Future 5G network implementation and open testbeds deployment for real 5G experiments

Marius Iordache, Oana Badita*, Bogdan Rusti*, Andreea Bonea*, George Suciu^, Eleni Giannopouloui$^{\beta}$, Giada Landi$^{\theta}$ Nina Slamnik-Krijestorac*[♦]

* Technology Department, ORANGE ROMANIA, Bucharest, Romania

* E-mail: marius.iordache@orange.com; oana.badita@orange.com; bogdan.rusti@orange.com; andreea.bonea@orange.com

^BEIA Consult International, Bucharest, Romania, e-mail: george@beia.eu

$^{\beta}$ WINGS ICT Solutions, Greece, e-mail: nellygiannopoulou@wings-ict-solutions.eu

$^{\theta}$ Nextworks, Italy, e-mail: g.landi@nextworks.it

[♦]University of Antwerp - imec, IDLab - Faculty of Applied Engineering, Belgium, nina.slamnik@imec.be

***Abstract*—5G Stand Alone (SA) networks are in the process of implementation, as the adoption of the 5G services by various industries will be adopted step by step, as today's progress of the main business services to migrate to the 5G new services communication (eMBB, URLLC, mMTC) is estimated to slowly increase. There have been identified some key aspects responsible for this process adoption of the novel 5G communication, as the complexity of the services deployment and the clear understanding of the huge potential of the technology that can further support the 5G vertical's stakeholders. This paper is representing the work of the EU funded project VITAL-5G in deploying 5G SA 3GPP Rel.16 testbeds, with enhanced network and services capabilities, 5G resources available to be offered to industries vertical's customers. The 5G solution of the testbed design is covering several aspects of the future 5G network implementation, as services management and orchestration, automation of resources allocation, 5G network slicing (RAN, Core and Transport) and user traffic prioritization according to the service slice needs, as eMBB and URLLC. Another key aspect is the availability of the entire 5G ecosystem to be offered to the 5G developers and 3rd parties for advanced and extensive trials, as VITAL-5G is presenting an open and secured environment for real testing and experiments, with focus on NetApps implementations.**

Keywords—5G, NetApps,5G testbed, 5G SA, MEC, OSM

I. Introduction and motivation

VITAL-5G[1] aims to utilize the existing resources and knowledge from previous 5G PPP projects (e.g., 5G EVE [2], 5GSOLUTIONS[3], 5G-Blueprint[4]) as well as other relevant projects and commercial assets to support a significant 5G enablement for the T&L vertical sector and relevant actors. In addition, VITAL-5G will overcome critical limitations identified regarding the adoption of 5G in production services by T&L industry verticals, namely a) a network-centric vision on 5G orchestration tools, b) a substantial mismatch of backgrounds exists between Telcos and Verticals, and c) packages for 5G/NFV experimentation which are network-only services or are usually applied to small scale trial experiments. Moreover, orchestration and network slicing platforms available in state-of-the-art (both in the form of design artifacts and prototypes/products) do not provide high level interfaces for allowing T&L verticals to design and deploy services in a completely automated and autonomous manner. Furthermore, T&L has become increasingly complex over the past years, as the collection and analysis of enormous amounts of data must be conducted in real time. Cameras, sensors, and other interconnected devices have to communicate across a network with an uninterrupted connectivity and large swaths of bandwidth. To overcome this complex transformation, VITAL-5G will embrace 5G technology to design a set of innovative Vertical T&L NetApps and vertical-agnostic NetApps associated with an open repository and a service orchestration platform to create an enhanced 5G experimentation facility. In order to showcase the functionality and added value of the proposed experimental facility Vital-5G targets three versatile T&L use cases will be instantiated and executed from vertical industry actors and SMEs, namely UC1: Automated Vessel Transport, UC2: 5G connectivity and data-enabled assisted navigation using IoT sensing and video cameras and UC3: Automation & remote operation of freight logistics (Warehouse logistics).

To this end, VITAL-5G aims to create an open validation platform for advanced multi-modal logistics services to automate freight transport. Three 5G testbeds are being integrated in the platform to validate their T&L related solutions and services utilizing real-life resources and facilities. In addition, the platform has been designed to ensure third parties can readily engage with the platform and other available VITAL-5G resources to conduct their own experiments.

10.1109/FNWF55208.2022.00069

As mentioned above, there are specific gaps and limitations that Vital-5G addresses by introducing specific innovations, as detailed below:

- Enhancements to Intent-Based APIs for NetApps
- Platform-agnostic vertical slice design and control for NetApps
- Advanced KPI Analytics & Diagnostics tools for NetApps
- Reusability of the 5G EVE and the 5G-Blueprint 5G facilities
- Replication in non-ICT-17 5G facilities
- Seamless integration of 5G-powered devices for freight logistics (vessels, robots, AGVs)
- VITAL-5G Open Online Repository & NetApps
- NetApps for T&L sector
- Vertical-agnostic NetApps

II. VITAL-5G Architecture

A. *VITAL-5G Experimentation Services*

VITAL-5G implements a framework to support experimentation services for the design, provisioning and performance validation of 5G-enabled vertical services in pre-operational, flexible and customizable 5G infrastructures, deployed over three target testbeds in Athens, Antwerp and Galati. VITAL-5G specifically addresses vertical services for the T&L sector, with testbeds deployed in different types of T&L facilities (a river port, a sea-ports and a warehouse) properly extended with 5G networks. The offered testing infrastructures feature network programmability and network slicing, to meet the requirements of different T&L services in a dynamic and on-demand manner. The high level of configurability allows it to emulate different network conditions and tune the services for a variety of operational contexts. Virtual computing resources are available at edge and cloud domains for the provisioning of virtualized applications which can be deployed as VMs or containers following a cloud-native approach. Finally, extensive monitoring functionalities allows the collection, real-time distribution, storage and visualization of service and network metrics, as input for experiment validation, automated and close-loop service management, as well as dynamic and programmable re-configuration of the service applications, bringing network awareness in the design and provisioning of 5G-enabled vertical services.

VITAL-5G experimentation services target T&L vertical industries and, as such, have the objective of facilitating the understanding and usage of 5G connectivity services and infrastructures without requiring a strong know-how in networking technologies. Service modeling follows an application-oriented pattern, hiding the 5G network complexity and automating all the procedures related to the network management and configuration starting from the high-level requirements of the mobile connectivity. As a consequence, services are modeled as a collection of NetApps, i.e., virtual applications that can be deployed in 5G infrastructures and make use of 5G connectivity and/or 5G services (e.g., network data analytics). T&L services are composed of one or more NetApps [5], which can be designed and delivered by different software providers. Their provisioning, configuration, monitoring, and lifecycle automation is entirely handled by the VITAL-5G platform, which coordinates the allocation of the application resources in the virtual infrastructure and the configuration of the 5G network, e.g., in terms of selection or creation of new network slices dedicated to service traffic.

The VITAL-5G platform covers all the phases of the experimental validation of a NetApp-based T&L service (Figure II-1).

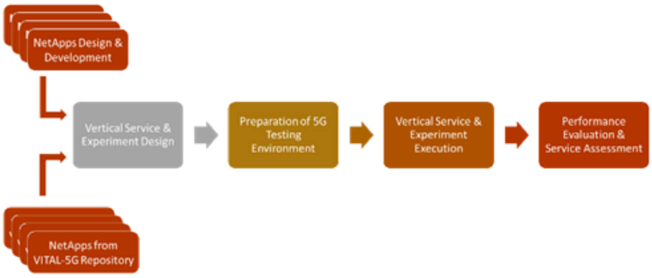

Figure II-1: Experimental validation of T&L services

During the design phase, the vertical can define new NetApps or re-use and compose the ones available in the VITAL-5G catalog to define and customize new T&L services. NetApp and Vertical Service Blueprints provide a common template to describe services and applications, declaring their requirements in terms of mobile connectivity, coverage, monitoring, edge/cloud resources, T&L devices to interface with (e.g., IoT sensors or cameras installed on-board), etc. The provisioning of the service is handled automatically from the platform, starting from the information defined in the blueprint. The application components are instantiated in the virtual environments available in the target testbed, the required network slices are properly created and configured for the application traffic, and the monitoring is activated for the network or service metrics to be evaluated during the experimentation. Additional features are available, in terms of optimization of the service deployment, service intent translation, automated functions scaling, results analysis, troubleshooting and diagnostics. AI/ML techniques support diagnostics and service lifecycle management decisions.

B. *VITAL-5G architecture*

The architecture of the VITAL-5G platform is shown in Figure II-2.

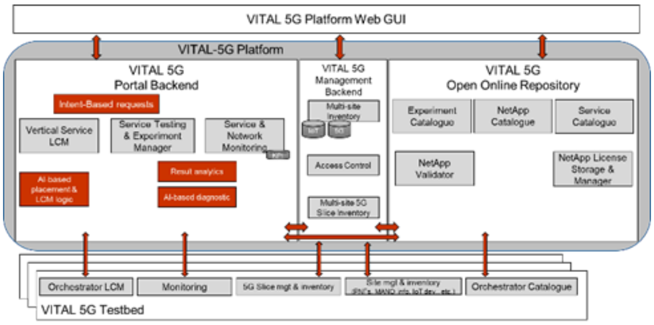

Figure II-2: Architecture of VITAL-5G platform

On its north-bound interface the platform provides a unified access to all the VITAL-5G experimentation services, via REST APIs (for programmable interaction with third-party systems) or via web GUI, to facilitate the processes for experimenters and vertical users. At the south-bound, the VITAL-5G platform interacts with the 5G networks, edge/cloud infrastructures and T&L systems deployed in each specific testbed, using a set of drivers for commands' and protocols' translation.

The core of the VITAL-5G Platform is composed of two main functional elements: the Open Online Repository and the Portal. The former implements the catalog of NetApps, vertical services and experiments onboarded in the system, described through unified blueprints, and enables the onboarding of new services or NetApps coming from third-parties. The latter implements the services for provisioning and management of T&L services, experiment execution and control, collection and visualization of monitoring data, as well as experiment validation and reporting of diagnostic results.

VITAL-5G platform interfaces with the three VITAL-5G testbeds, mostly through their 5G management system, NFV orchestration system and monitoring system. The actions performed over the testbeds allows to automated the onboarding of new packages, the lifecycle management of NFV-based services, the NetApps configuration, the selection or provisioning of custom network slices, as well as the retrieval of the network KPIs required to evaluate the performance of the end-to-end service. Since each testbed deploys its own 5G network, SDN/NFV controllers and orchestrators, T&L facility systems and monitoring platforms, a unified and abstract interface has been defined to expose common and technology-independent functionalities towards the VITAL-5G platform.

III. VITAL-5G USE CASES AND RELATED SERVICE

As mentioned in Section I, the VITAL-5G project is focused on three T&L use cases deployed in three different testbeds, addressing challenges in the river/sea port and warehouse environments, leveraging the 5G ecosystem benefits. The Romanian use case, "5G connectivity and data-enabled assisted navigation using IoT sensing and video cameras" is focused on the implementation of a data-enabled assisted navigation application using IoT sensing system and video cameras installed in Galati port and on ships and barges (cargos). The transmission of all these data (velocity, heading, water depth etc.) to the ship local monitoring equipment and the access to live video streaming from the surroundings through high definition video cameras, allowing real-time operations on the ships, both for safer navigation and on-board diagnosis, require very low-latencies, very high data rates, high network availability and low service creation times, uniquely offered by 5G. It targets three distinct services, enabled by a mix of vertical-specific and vertical-agnostic NetApps, while trying to reach the business KPIs of the vertical stakeholder, Navrom, making use of eMBB and URLLC services types (multi-slices with different service descriptors). The three services are described in the following paragraphs.

A. *Data-enabled assisted navigation*

The service uses the IoT sensing system and video cameras installed in Galați port and on the Navrom vessel. It uses VS8 for specific collection of data from the Navrom vessel. It uses one vertical specific NetApp, "On board data collection & interfacing for vessels" (VS9) and one vertical agnostic NetApp, "Data stream organization" (VA6). The first one focuses gathering information from sensors on board the ship (such as those measuring water depth, water speed, outside and internal temperatures, and engine operational characteristics) as well as from cameras mounted there. The local onboard server receives all data and acts as an interface to/from external edge nodes and the 5G network. This software program is being created at the server level, with particular interfaces for various onboard installed devices and surveillance modules. The second NetApp contributing to this service handles the organization data streams to the navigation center using 5G network parameters for efficient transmission. Video streaming and data from various sensors (GPS, humidity, smoke, velocity, etc.) are transmitted to the navigation center via wireless protocols over a private 5G network, allowing the sensing system's Internet connectivity to be extended for use by specific applications, such as assisted navigation for collision avoidance and diagnosis.

This service is eMBB and ULLC combined service (multi-slice), requesting very low latency (15 ms at most), high throughput and very high reliability, in order to provide near real-time reliable access to sensing data and video streams and proper processing to enable accurate warnings and rapid events classification, improving reactions time from vessels crew

B. *Accurate electronic navigation maps creation*

It is used for estimating the correct safe distance for a ship by using distributed sensor data ingestion, fusion, and post-processing. The data contains velocity, heading, water/wind speed, Global Navigation Satellite System (GNSS) data that are fed by VS9 NetApp described above and processed by another vertical agnostic NetApp, "Distributed sensor data ingestion, fusion & post-processing" (VA2). Within VA2 NetApp, distributed data sources are ingested, combined, and processed afterwards; cloud-based decisions are made as a result of the analytics; alerts, notifications, and reports are issued. As a starting point, already existing AI/Data analytics tools and inspection applications will be improved with additional fusion and analytics capability and converted to NetApps.

This service is an ULLC service requesting very low latency (20 ms at most) and very high reliability, in order to estimate the correct safe distance for a vessel by using distributed sensor data ingestion, fusion, and post-processing.

C. *Predictive maintenance and sanity checks*

The service is applied on the sensor data for ship safety purposes, thereby using monitoring and on-board diagnostics data supplied by VS9 NetApp and processing them using the third vertical agnostic NetApp, "Remote inspection & risk assessment" (VA3), for limiting human error and potentially wrong decisions. The VA3 NetApp utilizes data coming from other NetApps and specifically in Romanian use case, the VA2 NetApp, offering fused real time and batch information. It then offers Machine Learning and/or Artificial Intelligence mechanisms depending on the purpose, i.e. the specific needs of the T&L site and the type of information to be employed for the decision making. This way, various functions are achieved like automated labeling, outlier detection, trace back analysis, graphical representations, predictions/forecasts for the near-future and therefore offer advanced diagnostics to aid decision making and specifically for the case of predictive maintenance. To sum up, the incoming data exposed by VA2 are fed an ML/AI module that is responsible for the model development with respect to the predictive maintenance functionality. Model usage and calibration of multiple ML models for the extraction of meaningful results is automated. The models' results are then sent to a Data Persistence entity, which is also responsible for the exposure of the results to other components/NetApps through the appropriate interfaces.

This service is an ULLC service requesting very low latency (20 ms at most) and very high reliability, in order to use monitoring and on-board diagnostics data supplied by VS9 and processing them through VA3 to reduce human error and potentially wrong decisions.

In order to set up the use case, several sensors, including GPS, humidity, smoke, and engine power sensors, are being implanted on the ship and barges. These sensors provide relevant information to the ship's local monitoring equipment, such as velocity, heading, water, and wind speed, allowing the captain and crew to make appropriate decisions and supporting on-board diagnosis. All associated data is transmitted via 5G SA network to a central server in a major port and used as input data to update an electronic map containing river parameters (water depth, temperature, velocity, various obstacles) and weather conditions in real-time. To maintain competitiveness, 5G IoT technology will be used to reduce logistics costs while also improving productivity and efficiency.
In the scope of VITAL-5G project Orange deployed and integrated a 5G SA Option 2 network configuration (5G RAN and 5G 3GPP Rel.16) that covers Navrom ship positions and headquarters, as shown in the coverage simulation output in the figure below, as the red coverage corresponds to NR sector 1, while the blue coverage corresponds to NR sector 2.

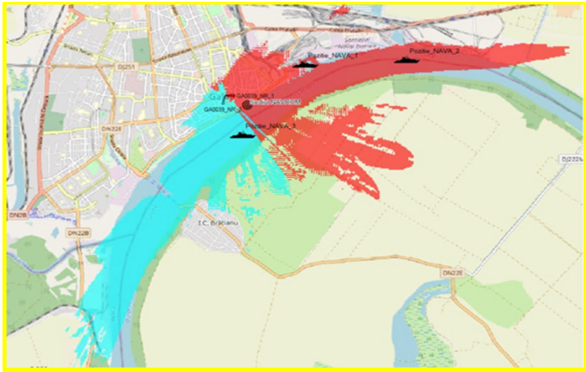

Figure III-1: 5G Galati site coverage simulation map with the use case interest area representation

IV. VITAL-5G TESTBED DEPLOYMENT AND NETWORK RESULTS [ORO]

VITAL-5G testbed architectures were specifically designed to sustain the NetApps [5] validation and experiments. The scenario of validation is performed in the real-life testbeds resources environment in line with the standards, 5G-PPP efforts and targeting 3GPP Rel16 capabilities. Upgrades and testbeds extensions have been deployed by integrating in the proposed architecture the new services orchestration platform and online catalog (VITAL-5G Platform), including advanced features such as network slicing and service orchestration, VNF onboarding, Life-Cycle Management (LCM), performance diagnostics and abstract experiment specification through intent-based mechanisms. The Romanian VITAL-5G testbed is designed and built as an adaptive 5G architecture evolving to 3GPP Release 16, having the following main capabilities; (1) 5G RAN and Core components, software and hardware; (2) 5G transport network (IP/MPLS/SR/DWDM); (3) virtualized environment, Openstack based and Kubernetes; (4) Orchestration, OSM related; (5) Security network and services implementation; (6)Network slicing implementation.

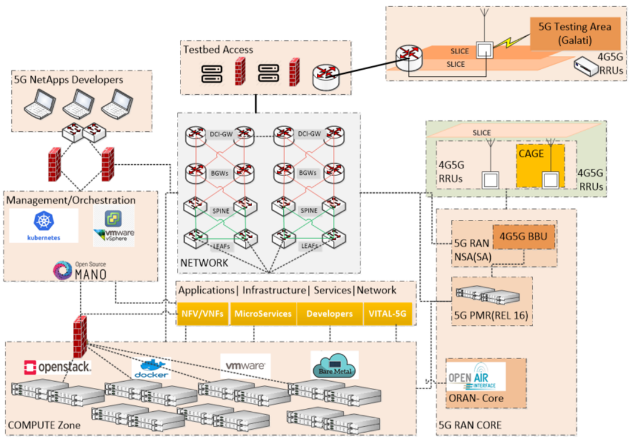

Figure IV-1: VITAL-5G Orange testbed infrastructure

Orange testbed deployment contains a datacenter composed of 4 racks units full of network and compute equipment's from various technology brands like Cisco, Fortinet, HP, Nokia and Huawei ready to host and accommodate applications and services for a 5G ready network and services, using as virtualization environment software tools Openstack Ussuri distributed cluster based on containers, ESXi VMWare [6] cluster and Container Kubernetes cluster.

The testbed network elements for RAN, Core, Virtualization and Network were deployed in two phases, for both 5G NSA and 5G SA services. The deployment started with the 5G NSA RAN in n78 band (3.5 GHz) using 4G as the anchor point of the control plane and Core (vEPC & 5G RAN network integration), Option 3x with an advanced IP-FABRIC [7] network infrastructure that has been introduced for cloud services delivery and an IP network open for transport service orchestration. The IP-FABRIC is using BGP EVPN as control plane and VXLAN as data plane encapsulation with a lot more benefits versus the legacy layer-oriented Datacenters using Core, Distribution and Access layers. The NSA Core architecture is composed of a vEPC deployed in an Openstack infrastructure capable of supporting broadband connectivity, configurable UL/DL speed at UE level at increased rate (1Gbps DL and 100Mbps UL) with the 5G services being manually configured using dedicated APNs and network provisioned capabilities in terms of throughput. Within the scope of VITAL-5G, a telco cloud infrastructure for VNF, CNF and bare metal services apps has been implemented, supporting IaaS/CaaS over Openstack and Kubernetes/Docker and OSM v10 orchestrator compliant with ETSI MANO architecture integrated with infrastructure controllers offering the capability to build different VNFs and Network Slices across all the platforms inside the lab. The 5G NSA testbed deployment includes also the 5G OAI [8] open software tool deployment in a Kubernetes cluster, experimenting with the 1st eMBB network slice able to provide a simple network slice based in APN.

The 5G SA 2nd phase of deployment includes the 5G service over a standalone network in a private mobile network concept integrated also in the Orange Romania Bucharest 3GPP Release 16 testbed. The 5G is running on dedicated virtualized infrastructure using 5G SA option 2 implementations. A 5G SA testbed extension has been deployed in Galati city and will contain the 5G network architecture containing the 5G UPF and MEC functions with all the network components deployed and integrated. The extension facility in Galati is connected via the IP multi-protocol label switching (IP/MPLS) high speed technology with 10Gbps links to our central cluster which performs advanced network control functions, as well as analytics, computation and data storage. A list of 5G devices has been selected, UEs, CPEs and industrial CPEs to support Galati port use cases, for both NSA but mainly the 5G SA technologies, in order to benefit of 5G Rel. 15/16 for URLLC/eMBB services with 5G RAN support.

The monitoring solution is a key component of the Vital-5G Testbeds and Platform as it provides the path to T&L use cases validation through metrics collected at network, infrastructure, service and platform level. These metrics will result in a set of KPIs that will be further analyzed in order to identify potential issues or bottlenecks in the end-to-end deployment. The Orange testbed monitoring solution is based on the framework presented Figure IV-2 below, setting up the collection of the data from the different infrastructure sources, 5G SA Core and RAN and transport network.

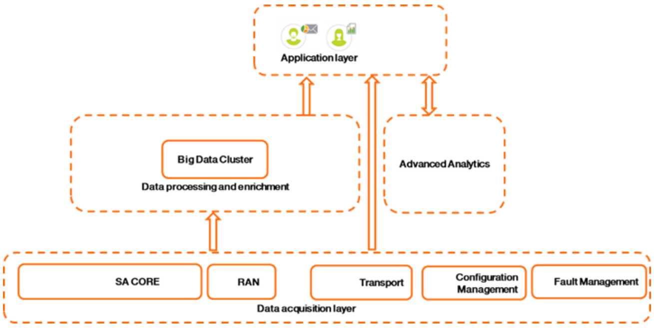

Figure IV-2: VITAL-5G Orange testbed monitoring framework [9]

Based on network tests several generic functional KPIs can be extracted at network and at slice level. By setting up probes in different points of the flow from the UE to the core, one can review KPIs on UE side, at the UPF Data, Network Interface and also in various points of the RAN and Core. The VITAL-5G testbed owners have agreed on a common set of network KPIs to be measured across their 5G ecosystem, to facilitate the extraction of common insights, grouped by testbed components. Certain KPIs are collected in several points (RAN, Core and Infrastructure) such as user-experienced UL\DL, packet successfully delivered or total packets sent and packet loss rate. At UPF level, we focus more on minimum UL\DL throughput, latency and reliability. Also, the number of dropped and forwarded packets is measured. From UE benchmarking, the indicators that can be extracted focus on guaranteed network latency, application guaranteed bit rate, bandwidth, coverage, UL\DL peak throughput. The jitter and end-to-end latency are also considered.

Besides the common agreed metrics mentioned above, the monitoring component of Vital-5G Orange Testbed also collects and makes available for analysis several other KPIs, the most relevant reported from RAN part being: average number of users, call setup success rate, drop call rate, QoS flows establishment success rate, 5G average reported CQI, PRB load in UL and DL, intra-RAT handover success rate, average downlink user throughput, paging discard rate etc.

D. *KPI Methodology and VITAL-5G practice*

In this Section, we present an overview of metrics that will be collected during the pilot trials, for each of the experiments associated to the defined tests. Given the diversity of pilots in the project, as well as the presence of different 5G ecosystem components such as 5G radio and core network (jointly referred to as Network), NFV infrastructure for deploying services, VITAL-5G platform, and service that are designed and developed for each of the use cases, we made a thorough analysis of all types of metrics that are essential to collect and study towards testing and validating the performance of 5G-enhanced vertical services for T&L environments.

In Fig. X, we first define four different metric categories, depending on the scope of the overall 5G ecosystem to which they apply, i.e., network, infrastructure, platform, and service metrics. Second, for all metric categories, we create a common methodology of defining metrics, which consists of the metric type (Non-functional and Functional metrics), as well as parameters such as measurability, priority, description, testbed components, involved parties, measurement granularity, source, and measurement description. In particular, Non-Functional metrics reflect the performance of deployment and management of vertical services (e.g., network, platform, infrastructure, and service configuration/management/orchestration), i.e., and these metrics do not directly affect the service performance that is experienced by end users (e.g., vessel, and AGV). On the other hand, Functional metrics are related to network/infrastructure/platform/service performance that has a straight impact on the users' perception. The assessment of measurability and priority is done per each metric.

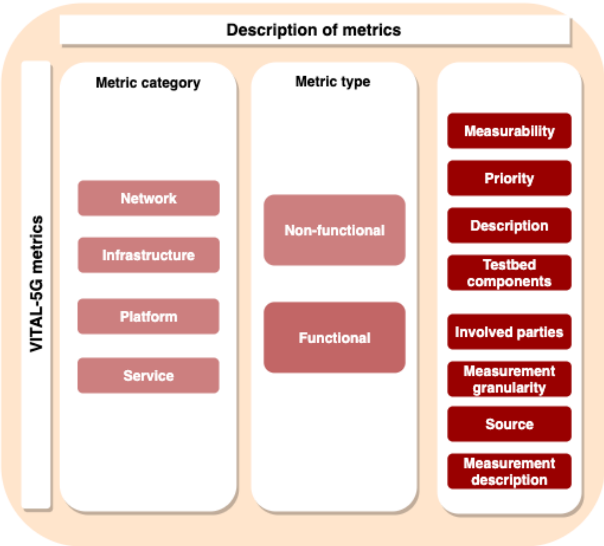

Figure X: KPI methodology in VITAL-5G

The overview of involved testbed components helps us to distinguish which components on a particular 5G testbed (e.g., Galati) are involved in measuring the KPI (e.g., 5G RAN, 5G Core, Uplink classifier, UE, OSM, or NetApp). The measurement granularity determines how often the metric is measured, i.e., either in real-time or non-real-time (historical data collected after an experiment is executed), also referring to time granularity, i.e., per second/minute/day. The measurement description is further described in testcases, where partners define a detailed procedure of performing tests and collecting respective relevant measurements. Some examples of network KPIs are end-to-end latency, bandwidth utilization, peak throughput on the uplink and downlink, and network reliability. Concerning service KPIs, we define them as common for all vertical services in all three use cases within the VITAL-5G project, such as service availability, reliability, and scalability. Under the umbrella of platform-oriente KPIs, we define the list of metrics that reflect on the performance of management and orchestration operations, and study how their performance affects the performance of vertical services. Some of them are on-boarding delay, service deployment and termination delay. Finally, infrastructure metrics are defined to determine the computational/memory/disk load imposed on the RAN, Core, and NFV infrastructure (servers with NetApps), while running vertical services in all three use cases within the VITAL-5G project.

V. Conclusions

In this paper we have presented the technical implementation of an advanced 5G SA Rel.16 testbed ready to cope with all the requirements related to the future 5G application and services, based on two main pillars. The first is the 5G services functionality in terms of network tested impressive performance, as for the eMBB slice we have obtained up to 1.6Gbps DL throughput and up to 160 Mbps UL per users, URLLC slice delays less than 1.5ms in MEC environment. The second pillar is related to the entire suite of tools and services supporting the 5G services, as automation and orchestration, advanced network and services monitoring, KPIs evaluation, service slice offered to the end-users and the capability to expose the testbed to the 3rd parties experimenters for future 5G application developments, tests and experiments. Supported by the developed 5G infrastructure in the VITAL-5G project, we will facilitate the 5G access for the future startups, SME and academic researchers, to fully benefit from the extraordinary resources made available by the project's developed solution.

Acknowledgment

This work was funded by the European Commission under the European Union's Horizon 2020 programme – 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.

References

[1] VITAL-5G: Vertical Innovations in Transport And Logistics over 5G experimentation facilities, H2020, Grant Agreement No. 101016567, https://www.vital5g.eu/consortium/

[2] 5G EVE: 5G European Validation platform for Extensive trials, H2020-ICT_2017, https://5G-ppp.eu/5g-eve/

[3] 5G SOLUTIONS for European Citizens, H2020, Grant Agreement No. 856691, https://5gsolutionsproject.eu/about/consortium/

[4] ICT-53 5G-Blueprint, H2020, Grant Agreement No.952189, https://www.5gblueprint.eu/about/consortium/

[5] VITAL-5G Deliverable D2.1, "Initial NetApps blueprints and Open Repository design", https://www.vital5g.eu/wp-content/uploads/2022/01/VITAL5G_D2.1_Initial_NetApps_blueprints_and_Open_Repository_design_Final.pdf

[6] VMware ESXi, https://www.vmware.com/products/esxi-and-esx.html

[7] Cisco IPFabric, https://www.cisco.com/c/en/us/td/docs/switches/datacenter/pf/configuration/guide/b-pf-configuration/IP-Fabric-Underlay-Options.html

[8] OpenAirInterface 5G Core Network, https://openairinterface.org/oai-5g-core-network-project/ (visited on 15/02/2021).

[9] VITAL-5G Deliverable D3.1, "Report on VITAL-5G infrastructure upgrades & extensions", March 2022, https://www.vital5g.eu/wp-content/uploads/2022/04/VITAL-5G_D3.1-Report-on-VITAL-5G-infrastructure-upgrades-extensions_v1.0.pdf