveraging the flexibility of 5G architecture. More interestingly, the virtualised approach enables on the fly deployment of new resources close to the users.

Concerning PS deployment, 5G ESSENCE project contributes to the 5G PPP KPIs as described in Table 1. The value of a KPI is determined by both the control and data plane issued functional components and interconnections. Concerning the service deployment time, the control plane impact is more relevant as the request of a network slice is elaborated (including resource deployment, configuration or generation of signalling messages) by the service and resource orchestrators, CESC-M, CSD-RAN controller, CRRM and VIM (with VMs/VNFs up and running). Concerning the service reliability, control plane components are deployed as sw by the cloud platform facilities providing very high reliability, while on the data-plane, the loss of packets is on the links, mainly wireless, where proper radio resource allocation has been performed beforehand.

IV. VALIDATION

The reduction of latency is one of the key pillars of 5G and the use of network slicing, along with VNFs, is critical. In 5G ESSENCE two-tier architecture, this kind of structure is perfectly matched with the use of CESCs on the Edge of the network, having enough processing power and network capacity to run services distributed between multiple locations (small cells deployed on fire brigade or police trucks in this case), in a way that it is possible to deploy and use mission critical messaging and localization as well as Push-to-talk applications much closer to the end user and, as a result, to achieve lower latencies. This is possible since the petitions and responses, sent using the specified tenant slice to the server, are not necessarily managed by the Main DC that is further from the end user and, at the same time, reducing Main DC traffic or eliminating it completely as an added value.

The desired capabilities of the implemented use-case enable:

- Deploying slice-oriented management and operation features of 5G ESSENCE with selected open-source LTE SDR (e.g. OAI, SRS) and Orchestrators
- Configuring per slice QoS guarantees and also inter-slice priorities in accordance with the Use Case needs;
- Demonstration of selected radio resource management techniques for radio resource allocation, configurable per slice (e.g. radio scheduler, admission control);
- Provisioning of an e2e slice and service which spans across EPC, RAN and eventually also the end-terminals (UE);

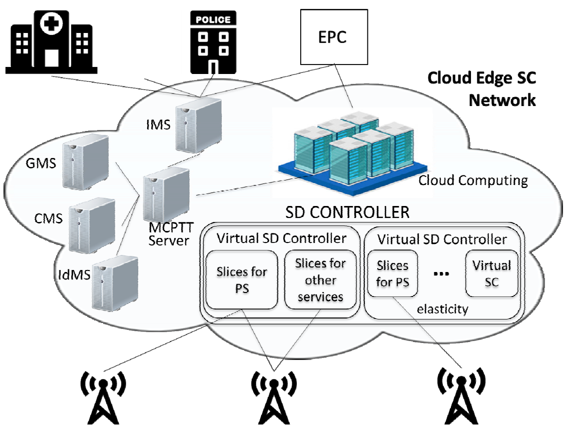

Fig. 2. Components involved in a MCPTT service for PS deployment.

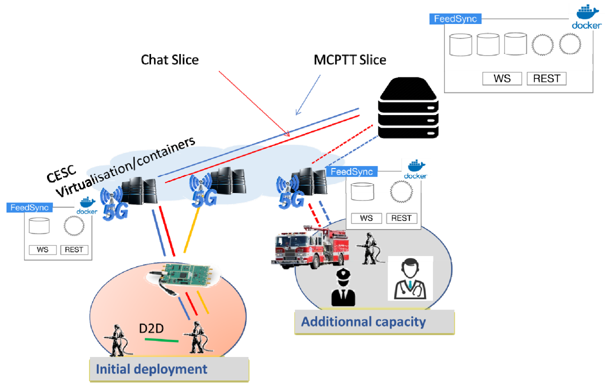

Fig. 3. Mapping the 5G ESSENCE architecture to a PS deployment for messaging and localisation.

- Defining an interaction between the slice operation and the D2D "infrastructureless" modes;
- Extending on the fly a slice with new resources (e.g. LightDC with small cell) as well as extending a slice with new heterogeneous resources (e.g. LightDC with small cell + LightDC with WiFi)

The validation is carried out by implementing a PS use-case and running a real-time demonstration on the ground. The demonstration of the PS use case cannot be based on a static scenario, since one of its objectives to be proven is the elastic allocation of resources attending to different levels of emergency conditions detected by the monitoring system. Therefore, a deployment topology in three main stages is considered. At the beginning, in a situation under normal circumstances, the system instantiates the network slices that correspond to a default service agreement. Here, the first responder only needs a reduced amount of access capacity and communication features for its normal operations. Then, triggered by an emergency incident, the first responder requires increased capacity in terms of both data rate and edge computing resources, in order to serve a higher number of communications and/or PS users. This situation may involve a deterioration of the service for legacy users, since their network slice must be reduced in order to appropriately allocate the higher priority PS service. Finally, the service responds to an extreme situation of damaged infrastructure where a coverage extension is needed. In this situation, backhaul connectivity is lost, all the resources must be dedicated to the public safety network slice and the PS organization may dynamically add new access points to the network to improve connectivity.

The validation scenario is described in Fig. 4 that highlights the issued 5G ESSENCE architecture and relevant components to support the PS use case implemented within the project [17].

Each supported PS service is associated to a different network slice. The first one is the MCPTT service corresponding to slice 1 in the figure. The second one is the chat messaging and localisation service corresponding to slice 2. Other slices including e.g. commercial services are also naturally considered, but are not depicted in the figure for simplicity. Both PS services rely on different VNFs running at the Edge DC and on the radio transmission capabilities provided by the small cell at the CESCs.

TABLE 1. 5G PPP KPIS ADDRESSED BY 5G ESSENCE

KPI	Service deployment time (SDT)	Service reliability
Definition	Duration required for setting up end-to-end logical network slices characterized by respective network level guarantees	Maximum tolerable packet loss rate at the application layer within the maximum tolerable end-to-end latency for that application
Enhancement work	The project offers small footprint virtualized elements (in the form of VNFs running in Unikernels or Containers) that are executed at the edge computing infrastructure	The CESC-M framework, supports reliability functions that are able to re-direct and re-allocate in alternative (stand-by) MEC or Small Cell infrastructure able to serve the deployment of the Use Case VNFs in case of failures
Where to measure	At the level of CESC-M (Cloud Enabled Small Cell Manager) where Requests for service deployment are directed	At CESC-M where the health of deployed components and infrastructure elements is monitored and decisions on actions for preserving operation are executed
How to measure	SDT = Time (service deployed /all VNFs and resources available) - Time (request sent)	Percentage of Service Status over time = Operational (uptime)

The MCPTT service includes an MCPTT server at the network side, an IMS, a DNS and an HSS. These functionalities can run as VNFs in the Main DC as they are common to all the CESCs in a service area. In turn, the MCPTT client will be hosted at each UE. Based on this, the creation of network slice 1 involves the instantiation of the abovementioned VNFs, done through the NFV MANO entities (NFVO/VNFM/VIM), and the instantiation of a RAN slice that provides a certain capacity to support the MCPTT transmissions at the radio interface, configured by the RAN slicing management function (a number of descriptors that specify the operation of the RRM algorithms. The services and features to support MCPTT are the followings.

- Group calls (with preemption for priority): to start a group call, the caller just selects the target group, presses the PTT button, speaks and the voice message is delivered instantly)
- Private calls (in a one-to-one manner)
- Emergency calls: pre-emptive calls due to an emergency condition. Upon the request of and emergency call, on-going calls can be terminated in order to free up resources for a higher priority call.

The demonstration of the MCPTT use case must meet the performance requirements of the standard [18]: 300 ms for the access time, 1000 ms for the end-to-end access time and 3000 ms for the mouth-to-ear delay. One of the most important performance criteria is the MCPTT access time, which is defined as the time between an MCPTT user requests to speak and when this user gets a signal to start speaking. In addition to these PS users (i.e. first responders by a PS Institution), the other actors involved in an emergency scenario related to MCPTT service are: a legacy Mobile Operator, a PS Operator and the legacy users.

The MCPTT-enabled architecture (and actually, correspondingly also the FS solution) involves the following elements: MCPTT clients (devices of first responders and personnel at the central station) and server (providing connection to clients and control-plane operations), media distribution unit (for media transmission on the data-plane), media mixer and the MCPTT user database (for profiling, AA and security).

In detail, there are more options for the virtualization of the MCPTT service architecture. The basic option is with all the functional blocks of the service packed in a single VNF. This configuration simplifies the connection between blocks, but provides little flexibility for scaling possibilities. While, the ultimate step of separation corresponds to the separation of also the data and Control Planes of the MCPTT service, bringing the data plane and needed control plane elements to the edge to reduce the transmission latencies.

As for the Network Slice 2 associated to the messaging service, it involves three types of functions, namely the FeedSync (FS) Client of the central station, the FS client at the UEs and the FS server. A FS server is assumed to be associated to each CESC deployed during the emergency situation to provide the communication with the UEs connected to that CESC and with the central station. Hence, it can be assumed to run as a VNF at the Light DC. In turn, the FS client of the central station can run at the Main DC or even at the PS operator premises outside the CESC infrastructure.

Applications such as WhatsApp, Telegram and others has motivated the interest of PS operators in these modern services. What is more, the one to many communication pattern allowed by these application, the facility in creating and modifying groups as well as the diversity of content these tool allow (text, and multimedia) constitute new features of high interest for mission critical operations.

Intensively relying on software and web based highly distributed frameworks, these new applications can be easily deployed on top of the 5G ESSENCE architecture (software components as VNFs).

In an operational situation, PS agents need to exchange a set of well-defined information. In addition to the communications between deployed rescuers, an interaction with the command centre is also required. The exact position of all deployed agents as well as a history track of exchanged messages can help enhance the efficiency of the operations.

Leveraging the 5G ESSENCE architecture the web application-based FeedSync framework as a publish-subscribe content distribution tool is adopted [17]. In addition to classical chat services, the implemented use-case ensures the set of features summarised below:

- periodic sharing of the position (GPS coordinates) of the deployed rescuers
- Direct communications between terminals
- A diversified content exchange
- Geo-content management with the configuration of areas for geo-targeting and geo-fencing.

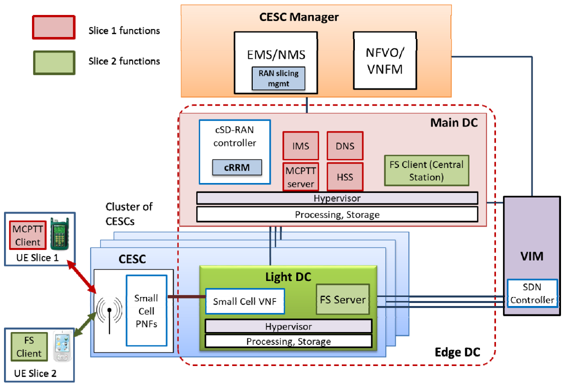

Fig. 4. 5G ESSENCE architecture instantiation for the PS use case

- Sharing of a content with multiple participants located in a precise geographic area (e.g orders to participant in a specific location)
- Management service with a centralized server for administration, configuration, and management as well as for authentication and authorization

The assessment of the implemented use-case covers unit, integration, functional and validation testing. To underline that Qualification and validation focus not only on verifying the correct functionality, but also on the performance of the platform, the overall satisfaction of the end-users and the fulfillment of all related functional and non-functional requirements.

The final demonstration of this use-case will take place at the B-APCO event in Newcastle (in early November 2019). The venue will be the Newcastle United Football Club premises at St. James's Park. In order to demonstrate the success of the 5G ESSENCE project to fulfil the PS workers needs for flexibility, it is proposed to show, in the context of a realistic operational end-user scenario, the real-time establishment of a 5G ESSENCE platform and the prioritised access to that platform by actors representing first-responders.

V. CONCLUSIONS

In this paper, the 5G ESSENCE project solution to properly support mission critical applications for PS has been described. Specifically, the MCPTT and group communications services have been addressed and instantiated through the realization of a real testbed. The 5G technologies have been leveraged and enhanced with a cloud-enabled small cell architecture with a flexible deployment of components at data and control planes. In this way, scenarios of PS, also with impaired backhaul can be enabled overcoming the current limitations of legacy PS solutions, yet providing the needed service quality and privacy.

At last, it is worthwhile to underline that the realization of such PS use-cases, demonstrates how 5G ESSENCE contributes to 5G architectural concepts, such as e.g., the realisation of the network slicing concept, also at the network edge. Indeed, this is a fundamental requirement of 5G ESSENCE for enabling that multiple tenants and vertical industries share the same CESC infrastructure.

Future work covers a full realization of the proposed solution at management and orchestration levels, as well as at the level of single functional components (e.g. control and monitoring). In addition, synergies with other 5G PPP projects are being carried out culminating in the sharing of testbed infrastructure, to make available for the final demonstrator.

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