5G Open Testbeds and Infrastructure extensions for NetApps advanced experiments

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***Abstract*—While 5G Non-Stand Alone (NSA) networks are quickly being deployed across multiple nations, providing a first sense of the capabilities of 5G connectivity, the adoption of 5G by various vertical industry sectors and its integration into their day-to-day operations is progressing slowly. This is partially due to the perceived complexity of deploying services over the 5G networks and due to the fact that the vertical stakeholders do not have a clear understanding of the potential and offerings of 5G. To address that, the concept of Network Applications (NetApps) is picking up steam which is set to assist with the deployment of vertical specific services and their seamless integration with 5G networks and vertical specific components. This paper, presents the work of the EU funded project VITAL-5G in deploying 5G Stand Alone (SA) testbeds in three real-life Transport & Logistics facilities across Europe, the necessary 5G network extensions and architectural considerations, their integration with a state-of-the-art experimentation platform and the use of NetApps to enable the seamless deployment of 5G-enabled vertical services.**

Keywords—5G; NetApps;experimentation platform; Transport & Logistics.

I. INTRODUCTION

5G is the key enabler for new business and digital transformation initiatives to integrate various vertical sectors such as automotive, logistics, energy, manufacturing, and more, into the network slice concept, maximizing the sharing of network resources and creating dedicated logical networks with personalized customer specific functions, which can deliver significant service added-value. Especially with the deployment of 5G Stand Alone (SA) networks, the service customization capabilities of the network reach a new all-time high, being able to flexibly, easily and quickly deliver targeted connectivity services to the various vertical sectors based on their specified needs, be it extremely high throughput (eMBB), extremely low latency (URLLC) or massive numbers of connected devices (mMTC).

Even though major experimentation campaigns and projects are ongoing already since the early deployment of 5G Non-Stand Alone (NSA) testbeds and networks (such as the H2020 ICT-17 projects[1]), to showcase the added-value of 5G connectivity for the various verticals, real-life adoption of 5G enabled solutions from the industry, remains relatively low. In order to address this issue, the European Commission has funded a series of Innovation Actions (projects), under the call H2020-ICT-41-2020[2], to demonstrate 5G-enabled services in various vertical sectors and to allow for external vertical experimenters to experience first-hand the potential of 5G connectivity and the ease of service deployments with the use of ***Network Applications (NetApps)***[3]. The use of NetApps is meant to obscure the underlying network complexity and to automate and streamline the necessary network slice selection and configuration and the respective integration of vertical components, in order to provide a way for non-network experts to easily deploy and configure end-to-end services.

VITAL-5G[4] is one of these projects, targeting to create 5G-enahnced services for the ***Transport & Logistics (T&L)*** sector by bridging the gap between the 5G experts, the T&L industry experts, and the application developers. The project engages key logistics stakeholders (port authorities, warehouse operators, etc.) and innovative SMEs, offering them an open and secure virtualized 5G SA environment, provided by leading European Mobile Network Operators (MNOs), to test and validate their T&L-related, NetApps. According to VITAL-5G a NetApp is a 5G-enabled virtual application which provides its own set of functionalities when deployed as a stand-alone entity and that can cooperate and interact with other NetApps to deliver more complex vertical services. NetApps extend the concept of Virtual Network Functions (VNFs) declaring (i) service level information to simplify their re-use, sharing and composition in vertical services and (ii) mobile connectivity requirements in terms of 5G network slice profiles or consumed 5G core services to automate their instantiation in 5G network virtual infrastructures.

In this paper the approach of VITAL-5G on 5G SA network design, configuration, orchestration and integration to the vertical infrastructure is presented. The necessary extensions and configurations to support the use of NetApps are discussed, as well as the integration of the 5G testbeds to the experimentation platform and open NetApp repository. The remainder of this paper is structured as follows: Section II discusses the relevant State of the Art, while Section III briefly presents the VITAL-5G T&L use cases, the resulting NetApps for each of them and their requirements which have driven the network design. Section IV discusses the VITAL-5G end-to-end architecture, orchestration and experimental platform choices and vertical infrastructure extensions and Section V presents the conclusions and future work.

II. STATE OF THE ART

5G architecture targets at supporting various vertical industries and high service performance in the 5G-PPP ecosystem over different 5G SA facilities. 5G vertical's diverse requirements, addressed by different NetApps, involve a multitude of architectural considerations and techniques according to different business area specificities on all 5G key pillars, as: service-based architecture (SBA), end to end network slicing, network programmability, Software-Defined Networking (SDN) and Network Functions Virtualization (NFV). End to end (E2E) Service Operations functions interact with the management of domain resources and functions that include Radio Access Network (RAN), Core & Transport Network, NFV and Multi-access Edge Computing (MEC), using closed-loop procedures specifically developed for resource fulfilment, resource assurance and network intelligence on building blocks within each management domain. Network programmability, another key concept of 5G networks, is used to ensure the end-to-end orchestration through a flexible configuration of the control plane and data plane (data plane programmability) of the transport network. Efficient 5G NetApps delivery is further improved through Artificial Intelligence and Machine Learning (AI/ML) enabled technique for data analytics for autonomous services and network optimization, predictions and service profiling.

In order to allow VITAL-5G project be focused on the development, management and sharing of innovative T&L NetApps, VITAL-5G planned to reuse the outputs of former/ongoing 5G PPP projects (e.g. ICT-17, ICT-19[5], ICT-53[6] projects) for the platform development (i.e. onboarding VNFs, orchestration functionalities, Graphical User Interfaces (GUIs), dashboards, etc.) and for the 5G-testbeds (ICT-17 5G-EVE[7] for Athens and Galati & ICT-53 5G-Blueprint for Antwerp testbeds reused and further extended for the purposes of VITAL-5G).

All three testbeds started with NSA configurations and 3GPP Rel 15[8] capabilities, with limited network slicing, resource orchestration and edge computing functionalities. In order to cope with the project objectives, they are being upgraded to SA option 2 configuration and 3GPP Rel 16[9], targeting end to end multi-slicing (RAN, transport and Core), enhanced orchestration capabilities, extending MEC infrastructure and coverage towards the vertical facilities. The VITAL-5G testbeds will be integrated with an open service validation platform to create a unique opportunity for 3rd parties, more specifically T&L application developers from SMEs, to validate their T&L related solutions and services utilizing real-life resources and facilities that would otherwise be unavailable to them.[10]

III. VITAL-5G USE CASES AND NETAPPS REQUIREMENTS FOR TRIAL SITES

VITAL-5G provides a complete framework that facilitates the design, provisioning and experimental validation of 5G-enabled vertical services in realistic and highly configurable 5G testing environments. VITAL-5G framework supports the verticals in all the phases of the experimental validation of T&L vertical services, starting from their design, and going through the different steps of 5G testing environment preparation, configuration, service instantiation, test execution and service performance evaluation.

A. Trials sites and use case overview

Three VITAL-5G vertical use case experimentation facilities were developed in Port of Antwerp, in Port of Galati on Danube River and in Athens[10]. The effort of VITAL-5G testbeds development was addressed in previous European projects such as 5G-EVE for Athens/Bucharest and 5G-Blueprint for Antwerp or derived from production 5G rollout initiatives as the one performed in Romania by Orange.

Antwerp facility deployed in the Port of Antwerp provides a fully standalone 5G network and has a similar blueprint comparable with Telnet's 5G commercial roadmap. It includes a 5G 3GPP Rel.16 NR, virtualized 5GC which will support SA architectures. In the port of Antwerp trial facility, the experimenters are able to test and validate solutions related with automated vessel transport through the VITAL-5G platform.

The Romanian facility started with 5G NSA implemented in Bucharest for early trials and continued with the extension made to offer 5G coverage in Port of Galati, running on dedicated virtualized infrastructure, targeting 5G SA deployment, based on virtualized network, with E2E network slicing and multi-slice capabilities. In Galati trial facility, the use case is addressing the testing and validation of solutions for the navigation sector with focus on efficiency and safer shipping operation. The use case will employ NetApps and 5G infrastructure together with data-enabled assisted navigation, systems of IoT sensors and video cameras with enhanced 5G enabled automations.

Athens 5G testbed, which is actually composed of three different platforms, one of them based on Open Air Interface (OAI)[11], will be upgraded from its existing NSA implementation to Rel.16 and SA architecture and will also be extended to the vertical facility for the purposes of the VITAL-5G trials. OTE uses a RAN, which is built on the Cloud RAN concept. NetApps functionality is validated in the real-life environment of the available warehouse, using real-life available data. The appropriate communication protocols (e.g. MQTT or HTTP) and interfaces are available to experimenters to facilitate the exchange of data from sensors/equipment in the warehouse to their own NetApps.

B. VITAL-5G NetApps network requirements

The VITAL-5G use cases will be realized via the instantiation of specific vertical services in each of the trial sites, through the use of vertical-specific (enabling vertical specific functionalities) and vertical-agnostic (enabling generic, customizable functionalities) NetApps, operating in tandem (chained) or in stand-alone mode. As discussed, NetApps contain both service-oriented and network-oriented aspects, and as such they become the key drivers behind the service-level and network level requirements, which in turn dictate the network architecture and configuration and end-to-end service design. To enable the implementation of its use cases, VITAL-5G is developing five (5) vertical-agnostic and nine (9) vertical-specific NetApps. An in-depth analysis of their service-level, application-level and network-level requirements is provided in [3], while a detailed description of each of their respective architecture and blueprints are provided in [12]. Due to space limitations, in this paper we will only address the network requirements analysis of an exemplary vertical service, with some of the most stringent NetApp requirements.

VITAL-5G used the vertical industries requirements analysis methodology proposed in [13] to analyze and categorize the network requirements of each of the envisioned NetApps and the respective T&L vertical services that are born from their chaining. Fig. 1 depicts the network requirements of a NetApps based T&L service to enable the remote control and autonomous navigation of vessels when birthing into ports. It can be seen that while the data rate requirements are not extreme (enough to support 3-4 UHD video streams and some additional sensor data), the latency, reliability and availability requirements for this (and most) T&L service are very stringent necessitating latencies below 5 ms (one way) and reliability/availability up to 99.999%. Additionally, increased capacity needs are foreseen to accommodate the multipole connected devices in the port and/or warehouse environment.

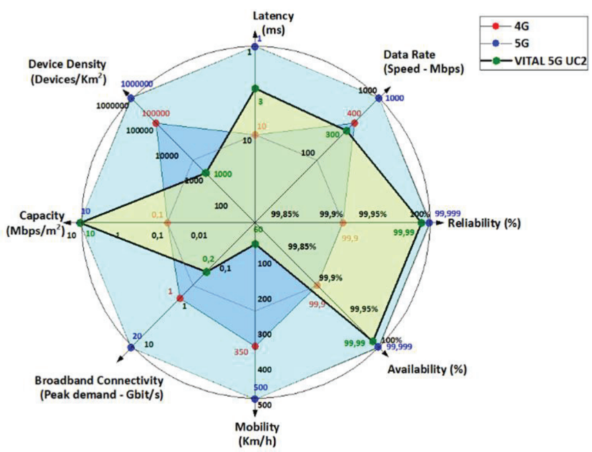

Fig. 1. VITAL-5G NetApps network requirements

The VITAL-5G end-to-end architecture was designed to accommodate the onboarding, configuration and deployment of NetApps and to accommodate these stringent network requirements. The final design and necessary infrastructure extensions are presented in the next section.

IV. VITAL-5G E2E ARCHITECTURE AND INFRASTRUCTURE EXTENSIONS

The VITAL-5G E2E Architecture represents the innovative technical solution and implementation framework for the 5G communication services required by the T&L industry's verticals. We are defining the new 5G processes of planning, design and deployment of the novel 5G infrastructures, including the major 5G components of the system, technical blueprints, interactions and interdependence between the elements in order to meet the system-relevant requirements. The architecture definition is trying also to cover the today's existing mismatches between Telco infrastructure's and verticals: (1) where network services can be deployed, (2) capabilities of dynamic services setup over 5G infrastructures with respect of testbeds available resources and interfaces interconnections, (3) new Vertical's NetApps interactions and trials in real T&L flexible infrastructures.

The proposed architecture and related infrastructure extensions are structured based on the VITAL-5G facility overall concept, as depicted in Fig. 1, focusing on the next main components:

a) Experimentation Platform & Open Online Repository, including the NetApps Development, Onboarding, Deployment, Experimentation tools

b) 5G-Testbeds and 3GPP Release 16 Stand Alone testbeds evolution in Antwerp, Athens and Danube (Galati)

c) 3rd party enrollment, as experimenmters and NetApps developers

As depicted in Fig. 2, the VITAL-5G platform is divided in two main blocks: The *Open online repository* and the *VITAL-5G Portal*. The *Open online repository* contains the NetApps, vertical services and experiment catalogues offering the services for vertical service and experiment design. In detail, this block supports the onboarding and management of NetApps packages, vertical services and experiments and interacts on the southbound interface with the Orchestrator catalogues to manage the NetApp Service Descriptors (NSDs) and VNF Packages associated with the NetApps and the vertical services. The *VITAL-5G Portal*, on the other hand, exposes the interfaces supporting the lifecycle management of the vertical services, execution of experiments and retrieval of monitored data and execution reports which allow to assess service performance. All the services of the platform are available through a GUI which interacts with the platform using the REST based Application Programming Interfaces (APIs) offered by the *Open online repository* and the *VITAL-5G Portal*. On the other hand, the *VITAL-5G Portal backend* contains different functional blocks responsible for exposing the interfaces and implementing the logic for: (i) lifecycle management of the Vertical Services; (ii) Execution of experiments (iii) Computation and retrieval of analytics and diagnostics. As depicted in Fig. 2, the VITAL-5G platform also contains a management backend block, which is used to provide the access control to authorize the access to the various services of the VITAL-5G platform, and to provide centralized inventories regarding the systems, platforms, IoT devices and 5G slices available on each testbed. This functional block interfaces with different modules of the testbeds in order to retrieve the available 5G slices and different elements of the testbed infrastructure.

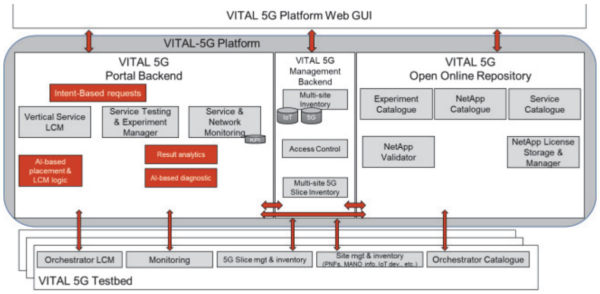

Fig. 2. VITAL-5G platform functional architecture

During the vertical service and experiment design phase, the different NetApp providers, service providers and experimenters use the services of the *Open Online Repository* to onboard new NetApp packages, vertical services and experiments. The platform validates the onboarded descriptors, determining if the testbed contains the required VNFs and 5G slices matching the 5G mobile traffic of the NetApp, and uses the interface with the testbeds to update the Orchestrator Catalogues with the VNF Descriptors (VNFDs) and NSDs associated with the NetApps and with the vertical services. After the design phase, a vertical service can be instantiated using the *VITAL-5G Portal backend* services, which maps the specific vertical service instance request to different network service level and 5G slice level requests towards the testbeds, based on the specific instance request and the 5G mobile traffic characteristics established by the different NetApps composing the service. During this phase the platform also configures the monitoring information to be collected from the testbed monitoring platforms based on metrics established during the service design phase. An experimenter can then run experiments on top of the running vertical service instance, which will trigger the execution of an experiment script and the configuration of the analytics and reporting functional blocks with the targeted Key Performance Indicators (KPIs) defined for the experiment as a combination of the different metrics. The results of the experiment execution, which asses the overall KPI validation during the experiment execution, can be retrieved from the different analytics and diagnostics modules.

VITAL-5G testbed architecture

The testbeds architecture is an evolution of the architecture described in Section II, evolution that is focusing on the existing VITAL-5G Stand Alone testbeds, software and hardware components, Rel. 16 capable and related interfaces, interacting with VITAL-5G Platform. Each of the project testbeds is designed to support the required 5G NetApps communication services, as depicted in Fig. 3.

In VITAL-5G we define the architecture with the support of the relevant 5G testbed's related network component, in order to fulfill the requirements of the NetApps deployment over 5G infrastructure. As expected, the base of the proposed architecture is composed by: (1) Virtualized Infrastructure environment, (2) NF communication framework – REST APIs, (3)5G RAN and (4) the CN functions, as the target architecture for VITAL-5G testbeds is 3GPP Rel. 16 compliant.

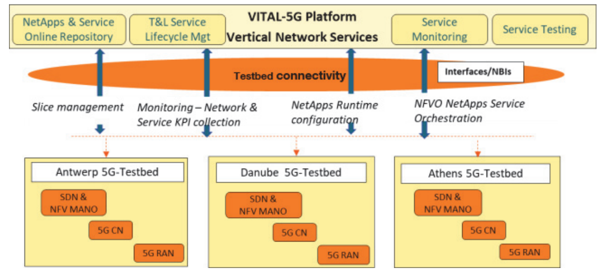

Fig. 3. 5G testbeds high-level architecture

We propose a fully virtualized environment for specific 5G core (e,g UDM, UDRs, AUSF, AMF, UPF) and NetApps functions, running on top of Open tools software for virtualization, based on Openstack[14] for specific NFV/VNFs and Apps being implemented in VMs, Docker[15] and K8s[16] for CNFs and Apps requiring OS-level virtualization delivering software packages in containers or Unikernels for specialized, single address space machine image.

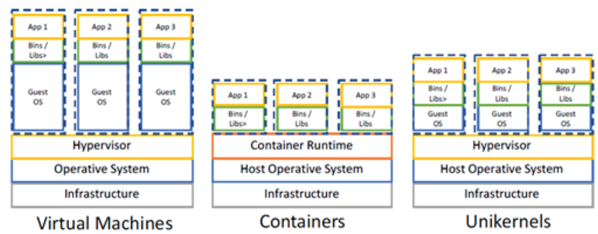

Fig. 4. VITAL-5G virtualized infrastructure capabilities

The scope of our E2E architecture is not mainly to describe the network and software components used in VITAL-5G, but to design the 5G E2E architectural reference and key points deployment to fulfill from the technical perspective the NetApps needs and to cover the existing gaps. Regarding this point, in the proposed architecture we are also considering as the starting point the availability of the virtualized infrastructure pool of resources, available to be used within the project for the NetApps and 3rd Party apps development, onboarding and further experimentation, within the 5G open testbeds, as detailed in Table 1.

The 5G RAN and Core functions are the mandatory network elements for VITAL-5G architecture, 3GPP 5G Stand Alone Architecture, Option 2, for 5G control plane and user plane system, mapped on the 3GPP Architecture. [17] The envisioned VITAL-5G radio and core architecture are in line with the 3GPP standards, as the network is evolving from 5G NSA to 5G SA, through several steps of deployment and integration activities to achieve the implementation of the 5G network system, as presented in Table 2.

The proposed architecture and the 5G open testbed implementation framework in VITAL-5G contains also the network interfaces between the testbeds and the Platform, covering activities like slice management, network monitoring and service KPIs collection, NetApps runtime configuration and NetApps MANO, defining and implementing RESTful APIs. The framework is in line with the Common API Framework

(CAPIF), 3GPP set of specifications ordering common capabilities exposed by 5G Northbound APIs.

Table 1 Virtualized infrastructure available resources

Resources Testbeds capabilities	Compute			Virtualization capabilities	
	RAM (GB)	CPU (Core)	Storage (GB)	VMs	CNs
				Virtualization software tool	
VMs/CNFs	16	12	40	Openstack	Docker/K8s
Total	1000	1000	4000	1000	1000
Features available	3[rd] Party resources exposure		Monitoring		Service Orchestration
			NetApps	Services	

Table 2 5G system and network resources

5G NF	RAN	Core	Transport	MEC
Features	NSA/SA	NSA/SA	Layer Architecture	Apps Platform
3GPP Rel15/Rel16	eNB/gNB Physical/VMs	vEPC/5GCN Virtualized	QoS/QoE Service Flow	System management
Slicing	APN NSSAI/SST	APN NSSAI/SST	QoS DSCP MPLS	E2E slicing
Security	Security Architecture and Procedures ENISA Security reports			
Orchestration	OSS/BSS	OSS/BSS OSM	Network Orchestrator	OSM

VITAL-5G infrastructure upgrades and extensions

The infrastructure upgrades and required testbeds extensions have to answer to several key factors provided by the 5G networks, identified as 5G system key components. For clarity, we have identified some main testbed extensions, within the VITAL-5G E2E reference architecture. The most important points to be highlighted are service layer evolution and vertical's APIs integration, E2E network slicing and slice management, 5G SBA, evolution to Rel.16, advanced monitoring and security and cyber security aspects related to 5G networks and service application.[9]. We extended our testbeds to support new interfaces and REST APIs between the 5G testbeds and VITAL-5G platform, as defined in the E2E architecture, Fig. 2. Based on this extension, we are able to perform and to expose the network and service KPIs collection to the centralized monitoring platform for analytics and AI-base diagnoses, runtime and orchestration of the NetApps, T&L services experiments.

The 5G E2E network slicing must be supported in 5G RAN, Core and Transport. We have performed the hardware and software upgrades to support the network slicing definition, based on NSSAI (Service Slice Template and Slice Differentiator). We have also defined the 5GQI for GBR-5QI 1,3 and non-GBR 5GQI 5, 6, 7, data traffic into the infrastructure and the mapping to DSCPs, GBR (EF, AF31) and non-GBR (AF41 and AF21).

Table 3 5G SA slicing parameters

Slice Name	Service Type	Slide Differentiator	DNN	5GQI/ DSCP	AMBR(Mbps)	
					DL	UL
NSSAI-1	1	abcdef	embb	5/AF41	2000	200
NSSAI-2	2	abcdea	urlcc	1/EF	50	50

The testbeds are upgraded to support the SBA for 5GC components, transformation that requires the deployment of the proper virtualized infrastructure, Openstack and Kubernetes based, where we run the microservices for core network components functions, as seen in Fig. 4. The testbed extension is also containing the orchestration software tool (OSM), that is aiming to orchestrate the E2E testbed and NetApps. At the time of writing not all the component and services are fully orchestrated through OSM, as we focused mainly for the NetApps services, due to the complexity of integration processes. The RAN and Core network upgrade to Rel.16 enhanced our capabilities to provide the network slices definition, as presented in Table 3.

Security in 5G networks is evaluated, following possible physical and cyber-attacks in 5G networks and applications, as described by ENISA, on topics as virtualized network, SBA modularized services, slicing, API exposure, for two main domains: (1) network and (2) application domains. From the 5G architecture perspective we follow the security architecture and procedures, as defined by [18], RestAPI authentication procedures and encryption. The 5G testbeds security is also offered by security rules and design, high capacity firewalls upgrades, control plane and use plane traffic separation, DDoS protection, secured interfaces between the testbeds and VITAL-5G platform, through IPSec VPNs tunnels.

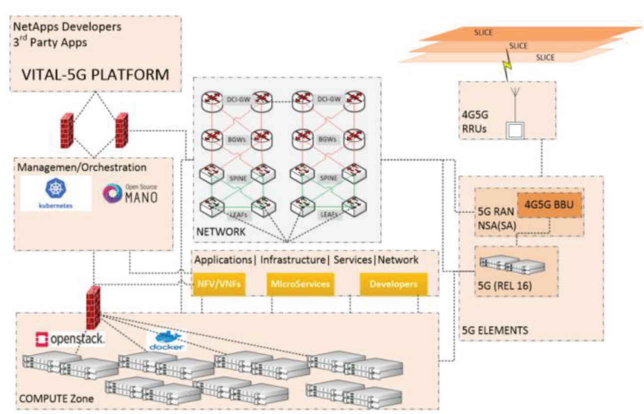

Fig. 5. VITAL-5G testbed components integration

The testbeds capabilities and need to support the 5G services, as seen in Fig. 5, summarizes from technical perspectives the required upgrades, extensions and components integration to provide the VITAL-5G open experimental framework from novel NetApps and services.

V. CONCLUSIONS AND NEXT STEPS

In this paper, we proposed our vision regarding the necessary upgrades and extension of the 5G testbeds and vertical infrastructures with appropriate RAN/Core functionality, and migration to Rel.16, described as enhancements to the actual state of the art existing testbeds for the new NetApps communication needs. We have defined the reference architecture, targeting the open concept of 5G testbeds, open and virtualized, for the vertical's use cases experimentation. We also proposed several key features related to 5G, aligned with standards, that are enhancing the existing 5G testbeds to support the new features. We have identified several steps, from technical testbeds design, new hardware and software development and integration, VITAL-5G Platform integration. We reinforced the value of virtualization in 5G SBA networks, introducing new capabilities and functions, RESTful APIs exposure and interfaces. We also highlighted the openness of the testbed to be accessed by the 3rd parties' experimenters, that will fully benefit by the enhanced 5G testbeds capabilities, network slicing(multi-slicing) and services orchestration. In VITAL-5G we have also integrated, based on the activities described in this paper, the 5G SA E2E network components, that allowed us to implement and experiment the enhanced communication capabilities provided by 5G SA networks. We have provided several early experiments on the testbed infrastructure, as in **Error! Reference source not found.**, with impressive relevant results, in term of 5G network capabilities, eMBB network slice, Uplink speeds more that 1000Mbps, as in Fig. **6** and Downlink speeds up to 160Mbps, as in Fig. 7.

Fig. 6. VITAL-5G SA eMBB DL experiments results

We will continue the integration work of the 5G concepts, experimenting the multi-slice environment, E2E slice and service orchestration and NetApps deployment in the proposed 5G testbed architecture, results that will be presented in the next paper.

Fig. 7. VITAL-5G SA eMBB UL experiments results

ACKNOWLEDGMENT

This work was funded by the European Commission under the European Union's Horizon 2020 programmed – grant agreement No. 101016567 (VITAL-5G project). The paper solely reflects the views of the authors. The Commission is not responsible for the contents of this paper or any use made thereof.

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