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Network Applications (NetApps) as a 5G booster for Transport & Logistics (T&L) Services: The VITAL-5G approach

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***Abstract*—By delivering end-to-end latencies down to 5ms, data rates of up to 20Gbps, and ultra-high reliability of 99.999%, 5G is extending the capabilities of numerous industry verticals, including the Transport & Logistics (T&L). As the T&L industry has a pivotal role in modern production and distribution systems, it is expected to leverage 5G technology to significantly increase efficiency and safety in the T&L operations, through automating and optimizing processes and resource usage. However, to be able to truly benefit from 5G, the design, the development, as well as the management, of T&L services need to specify and include 5G connectivity requirements, and the features that are tailored to the specific T&L use cases. To this end, in this paper we introduce the concept of Network Applications (NetApps), as 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). In this paper, we exemplify the concept of NetApps leveraging one of the VITAL-5G use cases, which provides faster and safer operations of vessels in the port of Galati, the largest port on the Danube River.**

***Index Terms*—5G, NetApps, Transport & Logistics, vertical services, NetApp blueprint**

I. Introduction and Motivation

The 5G ecosystems usually consists of 5G New Radio, 5G Transport network, 5G Core, and virtualized edge and cloud infrastructure. As such, they are enabling ultra-low latency (1-10 ms), ultra-high reliability (99.999%), and high data rates (up to 20 Gbps) [1], by creating logical and virtualized networks, i.e., network slices, over the common network infrastructure. Thus, by implementing Ultra-Reliable Low-Latency Communication (URLLC), enhanced Mobile Broadband (eMBB), and massive Machine-Type Communication (mMTC), 5G expands the perspectives for industry verticals such as automotive, e-health, and Transport & Logistics (T&L) systems, and it fosters new use cases (e.g., autonomous driving, remote navigation, teleoperation) that have not been possible with the previous generations of mobile communications systems, given the too stringent connectivity requirements for those use cases [2].

The T&L sector is a major component of modern production and distributed systems, as it significantly contributes to the macroeconomic development [3]. However, processes in the T&L industry suffer from insufficient automation and optimization, which highly affects efficiency and safety of the T&L operations. We discuss these issues further in the context of a very specific example, such as T&L operations in the river/sea ports. In particular, Aroca et al. and Oliskevych et al. [4,5] show that a highly specialized personnel in T&L industry (e.g., vessels captains, pilots, equipment, or train operators) is idle between

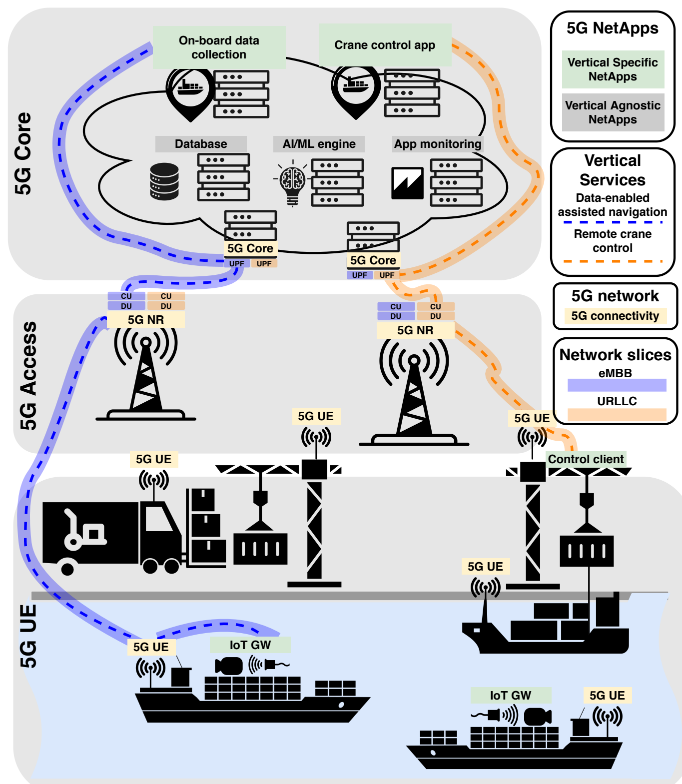

Fig. 1: 5G NetApps as building blocks of T&L vertical services for providing faster and safer port operations in 5G ecosystem.

15-50% of the time, being conditioned by the availability of their assigned equipment. As the operational activities such as loading/unloading, and cruising on auto-pilot, do not require any intervention, this means that personnel can be engaged more efficiently with the help of new network capabilities, thereby including them in the remote operation of equipment as well. On the other hand, a fast data transfer is a promising factor for ensuring safer T&L operations [6,7]. To this end, a relatively high number of devices (e.g., sensors) needs to be connected to decision-making entities towards increasing safety of the port and logistics operation, by e.g., preventing equipment collisions in autonomous navigation, reacting to weather changes in advance, or identifying unexpected movements of other non-autonomous steered equipment.

Therefore, as Fig. 1 illustrates, it is expected that T&L industry leverages benefits brought by 5G technology, by integrating 5G ecosystem components into the infrastructure (e.g., ports, vessels, warehouses), and by developing 5G T&L services that experience enhanced Key Performance Indicators (KPIs) through the use of URLLC, eMBB, and mMTC, network slices.

Considering the study provided by Marquez-Barja et al. in [8], automated control of barges/vessels/ships requires bandwidth of 5-25Mbps in the uplink, and latency lower than 22ms, per High-definition (HD) video camera stream, and latency lower than 35ms for vessel control interface. One example of such vertical service is illustrated in Fig. 1, where data-enabled assisted navigation of vessels in the river/sea ports needs an efficient data collection from sensors and cameras on the remote vessels. With the increase in number of connected vessels in the large ports, this requirement for uplink bandwidth becomes even more stringent (eMBB slice). Similarly, the remote crane control (Fig. 1) requires an end-to-end latency lower than 35ms so that the remote operation can be performed efficiently and safely (URLLC slice). Also, large and important ports are characterized by significant load, and require a more accurate control of the vessels, since the traffic is higher (i.e., low latency communication is needed), and the reliability is even more important.

Given the above-mentioned requirements, it is evident that only 5G technology is capable of providing faster and safer port operations with ms-level end-to-end latency, data rates above 100Mbps, which are not available in 4G systems, as well as a stable, remote and real-time control. However, given the heterogeneity of data sources, edge, and cloud components, as well as scarcity of resources (edge infrastructure usually contains small amount of computing resources), an efficient resource management is needed to define the way vertical services are developed, deployed, and managed, on the 5G infrastructure.

Thus, to be able to benefit from 5G, the design of vertical services needs to be tailored to particular use cases, taking into account vertical service-specific requirements towards 5G (e.g., service interruption for automated vessel control needs to be lower than 150ms [8]). To this end, in this paper we define the concept of Network Applications (NetApps), as a fundamental building block of the T&L service chains that are deployed on top of the 5G-enabled infrastructure (as illustrated in Fig. 1). The goals of breaking a complex vertical service to NetApps are: i) to simplify the composition of such vertical service chain, ii) to better describe the service-level information (vertical specific), iii) to specify 5G-related requirements for this service (e.g., 5G slices, 5G Core services), and iv) to abstract the underlying complexity, and thus to bridge the knowledge gap between vertical stakeholders, the network experts, and the application developers. The aforementioned is achieved by extending the orchestration-oriented models proposed by European Telecommunications Standards Institute (ETSI) Network Function Virtualization (NFV), i.e., Virtual Network Function Descriptors (VNFDs) and Network Service Descriptors (NSDs), which are service-agnostic, and limited to internal network service structure (i.e., the definition of computing resources, network functions in the chain, forwarding graphs and paths, virtual links, and internal/external connection ports). Such gaps in current standards can be bridged by adopting the NetApp modelling, i.e., through the declaration of i) protocols and languages used at the service interfaces of applications, ii) dependencies on hardware and devices, and iii) requirements on 5G mobile connectivity or 5G core network services.

In this paper we define the concepts and modelling of 5G-enabled NetApps, and categorize those NetApps depending on their specific features and vertical needs, as a work carried out in the scope of the VITAL-5G project [9]. Furthermore, we showcase the applicability of NetApps for providing faster and safer operations of vessels in the port of Galati [10], which is one of the trial sites in the VITAL-5G project.

II. Related Work

In their work on the advanced 5G architectures for future NetApps and verticals [11], Patachia et al. provide a telco-oriented perspective on the deployment of NetApps, focusing on the adjustments that need to be accommodated in the 5G network itself. They identify the gaps in current network deployments of telco operators, which hinder the implementation of innovative use cases, and then propose the adaptations such as DevOps and Artificial Intelligence (AI)/Machine Learning (ML)-based cognition, which need to be deeply integrated in the telco network infrastructure to enable end-to-end network automation capabilities. In particular, Patachia et al. [11] envision that such changes will pave the way towards an increased development and testing of 5G NetApps, thereby enabling dynamic allocation of 5G network, computing and storage resources, as well as flexible deployment of vertical services in distributed cloud infrastructures.

Based on the overview of satellite network integration in the 5G ecosystem studied and experimented in the 5GENESIS project [12], Fornes-Leal et al. [13] demonstrate how an integration of satellite backhauling can extend 5G coverage to the rural and underserved areas by deploying 5G applications on the network edge, as a part of a smart farming use case. The concept of NetApps that we propose and present in this paper could be also leveraged in such use cases, where the requirements on the bandwidth and low latency to enable faster field sweeps, higher accuracy, and lower energy consumption, can be also embedded in the NetApp blueprints and descriptors, as further described in Section III.

Finally, in [14], Trichias et al. presented a comprehensive overview of the Vital-5G project, thereby spanning the Vital-5G platform, the three trial sites and use cases (Antwerp sea port, Galati river port, and Athens warehouse/hub), as well as key innovation and commercialization aspects. On the other hand, the focus of our paper is particularly on the NetApps, detailing on the NetApp structure and packaging, their unique role in enabling T&L services to leverage 5G capabilities, followed by a few examples of real-life NetApps that are designed for improving the safety and efficiency of operations in the river port.

III. The Concepts and Modelling of 5G-enabled NetApps

A. Packaging and management of NetApps

The NetApp concept facilitates the creation, design, provisioning, life-cycle management, and performance evaluation, of vertical services in 5G network infrastructures. A NetApp is a 5G-enabled virtual application which provides its own set of functionalities when deployed as a stand-alone entity, capable to cooperate and to interact with other NetApps to deliver more complex vertical services. In this sense, a NetApp can be considered as an atomic component of vertical services, which can be dynamically instantiated in multi-tenant virtual environments, re-used, composed, and shared, in the context of multiple service chains, as well as combined with 5G network slices to guarantee the required performance for the mobile connectivity (e.g., required uplink bandwidth for camera streams, and end-to-end latency for control signals towards vessels).

NetApps are derived from the concept of the ETSI Virtual Network Functions (VNFs), inheriting their capability to be automatically provisioned, scaled, terminated, monitored, and re-configured, in a multi-tenant virtual infrastructure through the creation and management of Virtual Machines (VMs) or containers, as defined in their VNF packages [15]. In particular, NetApps extend the original VNF concept declaring i) service

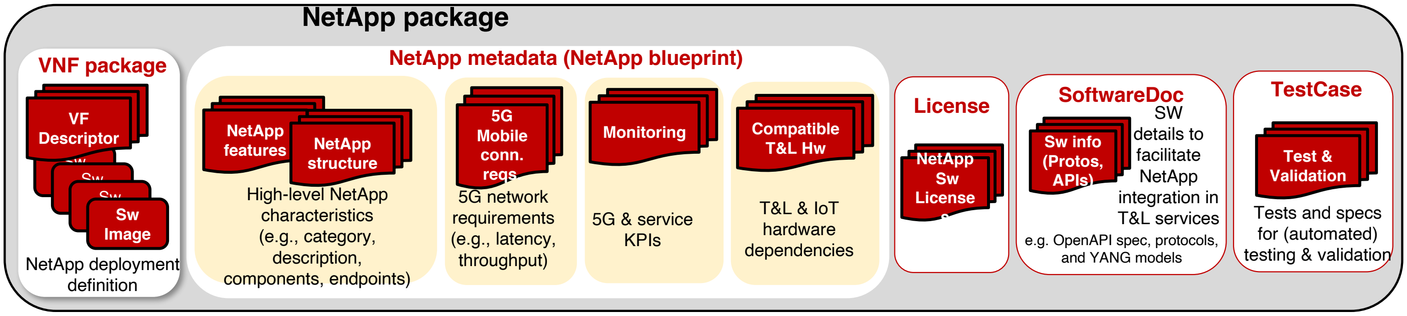

Fig. 2: High-level NetApp package representation

level information to simplify their distribution, sharing, and integration 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 networks. This additional information is encoded as metadata in a NetApp blueprint, which is included in the NetApp package.

As illustrated in Fig. 2, the NetApp package includes i) the references to the VNF package that defines how to orchestrate the NetApp in an NFV Management and Orchestration (MANO) environment, ii) the NetApp blueprint, and iii) the additional elements like software licenses, software documentation, test cases, and target KPIs for automated validation. The NetApp packages can be on-boarded, searched, and visualized through an online repository, such as VITAL-5G Open Online Repository [10]. This repository provides an open catalogue of NetApps which can be provided by different developers and combined to deliver new services. This approach will facilitate the sharing of NetApps produced and distributed by different software developers.

Fig. 3 provides a graphical representation of the NetApp modelling, using as example a NetApp for management of IoT devices reachable via 5G network. In this example, the NetApp handles IoT data from/to IoT supervisors acting as IoT gateways installed in the field (e.g., in a vessel) and interconnected via 5G to the virtual computing infrastructure where the NetApp is running. A NetApp is composed by a set of internal Atomic Components (the red boxes), which correspond to containers or VMs implementing parts of the NetApp logic. These components interact via internal Connectivity Services (the dotted line in the NetApp box), which correspond to virtual networks that connect their endpoints. The endpoints can be internal ones (light-grey circles), used only for intra-NetApp interactions, or external ones, used to interact with external entities (e.g., other NetApps, end users, or hardware elements such as devices installed in the vessels).

The external endpoints that connect NetApps with the 5G network, using the N6 interface[1] of the 5G system [16], are characterized by additional attributes that describe the mobile connectivity requirements for the NetApp traffic in uplink and downlink. These endpoints are thus associated to one or more 5G slice profiles, describing the network slice characteristics, as defined in the 3GPP Network Resource Model [17]. Some examples of the attributes are the slice service type (eMBB, URLLC, or mMTC), QoS parameters (e.g., uplink and downlink data rate, latency, jitter), coverage area, and radio access technology. Moreover, the NetApp model describes the 5G network services consumed by the NetApp, e.g., the network data analytics service or the localization service, used to retrieve information about network performance or UE/vessel position, respectively. In T&L sector, several NetApps interact

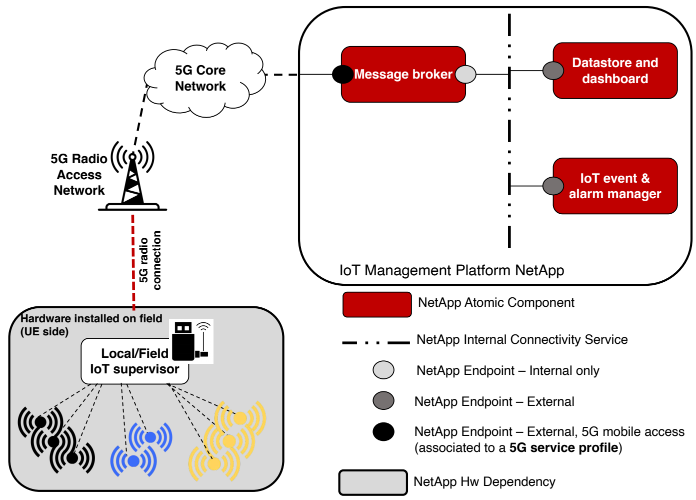

Fig. 3: The example of NetApp representation.

with hardware devices deployed on field, such as IoT sensors, actuators, gateways, cameras, and Automated Guided Vehicles (AGVs). In the NetApp model, this is expressed as hardware dependency (the grey box on the left of Fig. 3), since the NetApp functionalities are strictly related to the interaction with these components, and the NetApp validation requires presence of these hardware devices in the testing environment. The service interfaces associated to each endpoint are also specified in terms of protocol and message format, and documented with protocol-specific interface specification (e.g., OpenAPI for REST APIs, SQL schemas, etc.) embedded in the NetApp package.

Such an abstract NetApp model has been designed to offer a service-oriented description of the NetApps, and to facilitate the verticals in the selection and composition of NetApps towards creating new vertical services for various use cases they want to build and test. Following this abstraction level captured in the NetApp blueprint and package, the vertical does not need to i) understand the details of the application internal structure, ii) know the deployment specifics over a virtualized infrastructure, or iii) understand the complex configuration of a 5G network slice. The orchestration-oriented and network-oriented model, captured by the VNF descriptor/package and any related 5G network slice template, remains hidden for the vertical and it is instead handled internally by the VITAL-5G platform for provisioning, lifecycle management, and testing purposes.

B. *NetApp Classification*

In order to make the concept of NetApps more palatable, and to assist users in the correct deployment, configuration and use of the appropriate NetApps for their specific use case, we have

[1] In the 3GPP 5G architecture, N6 reference point is connecting User Plane Function (UPF) in the 5G Core, with the Data Network (DN), where the NetApps are deployed in our case.

adopted a twofold classification of NetApps depending on i) their intended service, and ii) their composition and deployment methodology.

In terms of intended service, we categorize NetApps into vertical-specific and vertical-agnostic.

- *Vertical-specific NetApps* implement functionalities designed specifically for a given vertical scenario and vertical service (as illustrated in Fig. 1). Its usage is related to a specific use case, and it is not designed to be easily customized or configured to adapt to different environments or services. Such NetApps provide strong focused services addressing specific and complex issues in a vertical domain (requires strong field expertise).
- *Vertical-agnostic NetApps* are generalized NetApps that can be easily adopted in different services since they support multiple customizations, data models and processing types. Examples of such NetApps are databases, message brokers, generalized monitoring probes or generalized AI/ML engines, as illustrated in Fig. 1.

In terms of composition, we make a differentiation between component-based and service-based NetApps, as follows:

- *Component-based NetApps* are atomic and elementary software components that operate in a generalized manner, and can be composed together and configured in a flexible manner, so that they can be customized to serve different purposes. A component-based NetApp can be delivered as a packaged set of software images with predefined configurations and interfaces, which can be then updated and customized to build more specialized NetApps delivering their own service.
- *Service-based NetApps* provide independent services that can be accessed in a standardized manner to support specific business requirements, and as such, they can be deployed in a stand-alone mode, without any dependency on additional NetApps, providing their own complete set of functionalities.

In general, multiple component-based NetApps, properly configured and customized, can be combined together to form a service-based NetApp.

IV. NetApps for 5G T&L Vertical Services

In the scope of the VITAL-5G project, we have defined several use cases that aim to demonstrate the applicability of 5G NetApps to the realistic vertical service deployments that enable process automation and optimization, resource usage optimization, as well as improvements of time/cost efficiency [10]. In this section, we focus on the 5G-based river port use case, which leverages 5G connectivity and functionalities deployed as NetApps to improve performance and safety of the operations in a realistic environment such as Galati port. We first introduce the use case in Section IV-A, and then define the vertical services that are required for use case realization in the trial, as well as the NetApps that are building the identified vertical services.

A. Relevant use case: 5G connectivity and data-enabled assisted navigation using IoT sensing and video cameras

The use case is focused on the implementation of a data-enabled assisted navigation application using 5G network infrastructure, IoT sensing system and video cameras, as well as the vessels and barges (cargos), which are altogether part of the Galati port in Romania. The Galati port is an entry point for large shipping traffic from the Black Sea towards the continental Europe, and is a part of the Rhine-Danube TEN-T Corridor[2]. It is the largest port on the Danube River, and the second largest Romanian port.

To realize the data-enabled assisted navigation use case, we design and propose two vertical service applications that enable a safer port operation of navigating vessels by providing an operation/navigation assistance, even in severe weather and water conditions. Such vertical service will be performed on a series of vessels belonging to the Romanian river transport company Navrom[3], which carries millions of tons of various goods through both internal and external routes towards the Western Europe.

The main objectives of this use case are:

- To reduce the number of dangerous navigation events (e.g., vessel collisions, or vessels stuck in the river because of sandbanks or shallow waters) by collecting and transmitting the sensor and video data to the control units that optimize port operations.
- To reduce the logistics costs due to proper decisions based on an on-board diagnosis and monitoring functions, therefore limiting the impact of the human factor to take potentially wrong decisions.
- To create a more accurate electronic navigation map.

To achieve the above-mentioned objectives, it is essential to implement technologies for communication and monitoring of voyages in the activity of operating the vessels. Thus, to avoid stationary downtime due to navigation errors, i.e., to reduce as much as possible the transport of empty units by achieving a higher percentage of loading, it is important to establish a better communication between vessels and dispatchers. This can be achieved by enabling a real-time connectivity between the sensors that monitor the operating parameters of the vessel, and the dispatcher office/navigation department. Also, to achieve higher levels of safety in sailing, a connection between the decision departments (e.g., the Fleet operation department) and vessels is necessary for enabling assisted navigation that would handle difficult situations.

Concerning the connectivity, all sensors and cameras installed on the vessels adopt the interoperable wireless protocols over a private 5G network, and enable the extension of Internet connectivity of the sensing system [11]. Several sensors (e.g., GPS, humidity, smoke, and engine power sensors), in addition to already existing equipment (e.g., automatic identification system, and depth sensor), need to be installed on the vessels and barges to collect relevant data, such as velocity, heading, and water/wind speed. Thanks to the 5G high-bandwidth and low-latency communication link, the NetApps presented in Section IV-B, fuse the live high-resolution video streams from the surroundings with the sensor data. With such an increased perception about the port, NetApps are coupled with an AI/ML module, producing relevant control signals for the captain and crew to take proper evidence-based decisions and provide an on-board diagnosis and predictive maintenance.

B. Related vertical-specific and vertical agnostic NetApps

In Fig. 4, we illustrate the use case described in Section IV-A, and the main NetApps that build the vertical services developed for such a use case. Both vertical services are built using the corresponding NetApps, and in Table I we show which NetApps belong to which vertical service. For our specific use case, we define two vertical services as follows:

- *Vertical service 1: Accurate electronic navigation maps creation* used for estimating the correct safe distance for a vessel by using distributed sensor data ingestion,fusion, and post-processing. The data contains velocity, heading, water/wind speed, Global Navigation Satellite System (GNSS) data[4].

[2]Rhine-Danube TEN-T Corridor: The main east-west link across Continental Europe: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/rhine-danube-corridor_en

[3]Navrom: https://www.navrom.ro/index.php/ro/

[4]The solution is currently considered for an application in areas where GNSS achieves a sufficient positioning accuracy (unlike in polar regions).

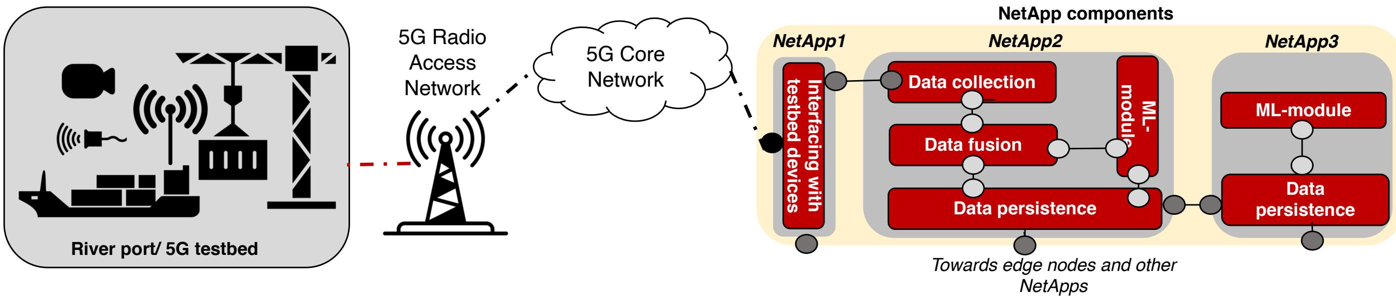

Fig. 4: The representation of vertical services and NetApps described in Section 4.

TABLE I: Vertical services and NetApps for the use described in Section 3.

Vertical service	NetApp
Accurate electronic navigation maps creation	NetApp1
	NetApp2
Predictive maintenance and sanity checks	NetApp1
	NetApp3

- *Vertical service 2: Predictive maintenance and sanity checks* applied on the sensor data for vessel safety purposes, thereby using monitoring and on-board diagnostics data for limiting human error and potentially wrong decisions.

Following the VITAL-5G approach, these vertical services can be built as the composition of vertical-specific and vertical-agnostic NetApps, and in Sections IV-B1, IV-B2, and IV-B3, we describe those NetApps as service building blocks.

1) NetApp1 - *On board data collection and interfacing for a river vessel:* The *NetApp1* is a vertical-specific NetApp that collects data from i) on board sensors (i.e., water speed, water depth, outside/inside temperature, engine functional parameters, etc.), and ii) from video cameras placed on the river vessels. All data is made available for the local on-board server and provides the interface to/from external edge nodes and the 5G network. The data is formatted in a way to be understood and treated by NetApp2. Based on the input data, this NetApp exposes output through the 5G-based Application Programming Interface (API) endpoints on the edge nodes towards *NetApp2* and *NetApp3*. The output ranges from vertical-specific sensor data (such as water depth, and environmental parameters) to 5G infrastructure-related metrics (such as latency, availability, and uplink data rate). The *NetApp1* targets the second objective i.e., the cost reduction.

2) NetApp2 - *Distributed sensor data ingestion, fusion and post-processing:* This vertical-agnostic NetApp is responsible for the ingestion of data from multiple distributed data sources, enhanced by data fusion and AI/ML-based analytics functionalities. The output that *NetApp2* produces supports reporting, advanced analytics, warnings (e.g. based on forecasts), and decisions, which all can be used by other NetApps. In particular, *NetApp2* is responsible for the following:

- Ingestion of data from various sources (including the 5G infrastructure, as well as the T&L devices) to enable training and testing of AI/ML models. The data collection component performs acquisition of both streaming and batch data, through the use of Hypertext Transport Protocol (HTTP) Representational State Transfer (REST) APIs, thus querying the data source directly or through the message bus services.
- Transformation of datasets is performed by the data fusion component. It offers capabilities for various logical transformations of data, such as cleaning and inserting missing values, time-space correlation, and transformations of unstructured datasets to structured and vice versa.
- Post-processing of data, starting from simple functionalities like aggregation and ranging to applying AI/ML models that enable advanced analytics. The AI/ML module is responsible for the training and deployment of post-processing procedures on the fused data. This module consists of i) submodules that apply unsupervised and supervised learning, the autotune engine, and the AI/ML registry. The autotune engine ensures the automated calibration of multiple supervised or unsupervised models that are trained in submodules, and then saved in the AI/ML registry.
- Data persistence for the data to be further utilized by other NetApps is performed by the data persistence component, which enables i) the storage of both structured and unstructured data, whether raw, or fused and post-processed as the result of the AI/ML models, and ii) exposing data through the appropriate APIs.
- Corresponding interfaces (APIs) for other components (e.g. dashboard), other NetApps, and 3rd parties, to utilize the enhanced information that has been produced and stored.

3) NetApp3 – *Predictive maintenance:* This vertical agnostic NetApp utilizes data exposed by *NetApp2*, but it can consume input data from various sources. The output is the results of advanced AI/ML-based diagnostics.

The *NetApp3* is responsible for the deployment of supervised and/or unsupervised modelling techniques to achieve functions like automated labelling, outlier detection, trace back analysis, graphical representations, predictions for the near future, and therefore support decision-making for predictive maintenance. In particular, data is fed to an AI/ML module consisting of various sub-components, which enables the automated model usage and calibration of multiple AI/ML models, as well as the extraction of meaningful results. The results are then sent to a data persistence component, which is also responsible for the exposure of the results to other components/ NetApps through the appropriate interfaces.

V. Lessons learned and Future work

In comparison with previous communication technologies, 5G enables the creation of logical virtualized networks, i.e., 5G network slices, enabling vertical T&L services to achieve ms-level end-to-end latency, data rates up to 20Gbps, as well as a stable, remote and real-time control. This is altogether crucial for efficient collecting of sensor and video data (uplink), and for performing T&L control operations (e.g., assisted or remote navigation of vessels) in a timely manner based on the optimized decisions made by decision-making entities (downlink).

In this paper, we introduced NetApps with the goal to abstract the complexity of network and infrastructure configuration in providing vertical T&L services, and to facilitate their deployments in real-life environments. The lifetime of NetApps is fluid, as they can be designed and created on-demand to boost specific aspects of safety and efficiency in T&L operations through the delivery of vertical services for e.g., preventing equipment collisions, in-advance preparation for weather changes, and identification of unexpected movements of non-autonomous devices. The life-cycle management and orchestration solutions are further used to optimize the work of NetApps, i.e., to scale, terminate, and/or recreate them if needed.

Although 5G is providing the means for enhancing T&L operations through creating network slices, these slices need to be configured to service-specific needs. Therefore, NetApps are the glue that binds the requirements coming from the vertical services [18], and the actual service deployments using 5G network and virtualized infrastructure resources. This is achieved by extending the ETSI VNF concept to include relevant service-specific information, as well as mobile connectivity requirements (5G slice profile, and 5G core services) that are translated to 5G network slice profiles in the NetApp blueprint. Thus, by translating vertical service requirements to network slice profiles, NetApps are paving the way towards i) reducing the number of dangerous navigation events, by timely and efficient collection of sensor and video data that is processed by enhanced decision-making entities, ii) reducing logistics costs due to more efficient use of resources enabling possibilities to eliminate ineffective time of highly trained personnel in ports (like vessels' captains, pilots or equipment operators) by allowing them to apply their skills remotely. There is also an increase in efficiency of the decision-making process. The advanced algorithms are capable of anticipating maintenance operations, by having access with low latency and high reliability to data for on-board diagnosis and monitoring sensors.

The concept of NetApps that binds 5G and the vertical services is relevant for entrepreneurs, researchers, and the T&L industry. Tech entrepreneurs can use this concept to develop further case studies in the T&L and other sectors. On the other hand, research can use these outcomes to study the further improvements in 5G and beyond applications. Last but not least, the T&L industry can benefit from a high-end contribution that details the role of 5G to tackle operational challenges.

The T&L sector requires a constant improvement of safety and efficiency of operations, but this gain should be always compared with the invested effort and costs to achieve the goal. Thus, we need to further study how the 5G NetApp deployment can be integrated with current technologies used in the ports, and to evaluate the impact of such deployment. From a sustainability perspective, further case studies need to investigate the impact of the NetApps on the environment (e.g., the potential increase in the activity of equipment), as well as the social impact of increasing safety of port operations.

Finally, to realize the true potential of NetApps that has been discussed in the points above, there is a need for an efficient NetApp management and orchestration. This means that automated testing and validation, which is included in the Test cases of NetApp package, needs to collect end-to-end NetApp performance metrics and constantly check whether these metrics comply with the 5G mobile connectivity and network slice requirements stated in the NetApp blueprint. This process is challenging, as it results in NetApp re-configurations and updates, and needs to be carefully studied and tested so that it does not deteriorate the NetApp performance. In the scope of the VITAL-5G project, we will validate these functionalities in real-life T&L environments as a part of the project trials, thereby allowing third-party experimenters to test their own, or the NetApps available in the VITAL-5G Open Online repository.

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