On Enhancing Transport & Logistics Sectors with 5G Testbeds and Edge Network Applications (EdgeApps)

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***Abstract*—The Transport & Logistics (T&L) industry directly employs around 10 million people and accounts for 5% of the Gross Domestic Product (GDP) of the European Union (EU). Effective T&L systems are fundamental for the ability of European companies to compete in the world economy. With the advent of 5G with the data rates of up to 20Gbps, its end-to-end latencies down to 5ms, and its very high reliability (99,999%), there is a significant opportunity to bring innovations to the T&L vertical, and why the T&L sector is expected to be one of the key adopters of 5G technology. In this paper, we define a 5G testbed tailored to T&L vertical services, which are designed and developed using the concept of 5G-based Edge Network Applications defined within the European project VITAL-5G. In addition to the testbed, we also describe the interaction with the testbed and its accessibility via the VITAL-5G platform, which supports T&L actors to experiment and validate their services within the real-life 5G-based T&L environment (e.g., sea ports, river ports, and warehouses).**

***Index Terms*—T&L, 5G, 5G 3GPP testbed, EdgeApp, VITAL-5G.**

I. Introduction

Some of the new capabilities 5G will deliver are 100x faster data rates compared than 4G, ultra-low latencies below 10 ms, support for 1 million connections/km^2 and ultra-reliable $>$ 99.999% availability of the network [1]. Furthermore, the 5G enterprise market for T&L is estimated to reach \$2.9 trillion by 2026 [1,2], with over 2.6 billion subscriptions anticipated by 2026, encompassing up to 65% of the world's population and producing 45% of all traffic [3]. As a result, it is expected that the T&L sector becomes one of the key adopters of 5G technology [1]. As a result, there is much potential across different industry verticals (automotive, T&L, eHealth, etc.) to leverage 5G systems and create innovative 5G-empowered applications.

One key enabler to incentivize growth in the T&L sector is through Edge Network Applications (EdgeApps), because they abstract the complexity of the underlying 5G infrastructure to T&L application developers [1]. Therefore, they have the potential to reduce service creation and deployment times, and optimize the utilization of 5G resources, thus leading to reduced service deployment costs. These EdgeApps operate at the edge of the network. The general advantages of Multi-Access Edge Computing systems (MEC) include lower latency, relieving network load in the core networks, and potentially keeping data locally for security/privacy reasons. That is also why we call our network applications EdgeApps to benefit from these advantages of the edge. One of the options to deploy distributed edge solutions is through Edge computing at the EdgeApp platform. In this solution, the User Plane Function (UPF) can be directly connected to the local customer data center via a regional break-out solution. In the case of the Antwerp testbed, the use cases have existing computing power and operation centers where data can be reached from the public network. A regional breakout point close to the Antwerp testbed is used to provide a direct connection towards the use case owners via fiber ring.

To help to accelerate this growth, adoption, and economic benefits that come along with EdgeApps in the T&L vertical, the European Commission has launched the VITAL-5G project [4]. VITAL-5G provides an enhanced 5G-empowered experimentation facility, with a portfolio of appropriate EdgeApps, which enables T&L application developers to test and validate their T&L applications within 5G ecosystems, in a user-friendly and intuitive manner, thus significantly reducing operational inefficiency and reducing market entry barriers prior to deploying their T&L service to live 5G networks [1,4]. The VITAL-5G platform backend operates on top of distributed 5G facilities, composing the three VITAL-5G testbeds, each of them offering a 5G infrastructure including cloud and edge resources where EdgeApps can be dynamically instantiated and orchestrated in network slices customized on the basis of the experiment requirements [1,4]. These enhanced 5G-empowered experimentation facilities consist of three well-established 5G testbeds [1,4].

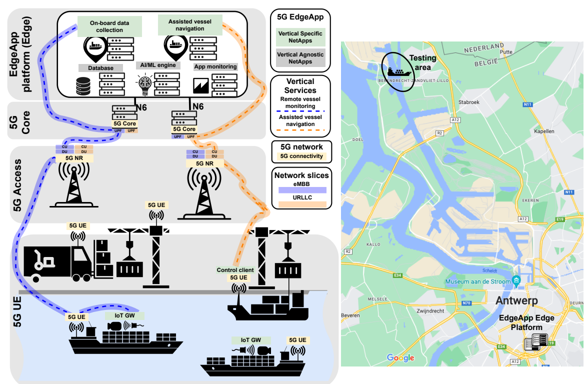

Fig. 1: VITAL-5G Antwerp 5G testbed and T&L pilot site.

In this paper, we focus on one of the enhanced 5G-empowered experimentation facility testbeds, more specifically the one located in the Port of Antwerp, as shown in Figure 1. We show how we use the VITAL-5G platform to connect to different 5G testbeds, how we use testbed resources to deploy various vertical services, and we explain in depth the goal and concept of EdgeApps and how we manage and orchestrate vertical services and EdgeApps in the Antwerp testbed.

II. Edge Network Applications (EdgeApps)

A. The Concept of EdgeApps

EdgeApps are the fundamental building blocks of T&L services in 5G, which simplify the composition of complex services, abstracting the underlying complexity and bridging the knowledge gap between the vertical stakeholders, the network experts, and the application/service providers, while specifying service-level information (vertical specific) and 5G requirements (5G slices and 5G Core services) [5]. The concept of EdgeApps is extending the declarations of the service level information to the conventional orchestration-oriented descriptors proposed in the European Telecommunication Standard Institute (ETSI) Network Functions virtualization (NFV) to make it easier to reuse and integrate EdgeApps into vertical services [6]. For example, the definition of EdgeApps interfaces allows us to compose different EdgeApps into vertical services, and share those EdgeApps across multiple T&L services. From the 5G slicing and orchestration capabilities perspective, the EdgeApps also extend the orchestration descriptors with the specification of the main characteristics of the required 5G slice for optimized orchestration decisions [6]. Additionally, the integration and validation stages of the EdgeApp development lifecycle are also covered by the VITAL-5G EdgeApp concept. In order to evaluate the performance of the EdgeApp in a given scenario from the perspectives of functional integration and overall performance, the VITAL-5G EdgeApp specification also comprises the definition of the test scripts and the intended metrics and Key Performance Indicators (KPIs).

Thus, an EdgeApp can be considered as a set of internal Atomic Components, which corresponds to virtualized deployment units (e.g., a container or a virtual machine) and implement the different parts of the EdgeApp logic [6]. These components interact with each other through a number of internal Connectivity Services i.e., equivalent of virtual networks [6]. Each component has one or more endpoints that enable this interaction [6]. These endpoints can be internal ones, used only for the interaction among the components of the same EdgeApp, or external ones to interact with elements external to the EdgeApp [6]. These external endpoints are used to model the connection points associated with the EdgeApp interfaces that provide access to the EdgeApps functionalities for final users or other service elements that interact with the EdgeApp itself [6]. Thus, an EdgeApp is a pure virtual application that can be deployed in a 5G infrastructure and can make use of 5G connectivity and/or 5G services. This enables the opportunity to consume network data analytics or location information offered by the 5G Core Network, to implement its internal logic and provide its functionalities for a service consumer.

B. EdgeApp design principles

The VITAL-5G project defines four different types of EdgeApps, i.e., Vertical Specific EdgeApps (VS), Vertical Agnostic EdgeApps (VA), Component-based EdgeApps, and Service-based EdgeApps [6]. More in-depth information on the types of EdgeApps can be found in our previous work [5].

Traditional VNF packages include software images for the Virtual Deployment Units (VDUs) that make up the VNF itself (or Containerized Deployment Units in the case of Container-based Network Functions - CNFs), as well as a VNF descriptor outlining how the VNF should be deployed in the target virtual environment (e.g., number and size of VDUs for different deployment flavors of the same network function, internal and external network connectivity, performance metrics to be collected, etc.) [6]. Additionally, VNF packages typically contain a number of additional files and metadata related to the VNF configuration files and software licensing [6].

The VITAL-5G EdgeApp packages extend this idea of VNF packages by offering additional information, with a focus on the EdgeApp integration chains and the automation of EdgeApps testing in a variety of 5G environments [6]. This enables the distribution, deployment, and reuse of EdgeApps across a number of application services and in a variety of settings [6]. The VITAL-5G EdgeApp metadata that is contained in the EdgeApp blueprint and incorporated in EdgeApp packages serves as a model for this additional information [6]. The VITAL-5G Platform uses this metadata for two different purposes [6]. On the one hand, to make it simpler and more convenient to browse and search for EdgeApps in the VITAL 5G EdgeApp catalog [6]. On the other hand to define the logic that is exclusive to EdgeApp itself. Additionally, a number of extra files provide additional documentation and test cases which make it easier to use and validate EdgeApps [6]. The VITAL-5G EdgeApp package as a whole is a compressed zip file that includes the EdgeApp metadata, the EdgeApp blueprint as a text file, and a variable number of folders including files, such as the specification documents of the software design and test cases, VNF packages and software licenses [6] as shown in Figure 2.

The EdgeApp packages are used to onboard new EdgeApps [6]. The format of the VNF package and VNF descriptor follows the specifications defined in the ETSI GS NFV-SOL 004 [7] and NFV-SOL 006 [8]. The VNF packages used in the VITAL-5G are compliant with the format adopted by the Open Source MANO (OSM) [9] NFV Orchestrator (NFVO), which are available in all the three VITAL-5G 5G-empowered 5G 3GPP experimentation facility testbeds [1].

C. EdgeApps and Vertical Services

Even when EdgeApps are used as stand-alone entities, they can still offer a full range of functionalities, such as a data collection function that includes authorization [6]. However, EdgeApps can also collaborate and communicate with other EdgeApps to deliver more intricate vertical services [6]. While the main focus of the VITAL-5G project is on T&L services, the concept of 5G-enabled vertical services composed of multiple EdgeApps is applicable to different sectors and does not only to the T&L services [6]. In particular, EdgeApps can be reused and composed across multiple vertical services speeding up the design and delivery of new services [6]. The primary distinction between a service-based EdgeApp, which is composed of multiple software functions and distributed with a single package (which may include multiple software images), and a Vertical Service composed of multiple EdgeApps is that the former is packaged and delivered as a single package, while the latter consists of multiple individual EdgeApps [6]. On the other hand, a vertical service, which adopts the NFV Network Services methodology, is made up of several EdgeApps that can be offered by various vendors and does not include the internal package distributions but simply their references [6].

III. VITAL-5G PLATFORM OVERVIEW

The core ambition of VITAL-5G is to implement an Open Repository and to consolidate an open platform for experimentation, which will be used for testing and validation of EdgeApps running on top of 5G networks in support of T&L actors [1,6] as shown in Figure 2. With the vision to improve the penetration of 5G-based solutions in T&L by overcoming the current challenges (such as delays in port operations, extreme fuel consumption, inefficient scheduling and delivery of goods, and staff shortage) the vertical industry currently faces the knowledge/expertise gap between the vertical industry, the telecommunication experts and the application developers [1,4]. VITAL-5G provides an enhanced 5G-empowered experimentation facility, which includes a portfolio of EdgeApps and allows T&L EdgeApp developers to test and validate their EdgeApp in a user-friendly manner. The open platform consists of an Online Portal which provides the point of access for the entire system through a web-based Graphical User Interface (GUI) that integrates all the tools and functionalities for the deployment, management, monitoring and experimental validation of EdgeApps in the target 5G facilities [1,4]. A complementary Open Online Repository allows users to store and exchange packages with EdgeApps and Virtual Network Functions (VNFs) that can be easily combined in end-to-end service chains for added value service compositions [1,4].

A. Platform components

The VITAL-5G platform as shown in Figure 2, is composed of the following software components:

- Portal Web GUI: The GUI provides a convenient and intuitive interface for the third party experimenters who

[1]https://www.vital5g.eu/

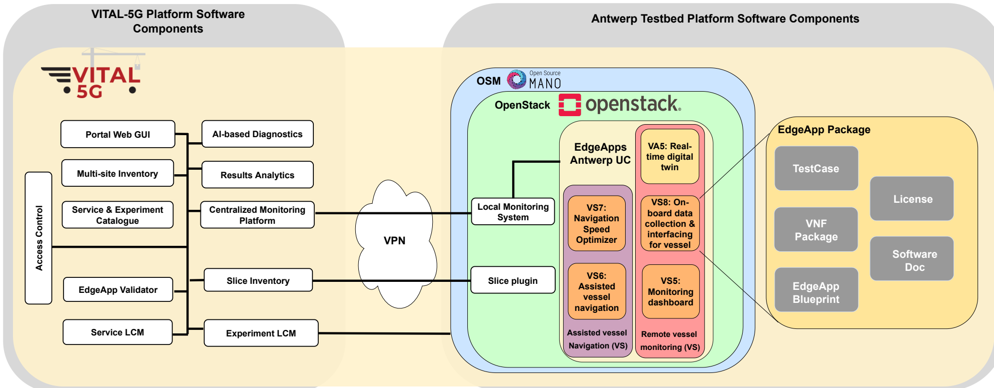

Fig. 2: A broader view on the 5G testbed, including its interaction with the VITAL-5G Platform.

wish to either onboard their own EdgeApps or use the existing catalog of the project-developed EdgeApps [10].

- EdgeApp, services & Experiment catalog: This software component is responsible for storing EdgeApp packages and blueprints, Vertical Service Blueprints and Descriptors (VSB and VSD), Experiment Blueprints and Descriptors (ExpB and ExpD). The catalog maintains synchronization with the NFVO catalogs at the three VITAL-5G sites, to keep the map between EdgeApp and Vertical Service Blueprints and the corresponding VNF packages and Network Service Descriptors (NSD), respectively [10].
- Service Lifecycle Manager (Service LCM): This software component is responsible for processing the lifecycle management requests to create, terminate, query and update vertical service instances [10].
- EdgeApp Validator: This software component makes static validation of the EdgeApp before runtime making use of a dynamic KPI monitoring and validation tool at runtime [10].
- Experiment Lifecycle Manager (Experiment LCM): This software component is responsible for the creation of experiments and the execution of test cases to experimentally evaluate the functionalities and performances of vertical services composed of NetApps and running in the 5G-enabled testbeds [10].
- Access Control: This Role Based Access Control software component enables authentication for all requested actions on the VITAL-5G platform [10].
- Slice Inventory: This software component is in charge of i) storing the information about the available 5G slices in each of the three 5G testbeds; ii) dynamic provisioning and management of 5G slices and attachment of UEs depending on the testbed capabilities; iii) selection of the 5G slice given the vertical service requirements [10].
- Multi-site Inventory: This software component stores the information related to the systems, platforms, infrastructure capabilities and devices installed into the three VITAL-5G testbeds and exposes these details to the other internal components of the VITAL-5G Platform [10].
- Centralised Monitoring Platform: This software component is responsible for: i) the collection of different types of metrics/KPIs coming from the three 5G testbeds, i.e., their local monitoring systems, and ii) the exposure of collected metrics to the other VITAL-5G platform components (e.g., AI-based diagnostics, or Result-based analytics). This monitoring platform interfaces with the local monitoring systems deployed on each of the three 5G testbeds, and it collects either real-time or bulk metrics that those local systems measure and monitor. Such a centralized monitoring platform facilitates the execution and monitoring of ongoing experiments, as it enables diagnostic elements to detect anomalies and changes in service and network quality and to correspondingly act upon those detected events [10].
- Results Analytics: This software component assists with the evaluation of the respective experimentation results. To do so, the result analytics component collects all the metrics generated during an experiment, calculating the KPIs selected by the experimenter and validating them using a set of acceptable parameters (also provided by the experimenter) [10].
- AI-based Diagnostics: This software component is in charge of gathering data throughout an experiment, analyzing it, and providing insights on how well the experiment's various components performed. It is also in charge of finding the source of any potential issues or performance declines during the experiment as well as anomalies in the behavior of the various elements [10].

B. Third party experimenters

Vertical stakeholders, i.e., third-party experimenters such as SMEs, companies, and research groups, will benefit from the creation of an open, flexible testing platform based on VNF and Service Function Chaining (SFC) [1,4]. The concept of EdgeApps enables experimenters to experience ultra-fast service creation, dynamic customization of the service, and flexible adjustment to real-time conditions. The role of the third-party experimenters in the VITAL-5G project, as well as the overall procedure of getting involved and starting with experimentation, are described on the project website[2]. Each VITAL-5G testbed is integrated with an open service validation platform to create a unique opportunity for third-party experimenters, such as 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 [1,4]. This will also allow T&L application developers to further fine-tune their T&L applications, as well as foster the creation of new EdgeApps while boosting the SME presence in the emerging 5G driven T&L ecosystem [1,4].

IV. Antwerp 5G EdgeApp testbed

The Antwerp 5G EdgeApp testbed is deployed in the port of Antwerp as shown in Figure 1. The testbed is based on the infrastructure of Telenet's (Belgian MNO) Innovation center which is located in Telenet's data center Artselaar, Belgium, and finally connectivity and supporting infrastructure of Telenet's 5G commercial launch in Flanders [1]. The complete 5G testbed provides a fully standalone 5G network with a similar blueprint comparable with Telenet's 5G commercial roadmap. The end-to-end 5G facility includes i) various types of 5G User Equipment (UE) from different vendors, e.g, 5G phones, CPEs, and 5G modems/routers for industrial use cases, Dedicated SIM

[2]https://www.vital5g.eu/get-involved/

card profiles are created and provided, ii) three 5G NR site with 700 MHz and 3.5GHz radio to support Ultra-Reliable Low Latency Communications (URLLC), Enhanced Mobile Broadband (EmBB) together with the MEC deployed on IMEC and University of Antwerp premises in Antwerp, Belgium, and collocated with network aggregation points. The RAN equipment supports 5G 3GPP Rel. 16. 4G radio operating on Telenet's commercial spectrum (800/900/1800/2100/2600MHz) which can also be allocated if 5G non-standalone (NSA) or existing NB-IoT/LTE-M is needed, and finally, a virtualized 5G Common Core which supports 2/3/4/5G with both NSA/SA architectures, network slicing and supporting features/tools such as 5G broadcasting. A Broader view on the Antwerp 5G testbed with its interaction with the VITAL-5G Platform is shown Figure 2.

A. 5G Network infrastructure

As shown in Figure 4, on the RAN side both 5G standalone (SA) and 5G Non-Standalone (NSA) share the same tower infrastructure, cabinets, and power supply [11]. The 5G SA cell is radiated by only N78 Time Division Duplex (TDD) RU, while the 5G NSA network is radiated by both N78 TDD RU and N1 Frequency Division Duplex (FDD) RU. The NR N1 is configured as Dynamic Spectrum Sharing (DSS) with LTE B1 to share the total 15MHz bandwidth. The baseband processing hardware between 5G SA and 5G NSA is also shared. The key to isolating the two RAN environments is by introducing a de-core function on the RAN. On the transmission side, Differentiated Services Code Point (DSCP) values for IP transmission priority are configured to map 5G Quality of service Identifier (5QI) values of different network slices. The 5G SA DSCP values are on top of DSCP values for legacy technology. On the core side, there are three core networks configured to work in the Port of Antwerp cluster. The production EPC is handling legacy 4G traffic from the production network, together with control plane messages for the production 5G NSA network. For 5G NSA users, their service is managed by production EPC, production 5G Core, and production 5G NSA radio . For 5G SA trial users accessing the Antwerp testbed, they access 5G NR and trial 5GC. Note that the 5G SA trial users have full priority on RAN and transmission, and they are isolated at the core level in order to secure the 5G SA network performance [11].

B. Antwerp use case

The VITAL-5G use case in the Antwerp trial site [1,4,6,12] using the Antwerp 5G testbed is called Assisted Vessel Transport, and it is built upon two vertical services, i.e., Remote Vessel Monitoring and Assisted Vessel Navigation. In the Assisted Vessel Transport use case, 5G connectivity and slicing are used to control semi-autonomous vessels in the challenging environment of a busy port area. High-bandwidth (preferably full HD) camera feeds and sensor data are sent in real-time from the vessels to the command center, and real-time assistance to the captain on-board [1]. The most important KPIs related to the network for the Antwerp use case are i) latency less than 20 ms, ii) a throughput for the camera's streams of around 300 Mbps. Due to the current 4G networks in terms of, QoS (in terms of coverage, throughput, and latency) and redundancy are pertinent shortcomings for the reliable deployment of remotely controlled vessels in a port area environment. Today, it is mandatory to have two captains onboard, and before this number can be reduced to one or even zero persons onboard, guarantees relative to both reliability and redundancy are required [1]. As connectivity is currently a main bottleneck, 5G will be able to fulfill these challenging requirements where 4G currently falls short due to bandwidth, latency, and throughput limitations. We have built an EdgeApp as a real-time digital twin around the vessel to support the remotely controlled (and later on autonomous) vessels [4]. In parallel, real-time route planning EdgeApp is leveraged to optimize port operations and avoid idle times. This EdgeApp is based on berthing time slots provided by the port authorities and terminal operators, and the

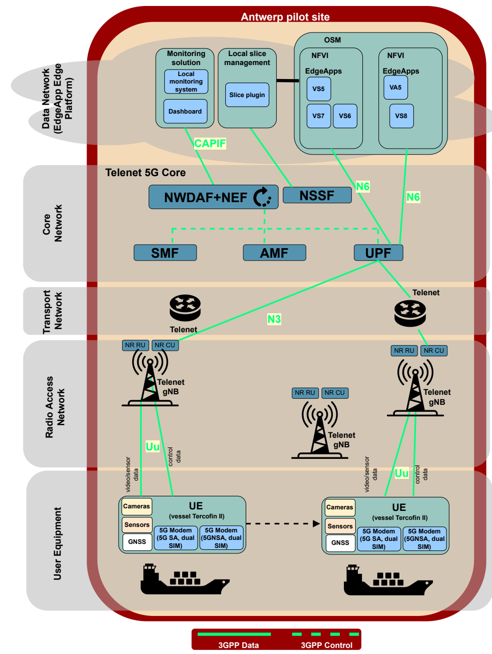

Fig. 3: VITAL-5G Antwerp testbed architecture.

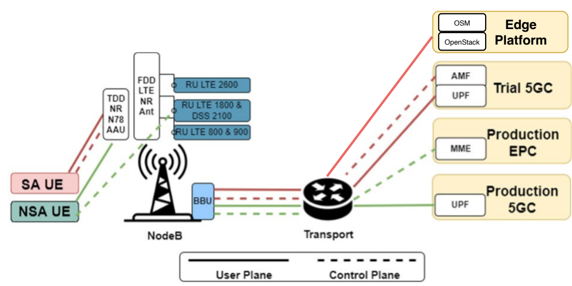

Fig. 4: Telenet 5G RAN & Core integration for NSA & SA.

optimization is performed based on ML/AI methodologies [4]. This could be linked to the different planning systems in the port, including the system of automated vessels. The URLCC and eMBB slices are the key for the remotely controlled ships of Seafar[3] (Belgian SME). The URLCC type of 5G slice is used for delivering real-time video streams from the vessel to the command center and for providing optimal navigable points and optimal speeds based on the analysis and enhanced observations provided by EdgeApps that collect video and sensor data and apply enhanced techniques. On the other hand, the eMBB type of 5G slice is used for supporting seven (or more) full HD video streams toward the remote captain at the command center. The challenges such as port safety, large waiting times, and excessive fuel consumption, in port areas, can be mitigated with such a 5G-enhanced assistance use case, with the operations and EdgeApps described in Table I. In addition, Table I also briefly lists and describes all the EdgeApps that support the Antwerp use case and thus run on the enhanced 5G testbed, thereby enabling operations for remote vessel monitoring, increasing situational awareness, and optimizing vessel navigation.

C. Management and orchestration of Vertical Services and EdgeApps

Besides the 5G RAN and Core elements from the Antwerp 5G testbed, we deliver a dedicated NFV infrastructure for deploying i) containerized (Docker) and VM-based EdgeApps,

[3]https://seafar.eu/

ii) a local monitoring system that interfaces and interacts with the centralized monitoring platform to provide either real-time or bulk metrics, and iii) slice plugin that interacts with the slice inventory component on the VITAL-5G platform for slice configuration and selection based on the vertical service requirements more information is provided in section III under the subsection platform components [11]. The overall architecture of the Belgian testbed is given in 3, while all of the components are further shown on the map of the Port of Antwerp area in Figure 1. In particular, Figure 1 showcases the location of the EdgeApp platform running on the 5G edge, deploying the EdgeApps that are accessible and used by the vessel sailing in the testing area (Port of Antwerp) [11].

The NFV infrastructure is entirely managed and orchestrated by Open Source MANO (OSM) version 12. The previous OSM version 10 is also available and used as a backup. The entire NFV infrastructure with all the software components is deployed and running as an EdgeApp platform, which is considered a 5G edge network directly connected with the Telenet 5G network. The 5G edge network is deployed using IMEC NFV infrastructure that is fully collocated with a Telenet network aggregation point.

Concerning the management and orchestration, the OSM running on top of the EdgeApp platform is deployed and working as an NFVO orchestrator, keeping the whole platform compliant with the design of the standardized ETSI NFV MEC framework [13]. EdgeApps are managed and orchestrated by the NFVO while using virtualized infrastructure resources managed by OpenStack and/or Kubernetes (both available). Kubernetes is an open-source system for automating the deployment, scaling, and management of containerized applications. Thus this 5G testbed is fully open for any third-party experimenter or vertical to run and validate their (vertical) services.

D. VITAL-5G Experimentation Procedure

This subsection explains the experimentation procedure on how to start an experiment on the VITAL-5G platform with the Antwerp 5G testbed with the GUI shown in Figure 5. To start an experiment the experimenter will do the following series of chronological steps:

1) **Design and creation of vertical services and EdgeApps:** This initial step can include either creating vertical services with brand new EdgeApps or using existing ones from the VITAL-5G catalog. At the Antwerp 5G testbed, the experimenter has already five pre-existing EdgeApps available, i.e., VA5, VS5, VS6, VS7, and VS8, and two vertical services. Besides the design and creation of the EdgeApp, the experimenter can also specify the mobile network requirements for its EdgeApps.
2) **Experiment design:** The second step is the experiment design where the experimenter can choose the Antwerp 5G testbed to execute the experiment and where the experimenter can choose which network and service KPIs need to be monitored during the experiment. The retrieval of the KPIs is possible due to the interaction between the VITAL-5G Centralised Monitoring Platform and the local monitoring platform on the Antwerp 5G testbed.
3) **EdgeApp onboarding:** The third step is the actual onboarding of the EdgeApp(s) via the VITAL-5G Portal Web GUI, which translates into VNF and network service package onboarding in OSM of the Antwerp 5G testbed [11]. Thus, the corresponding VNF package of the EdgeApp(s) will be onboarded and available on the local OSM of the Antwerp 5G Testbed. To meet the network requirements for the EdgeApp(s) and thus specific vertical service, the available slices on the Antwerp testbed will be configured to meet those requirements. This is dynamically performed with the interaction of the local Antwerp slice plugin and the VITAL-5G platform.
4) **Onbarding and instantiation of the vertical service(s):** The fourth step is to onboard and instantiate the created specific vertical service through the VITAL-5G Portal Web GUI. The vertical service will then become available on the local OSM of the Antwerp 5G testbed [11]. In the case the experimenter wants to do experiments with the Antwerp use case, the remote vessel monitoring vertical service and the assisted vessel transport vertical services are onboarded.
5) **Experiment execution:** The fifth step is the actual experiment execution, which means that the deployed instance of the vertical service, in the case of Antwerp use case the remote vessel monitoring and assisted vessel transport vertical services, are spawned up on top of the local OpenStack of the Antwerp 5G testbed, where all EdgeApps are running as VM instances in the OpenStack environment [11]. These EdgeApps are attached to the proper pre-configured OpenStack network in order to be able to communicate with each other. During the run time of the vertical service(s) real-time data collection of service and network KPIs is shared with the VITAL-5G Centralised Monitoring platform.
6) **Evaluation of the vertical service:** The final sixth step of the VITAL-5G experimentation process is the evaluation of the vertical service. This is possible through the interaction of the Antwerp local monitoring system and the VITAL-5G Centralised monitor. Furthermore, those reported service and network metrics will be further processed by the VITAL-5G platform, i.e., AI-based diagnostics component, to find anomalies in the experiment. The statistics, which are then made available to the experimenter, will be provided.

TABLE I: Overview of goals, operations, and enablers, for assisting vessel navigation with the help of 5G.

Goals	Operations	Enablers (EdgeApp)
Improving port safety	Remote vessel monitoring in busy port environment	Remote Vessel Monitoring (VS5): displaying notifications for the captain
		Onboard data collection & interfacing with vessels (VS8): collecting speed/heading/location data
Reducing dwell times	Increasing situational awareness in real-time	Assisted Vessel Navigation (VS6): assisting the captain with navigation suggestions (global trajectory)
		Real-time digital twin (VA5): creating a dynamic map of the environment in real-time, based on the vessel sensor data, via the 5G and VS8
Reducing fuel consumption	Optimizing assisted vessel navigation	Navigation speed optimizer (VS7): calculating the optimal speed for remote or autonomous equipment

E. Preliminary Validation and Integration tests results

Initial network performance test were conducted at the 5G testing area at the Port of Antwerp as shown in Figure 1.

The location on the roadside is 350 meters away from the gNB with a good signal strength of -64dBm Reference Signal Received Power (RSRP) and 23dB Signal to Interference & Noise Ratio (SINR) [11]. This reflects a good coverage scenario with a clear line of sight. The 5G UE is configured to connect to the eMBB slice. As shown in Figure 6, the average TCP uplink (UL) bandwidth is 29.7 Mbps with a standard deviation of 3.016 [11]. As shown in Figure 7, the average TCP downlink (DL) bandwidth is 409 Mbps with a standard deviation of 41.45 [11]. The drop in speed reflected in the graph for both UL and DL is caused by trucks passing by [11]. These preliminary validation and integration results reflect the same results as how we monitor the performance of the network for the particular Antwerp use case, during EdgeApp runtime. As the EdgeApps are running at the IMEC edge, and the results already show improvements over 4G [11], which is already promising for T&L services.

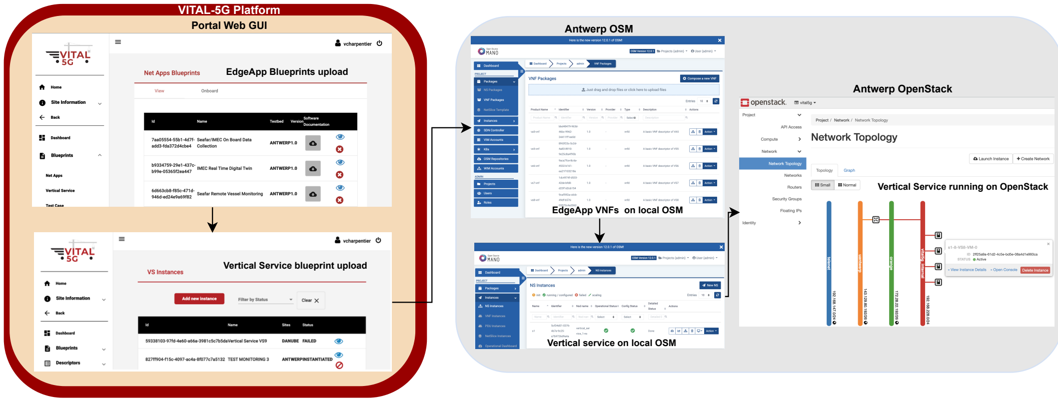

Fig. 5: Onboarding a vertical service on the Antwerp testbed through the VITAL-5G Portal Web GUI.

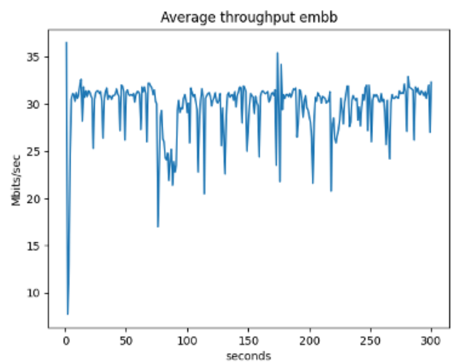

Fig. 6: TCP uplink single UE speed eMBB throughput.

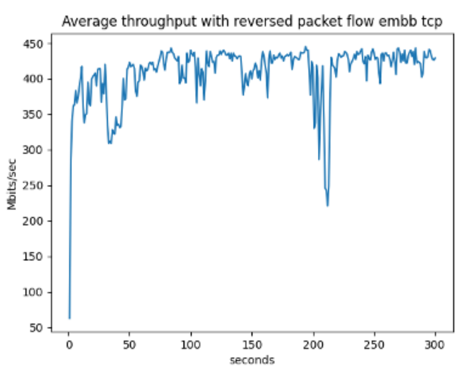

Fig. 7: TCP downlink single UE speed eMBB throughput.

V. Conclusion and Future Work

In this paper, we addressed the need for the open VITAL-5G platform with its open enhanced 5G- empowered 5G 3GPP (Rel 16) experimentation facility testbeds to overcome the current challenges and obstacles the T&L sector is facing. We discussed in depth what an EdgeApp is, the different types of EdgeApps, how they are constructed, and finally how they relate to vertical services. We then discussed in depth the VITAL-5G platform and its software components that it is composed of. To then end with an in-depth description of the enhanced Antwerp 5G 3GPP EdgeApp testbed and how it can be used by third parties to validate and test their (T&L) Vertical solutions and applications (EdgeApps) in real-life conditions.

As future work, we will study the possibility of deploying innovative EdgeApps in the context of other vertical industries as well (e.g., automotive use cases with vehicular applications), and validate their performance over orchestrated 5G infrastructure. The goal of deploying this 5G testbed is to offer it to external users and third-party experimenters such that they can test and validate their EdgeApp(s) within 5G ecosystems, in a user-friendly and intuitive manner, thus significantly reducing operational inefficiency and reducing market entry barriers prior to deploying their service to live 5G networks.

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References

[1] K. Trichias, G. Landi, E. Seder, J. Marquez-Barja, R. Frizzell, M. Iordache, and P. Demestichas, "Vital-5g: Innovative network applications (netapps) support over 5g connectivity for the transport & logistics vertical," in *2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2021, pp. 437–442, doi: http://dx.doi.org/10.1109/EuCNC/6GSummit51104.2021.9482437.

[2] futuremarketinsights. (2022, October) Reverse Logistics Market Outlook (2022-2032). [Online] Available: https://www.futuremarketinsights.com/reports/reverse-logistics-market,.

[3] Ericsson. (2019, November) ericsson Mobility Report. [Online] Available: https://www.ericsson.com/assets/local/reports-papers/mobility-report/documents/2019/emr-november-2019.pdf, Last accessed on: January, 2023.

[4] VITAL5G. (2020, December) H2020-ict-41-2020 vital-5g project. [Online] Available: https://www.vital5g.eu/,.

[5] N. Slamnik-Kriještorac, G. Landi, J. Brenes, A. Vulpe, G. Suciu, V. Carlan, K. Trichias, I. Kotinas, E. Municio, A. Ropodi, and J. M. Marquez-Barja, "Network applications (netapps) as a 5g booster for transport & logistics (t&l) services: The vital-5g approach," in *2022 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2022, pp. 279–284, doi: http://dx.doi.org/10.1109/EuCNC/6GSummit54941.2022.9815830.

[6] VITAL5G. (2021, December) Deliverable D1.2. [Online] Available: https://www.vital5g.eu/public-deliverables-2/,.

[7] ETSI GS NFV-SOL 004. (2019, January) Network Functions Virtualisation (NFV). [Online] Available: https://www.etsi.org/deliver/etsi_gs/NFV-SOL/001_099/004/02.07.01_60/gs_nfv-sol004v020701p.pdf, Last accessed on: January, 2023.

[8] ETSI GS NFV-SOL 006. (2021, July) Network Functions Virtualisation (NFV), Protocols and Data Models, NFV descriptors based on YANG Specification . [Online] Available: https://www.etsi.org/deliver/etsi_gs/NFV-SOL/001_099/006/03.05.01_60/gs_NFV-SOL006v030501p.pdf, Last accessed on: January, 2023.

[9] Open source MANO (OSM) . (2023, January) WHAT IS OSM? [Online] Available: https://osm.etsi.org/, Last accessed on: January, 2023.

[10] VITAL5G. (2021, December) Deliverable D2.1. [Online] Available: https://www.vital5g.eu/public-deliverables-2/,.

[11] VITAL5G. (2022, December) Deliverable D3.2. [Online] Available: https://www.vital5g.eu/public-deliverables-2/.

[12] VITAL5G. (2021, June) Deliverable D1.1. [Online] Available: https://www.vital5g.eu/public-deliverables-2/,.

[13] ETSI GS MEC 003 V3.1.1. (2022, March) Multi-access Edge Computing (MEC), Framework and Reference Architecture . [Online] Available: https://www.etsi.org/deliver/etsi_gs/MEC/001_099/003/03.01.01_60/gs_MEC003v030101p.pdf, Last accessed on: January, 2022.