A Framework to Support the Deployment of PPDR Services Across Edge and Cloud Domains

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Abstract. The 5G and beyond advancements will impact significantly the evolution of many vertical industries such as the Public Protection and Disaster Recovery (PPDR) sector. To this end, the requirements posed by PPDR operations and services can be satisfied to a certain great degree by 5G network capabilities associated with network slicing and incorporation of edge computing, while network coverage and availability even in disaster situations still remains a critical issue. However, the flexibility of 5G networks and the beyond 5G developments related to network and service orchestration can further lead the PPDR service provisioning. The 5G-PPP project Int5Gent aims at delivering a complete beyond 5G solution suitable for various PPDR operational scenarios, namely for day-to-day operations and for disaster scenarios; along with experimentation deployments for testing and evaluation. This paper discusses the service and technical requirements and provides an overview of the proposed technologies and deployment solutions.

Keywords: 5G · Public protection and disaster recovery · Edge computing · Vertical services

1 Introduction

In general terms, 5G and beyond networks move from network-driven to service-driven approaches, and this leads to a service provisioning transformation in terms of individualized services and user classification, and necessitates the shift to 5G and beyond distributed network deployments across cloud and edge domains. Of course, this transformation is also reflected in Standardization as we come across a number of 3GPP TRs

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focusing on vertical industries requirements and Key Performance Indicators (KPIs), layered service provisioning etc., such as those in [1–4].

Focusing on the Public Protection and Disaster Relief (PPDR) sector as key vertical industry, communications have for a long time relied on narrowband networks (TETRA - Terrestrial Trunked Radio, TETRAPOL- Terrestrial Trunked Radio POLice, etc.), mainly utilizing mission-critical voice and, in certain cases, low-speed data services as PPDR services were limited to voice communications what is called "the lifeline of the PPDR" [9]. From this point, PPDR Communications are increasingly being complemented by Intelligence ([8–10]) as they follow Information and Communication Technology (ICT) advances. In particular, advanced PPDR services are enabling more effective operations from the PPDR responders as well as more effective mitigation of disaster events, incidents etc. Such advanced services are search and rescue support using emergency robots and Unmanned Aerial Vehicles - drones (UAVs), sensing of the affected areas using high definition (real-time) video streaming and massive Internet of Things (IoT), Situational – Contextual awareness, multimedia messaging, high accuracy location services and mapping, etc. ([5–7]). The advanced PPDR service requirements, result in rendering traditional voice-centric network solutions tailored for PPDR incapable to effectively deliver modern PPDR services. 5G networks are considered the candidate technology for future PPDR services as they promise the required network performance and enable the necessary architectural options incorporating Edge Computing. At the same time, certain aspects such as automation and adoption of IT advancements are part of beyond 5G networks research, which can further elevate PPDR service availability and resilience.

A number of projects and programs (EU, national funded, equipment vendor supported, etc., e.g. [5, 11],) are focusing on the technical realization of the PPDR concepts and principles over 5G networks. In this landscape, the 5G-PPP Int5Gent project [12] focuses on delivering two implementation paradigms for future PPDR service provisioning. This paper aims at providing an overview of the PPDR services that drive future network deployments, such those to be demonstrated at a field testbed in Athens, Greece.

This paper is organized as follows: initially, the service and network deployment requirements and options are discussed on the basis of main PPDR operational scenarios. An overview of the Int5Gent deployment options -covering these requirements- and technologies is presented in the subsequent section. Following these, aspects related to the operational adoption of such solutions are discussed, while conclusions are drawn at the end.

2 PPDR Service and Network Deployment Requirements

The advanced PPDR services pose very stringent requirements to the network, such as low latency and quality guarantees for the support of these services. These come along with the technical requirement to have a deployment of applications/services close to the affected area in order to provide the necessary performance and availability requirements. At the same time, the ever since requirements for availability and reliability pose requirements for coverage augmentation, extremely high availability and reliability, isolated operation and network resilience during disaster scenarios. These come along with the technical requirements for on-demand network extension, as well as resilience at various network segments.

5G networks promise the required network performance in terms of latency, data rates, and architectural options by enabling Mobile Edge Computing (MEC), while certain aspects such as automation and adoption of Information Technology (IT) advancements are part of beyond 5G networks research. Int5Gent aims to deliver a solution for the PPDR sector addressing key deployment and operational models required for the successful commercial delivery of advanced PPDR services over the 5G-based deployments.

In particular, PPDR day-to-day operations require on-demand but scheduled provisioning of mission critical services even in areas lacking public network coverage. At network level, this can be translated into the need for supporting automated deployment of 5G Radio Access Network (RAN) to connect to public 5G Core network (5GC) wherever needed for a specific time period, supporting slicing for meeting the versatile PPDR services performance requirements. At application level, given the spatio-temporal character of the operations in this scenario, it poses the requirement for supporting automatic deployment and life-cycle management of mission critical services. Although these deployments do not pose strict KPIs with regard to the network and application deployment times, the service performance -latency and datarates- KPIs can be very strict depending on the application/ services (as appear in [1–4]).

In case of disaster situations when we can have total or partial unavailability of the public infrastructure (core network, cloud infrastructure etc.), a resilient solution for all network segments is required to enable the PPDR service provisioning. This can be translated into the need for supporting automated deployment of complete 5G network and applications wherever needed for a specific time period, supporting slicing for meeting the versatile PPDR services performance requirements. Given the time-criticality of operations, disaster situations scenarios pose strict requirement regarding the deployment times for the network and the mission critical applications, the target being less than 5 min. Similarly to the previous scenario, the service performance -latency and datarates- KPIs can be very strict depending on the application/ services.

Considering, also the fact that PPDR services in many cases are consumed at specific locations possibly from a small group of end-users, makes private network deployments for PPDR is a valid option. As aforementioned, currently, private networks –of various technologies- serve part of the PPDR sector needs however public telecom networks are also heavily used where private networks are not available; the latter option coming with the availability, resilience, isolation constraints. To meet the PPDR service requirements and KPIs, novel architectural solutions and network deployment options need to be considered, exploiting the 5G network service provisioning – e.g. slicing- and ICT capabilities. Apparently, there is no single solution to address such environment.

Other business factors may as well lead to public networks being extended for PPDR service provisioning. In these cases, a distributed core network deployment allowing service deployment and processing at edge compute resources, and traffic offloading at MEC components can serve well the purpose of meeting the performance requirements (especially for low latency), while optimizing public network utilization and performance. Latter trends are visible in many contexts, as presented in [17].

In other cases, the performance requirements and the diversity of PPDR services set as well as the need to support multiple tenants on top of a single infrastructure necessitates the adoption of the 5G concept of network slicing at service and tenant level. In general, PPDR services can be well-mapped to the 3GPP distinction of services to uRLLC (ultra-Reliable Low Latency), and eMBB (enhanced Mobile Broadband), as basis for network layer slicing, over either a single private network deployment or a distributed public one.

3 Int5Gent Architecture and Deployment Options for PPDR

Int5Gent aims to deliver a solution for the PPDR sector addressing key deployment and operational models required for the successful commercial deployment of the advanced PPDR services over the 5G. The solution is based on a disaggregated, layered, architectural approach, allowing for different deployment options depending on the situation [18].

In particular, PPDR day-to-day operations require on-demand but scheduled provisioning of network coverage and the enablement of mission critical services even in areas lacking public network coverage. Int5Gent proposes a solution of ad-hoc automatic deployment of 5G access network segments -namely the gNB and the MEC - dedicated to the PPDR sector at a compact server (an edge box as portable Infrastructure-as-a-Service), as an extension of the public network. The solution also includes the deployment/ configuration of a resilient wireless transport network segment. On top of this, the solutions allows for quick and automated deployment of reliable PPDR services exploiting cloud native principles and placing Artificial Intelligence- (AI) processing at network edge.

Secondly, in case of disaster situations when we can have total or partial unavailability of the public core network, PPDR services require a resilient solution for all network segments. Int5Gent solution proposes an ad-hoc automatic deployment of complete 5G-assured network -including all 5G network segments- dedicated to the PPDR sector at a compact server (edge box) – in the form of Non-Public-Network (NPN in 5G terminology). On top of this, as in the previous case, the solutions allow for quick and automated deployment of reliable PPDR services using cloud native principles and AI-based edge processing. The two main, Int5Gent deployment options are presented in Fig. 1.

Access Network Layer: The deployments imply the installation of the necessary Remote-Radio Units (RRU) at the location where the coverage extension is needed for both scenarios. For the Int5Gent experimental setup, there will be used RRUs optically connected to an (enhanced Common Public Radio Interface) eCPRI-based BBU (Base-band Unit) deployed at network edge capable to provide New-Radio (NR) in Stand-Alone (SA) mode, operating at N78 (Time-Division-Duplex, TDD).

Last Mile Transport: The deployment includes a multi-technology last mile transport network, taking into consideration cases where fiber deployment is expensive or eve not possible.

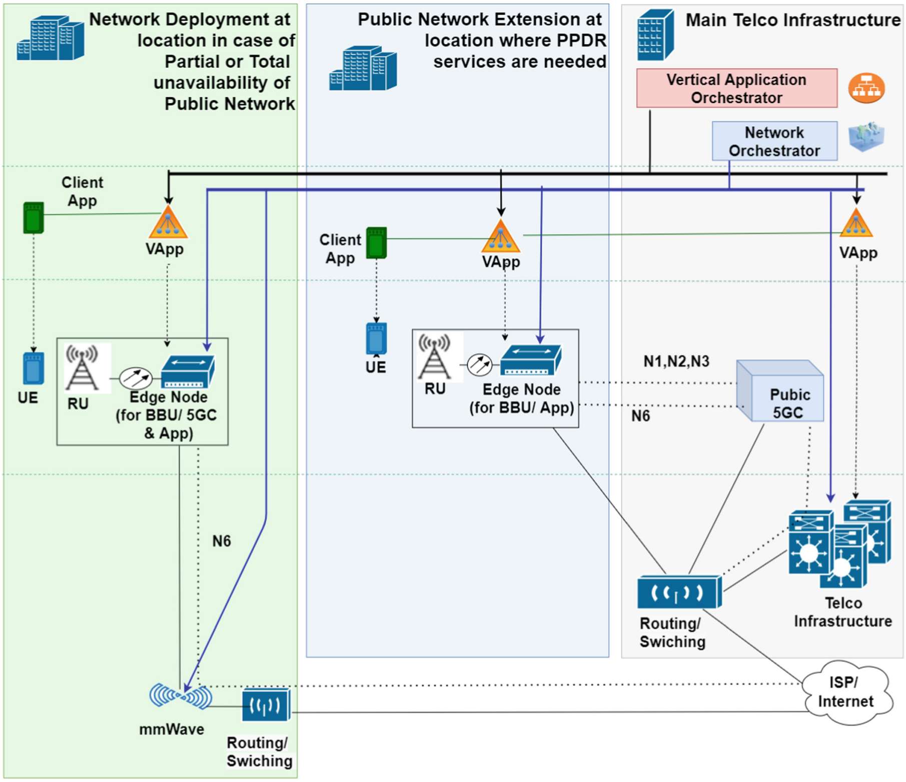

Fig. 1. Blueprint of Int5Gent deployments for PPDR services

Thus, besides the typical fiber network connectivity between the RRUs and the BBU (at edge compute resources), or/and from the edge towards a main switching point of the telco infrastructure, a number of millimeter-Wave (mmWave) mesh nodes supporting point-to-multipoint are deployed and configured at the transport network segment. The mmWave mesh nodes operate in the 60 GHz spectrum band and they use antennas with 360° total coverage, connecting in this way multiple low-cost client nodes which are used as the endpoints of the wireless transport network. In the disaster scenario this is particularly relevant, as these mmWave solutions aim to provide the necessary resilience this network segment.

Edge Computing: For the deployment of services, the central cloud infrastructure of a Telco could be considered for the day-to-day scenario. However, to meet the PPDR service requirements and to cater for the case of telecom operator (Telco) infrastructure unavailability, edge computing is considered in various ways - deployed at the location of the areas to be served. In the day-to-day scenario, edge computing will be used for the deployment of the necessary BBU functions, and edge applications with low latency and high resource requirements such as Artificial-Intelligent (AI) – based video services. In the disaster scenario, edge resources can be used for the deployment of the complete 5GC and applications.

For this purpose, the 3GPP network deployment shall be based on radio and network functions in the form of Cloud-Native Network Function (CNFs), namely: gNBs prepared as virtual BBU (vBBU) (extended with eCPRI-based RRU), 5GC prepared as a single CNF - that is integrating 3GPP Access and Mobility Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF) and Authentication Server Function (AUSF) and that is exposing 3GPP interfaces N2 and N3).

Virtualization of the edge resources allows their use for automated deployment of the necessary network functions and applications via appropriate orchestration layers.

In the context of Int5Gent project, the implementation is based on a portable Network Functions Virtualization Infrastructure (NFVI) prepared to be deployed at the network edge (edge box), at hardware level including Commercial off-the-shelf server (COTs) (x86 architecture extendable with eCPRI processing cards) over which various virtualisation frameworks can be deployed such as OpenStack and Kubernetes.

Network Management, Orchestration and Slicing: Adhering to the Int5Gent architecture [14], a network management (based on Open Source Management and Orchestration (MANO) (OSM) [15]) and service orchestration framework will support highly reliable and fully automated PPDR services and network deployment, and their life cycle management. In particular the network management framework includes, a number of SDN controllers and number of network orchestration functionalities providing the following functionalities/capabilities:

- mmWave backhaul transport network management and control
- CNFs and VNFs (Virtual Network Functions) lifecycle management including: Radio Network Slice components (vBBU) orchestration at the Portable NFVI (Edge), 5GC Slice components orchestration at the Portable NFVI (Edge)
- Exchange of information with Portable NFVI and Telco cloud for: application's quota arbitration and reservation, application's quota management,
- 5G Network Slices' modelling
- Application's high-level requirements mapping into 5GQI (5G NR Standardized QoS Identifier)
- End-to-End (E2E) Network Slice composition and orchestration

On the other hand, the Application Orchestration framework is compatible with state-of-the-art cloud orchestrators (k8s or OpenStack) undertaking the application lifecycle management, including:

- (User Interface) UI-based application onboarding
- UI-based application policy definition
- Automated application graph composition
- Application components' lifecycle management, orchestration, scaling
- Data analytics and monitoring dashboard

PPDR Applications at Network Edge: At application level, the PPDR services can be versatile; one of the most commonly targeted is drone-based real-time video streaming services enhanced with video processing capabilities and visualization of processed outcomes and extracted results. For such applications, Int5Gent considers the deployment of AI-based edge processing functions for the advanced functionalities. In the context of Int5Gent, a drone-based real-time video streaming service is used that exploits the network edge for delivering:

- live transcoding to various formats and resolutions depending on user type (e.g., field unit, dashboard/tactical command, AI),
- video source to leverage AI capabilities,
- core AI/ML (Machine Learning) (learning/inference) functions.

4 Further Challenges and Requirements

Apparently, different network architecture designs and various deployment options (e.g. extension of public networks, provisioning of network slices over public networks and NPNs etc.) are feasible for offering PPDR services. However, as aforementioned relying on public networks availability may not be the option especially in disaster situations, while extending public networks may no be feasible due to inexistence or inadequate resources of transport network deployment. In such cases, the deployment of NPN can provide the necessary connectivity for PPDR services.

In such niche 5G networks (NPN) deployed by the vertical at issue, additional challenges may arise, that need to be tackled. Indicatively, the deployment options to be followed at the access and fronthaul network layer entail significant network planning challenges that depend on the area morphology/cluster, the coverage area size, the services to be deployed etc. For instance, in some cases point-to-point fiber (p2p) between the access network equipment and the edge node can be a solution, however in cases where multiple access network sites are needed, the transition towards beyond p2p topologies is required. Deployment-oriented challenges are associated with these p2mp fiber distribution network connections between the radio and baseband resources though, such as the high-precision synchronization and the strict packet delay requirements [19]. In deployment scenarios where fiber is not an option, wireless fronthaul technologies need to be considered. In the latter case, on the other hand, wireless fronthaul links pose their own requirements related to their wireless signal propagation characteristics. On the other hand, services may pose significant challenges related to coverage and performance that need to be tackled at network deployment time; for instance, UAV applications imply spatial coverage in three dimensions.

For services that are not locally restricted to disaster area, it is needed to ensure continuity outside the boundaries of the niche 5G systems (NPN), which will involve the interconnection or even tighter interoperability with public ones (e.g. in the form of networks' roaming, or even in the form of service migration across networks). In other cases, for PPDR NPNs that aim to provide also public services in disaster situations, Multi-Operator Core Network (MOCN) or Shared RAN configurations may need to be considered. At this point, a policies framework fostering the deployment and operation of small-scale networks is key.

5 Conclusions

This paper has provided an overview of key PPDR operational scenarios -namely the day-to-day operations and the disaster situation- and the relevant service requirements. These requirements have been used as a basis for the definition of system specifications of the Int5Gent solution. The solution addressing this vertical is based on a resilient, automatically deployed network layer that entails the incorporation of edge computing at the proximity to service area. Edge computing serves for placing the necessary virtualized network functions –ranging from vBBU, to specific data plane Network Functions, and further to complete 5G network- and for processing intensive service intelligence (AI/ML) functions. The solution is completed with a cutting-edge network orchestration framework, with intelligent service allocation and management capabilities.

To this end, specifications have been nailed down to an experimentation deployment for testing and evaluation of the PPDR scenarios and drone-based real-time video streaming services. Future work will focus on evaluating the capabilities of the solution in a real setup and on identifying the challenges related to the operation of the solution.

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