Enabling end-to-end freight transport visibility using 5G technology:

the case of the FOR-FREIGHT Project

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***Abstract*—The Transport & Logistics sector is one of the most prominent business sectors which the wide adoption of 5G cellular communications is expected to impact. The need for enhanced visibility and transparency during the execution of end-to-end logistics processes and freight transport enforces stakeholders to invest more and more in installing 5G in their businesses. In this context, the FOR-FREIGHT project targets to provide end-to-end optimization of multi-modal logistics and improved access to transshipment services through the adoption of 5G-enabled functionalities. This paper outlines the project alongside its real-world use cases, as well as an update of the progress made so far. The preliminary analysis presents the main areas of application and the expected benefits that will derive from the implementation of 5G technology in FOR-FREIGHT's trials. In addition, correlations with other projects and potentially reusable (by FOR-FREIGHT) technologies implemented on them are identified. Moreover, an analysis of the "pain points" and the implementation barriers is conducted, regarding the installation of proper 5G connectivity in the project's end-to-end scenarios.**

Keywords—Transport & Logistics; 5G technology; Multi-modality; Connectivity; Freight Transport

I. Introduction

The Transport & Logistics (T&L) sector plays a crucial role in the international trade of goods, with the EU being one of the top-3 players world-wide. However, despite its importance, still various parts of the end-to-end handling of multimodal transshipments are handled independently by the different stakeholders using disjoint systems, resulting in information silos and increased probability of mishandling errors. To cope with the needs of modern logistics, T&L stakeholders are now shifting their attention to 5G technology [1, 2, 3] to provide the necessary ultra-latency communication for enabling the management of material flows and enhancing the visibility and transparency in modern supply chains.

In this context, the FOR-FREIGHT (**F**lexible, multi-m**O**dal and **R**obust **FREIGH**t **T**ransport) project aims to develop a 5G cloud-based platform used for integrating legacy logistics systems from various stakeholders and enabling seamless, end-to-end freight data exchange. Through this platform, it is foreseen to (i) maximize the utilization of multimodal freight transport capacity; (ii) achieve competitive sustainability with higher levels of efficiency; (iii) reduce average costs of freight transport; (iv) enable secure information exchange based on Blockchain technology; and (v) increase supply chain resilience against large-scale disruptive events.

The purpose of the paper is to analyze the connectivity gaps in real-environment transport and logistics operations that were recognized in the analysis of the FOR-FREIGHT project use cases, as well as to suggest potential opportunities for enhancing connectivity through the use of 5G technologies and to examine the associated application challenges. Furthermore, it aims at providing awareness of the project and disseminate its up-to-day progress.

In the remaining, the paper is structured as follows: Section II provides a State-of-the-Art analysis of 5G connectivity in T&L applications, whereas Section III gives a brief overview of the project's use cases. Finally, Section IV analyses the pain points and the expected benefits from the use of 5G in FOR-FREIGHT's use cases, while Section V summarizes the project's outline and highlights the next steps of the work.

II. State of the Art Analysis

A. Connectivity with 5G technology

The 5[th] generation cellular networks, commonly referred to as 5G, are considered as a prominent approach for dealing with the ever-growing number for simultaneously interconnected users and demand for enlarged bandwidth zones. In particular, 5G networks aim to enable synchronous communication between user equipment [4] by making use of different radio access technologies (e.g. cellular, satellite, Wi-Fi) [5]. The concept behind 5G technology lies down to enabling assets to be continuously connected to different network nodes, which could be probably more reliable for moving devices, reducing disconnection incidents [5]. According to the first specification released by 3GPP [6] the key features of this communications "revolution" are the: (i) Enhanced Mobile Broadband; (ii) Ultra Reliable and Low Latency Communications, and; (iii) Massive Machine-Type Communications. Despite that 5G networks are relatively immature and only few paradigms exist (mainly due to funding barriers related to infrastructure [7]), many sectors are already expected to benefit from 5G connectivity, with (i) T&L; (ii) retail; (iii) manufacturing; (iv) healthcare; (v) autonomous mobility, as well as; (vi) smart cities being among others [6].

B. Implementation of 5G in the T&L sector

As mentioned above, the T&L sector is expected to be one of the key beneficiaries of the innovations in 5G technology. 5G connectivity can provide the required low-latency and timeless information exchange between freight, freight transport vehicles and legacy systems operated by various stakeholders. This kind of interconnectivity will be able to increase the intelligence in the management and coordination of material flows, and therefore to improve supply chain visibility and control [7]. However, there are several hurdles that currently delay the adoption of 5G in the sector and, as a result, only few applications occur in logistics systems [7, 8] and generally the area is still under-researched.

A critical issue that postpones the expansion of 5G technology in T&L enterprises is the problem of standards integration with other technologies such as RFID sensing and Blockchain [9, 10], as well as with stakeholders' legacy systems, which in fact remains difficult. Especially in the case of legacy systems integration, the are several challenges that remain unresolved even nowadays, such as (i) increased security risk; (ii) inflexibility and inadaptability to changes and, thus reduced system resilience, and; (iii) unreliability and thus increased probability of disruption [7, 11]. This problem becomes essentially important in the case of crossing borders between different nations [12, 1]. Moreover, apart from being incompatible with new technologies, the maintenance of integrated legacy systems is costly. Secondly, even in case of resolving the technical integration affairs, companies need to invest additional funds in ancillary technologies and employee upskilling/training to bring logistics 5G networks into effect [13]. Finally, 5G networks also raise several privacy issues related to freight drivers and forwarders [7]. It is evident that further attempts are required to resolve the challenges that are holding back companies from investing in 5G.

III. USE CASES

FOR-FREIGHT focuses on end-to-end optimization of logistics processes, and the application of disruptive technologies such as advanced AI/ML techniques. Through the development of novel and interoperable T&L solutions and their integration with legacy logistics systems, the use of cutting-edge devices, alongside the increased efficiency and sustainability of multimodal and transshipment T&L services in multi-stakeholder environments, as well as the increased sustainability through the reduction of Greenhouse Gas emissions, freight transport costs and environmental footprint, FOR-FREIGHT brings a range of added value to the field of freight transport. It, therefore, emphasizes the increased security using Blockchain technology that brings together key stakeholders such as port, airport, rail, or road operators, while taking into account the existing EU/global standards. The idea is to digitalize and automate the freight transport process with the use of new technologies, solutions and businesses so that logistics chain players are able to increase their competitiveness and ensure sustainable development. For this reason, different domains of the multimodal logistics chain will be deployed (Fig. 1), which refers to three Use Cases (UCs) [14].

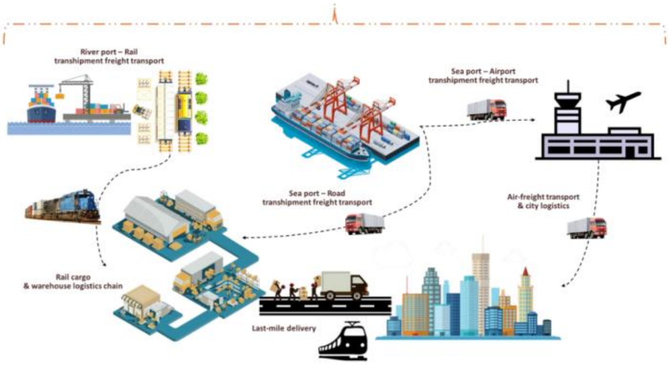

Fig. 1. FOR FREIGHT overall concept

Starting with the first UC, the Spanish Trial Site located in Valencia and Madrid will take advantage of the facilities assets and technologies such as Digital Twins and Blockchain, as well as the Subway-Based Network to support the decision-making process in multimodal transport and provide sustainable last mile distribution to the end-users. The target is to optimize the planning of multimodal transport from ships to the port, to the central warehouse. Taking advantage of individual management systems and resources, as well as the Galileo/EGNOS GNSS, IoT devices supported by 5G will track each container so that the transport process is completed successfully. Henceforth, Blockchain and Digital Twins will simulate optimal situations by using historical data, to demonstrate real-time data exchange that supports the Decision Support Systems (DSS). Such data refer to vessels' schedules and latest updates on time of arrival, resources for unloading containers, destination of containers, truck/train assignation, etc. It is expected that this process will help reduce emissions (>80% less) and transport costs (>12% less). The technologies that will be used for UC1 are AI/ML (e.g., traffic analytics and dynamic vehicle routing models, etc.), Blockchain for time reduction in administrative and operational processes, IoT sensors for real-time tracking, and Digital Twins.

The second UC which refers to the Greek Trial Site combines sea-port, airport (air-freight), and road transport (truck) for end-to-end optimization with DSS, as well as real-time monitoring and control capabilities. This solution will integrate information from legacy individual management systems of various stakeholders, field devices and equipment, as well as newly deployed sensors, data, and ML analytics functions. To shift from manual execution to automation (e.g., automatic reservation of air-freight tickets, automated update of ships' Estimated Time of Arrival (ETA) at the port of Piraeus, etc.), the FOR-FREIGHT platform will accommodate historical as well as real-time data referring to containers being loaded in Ukraine, in COSCO owned/operated ships, heading for Piraeus, for better monitoring of the cargo shipping process. The technologies that will be used for UC2 are IoT sensors for real-time and status tracking, 4G/5G network, Big Data and Cloud Computing (e.g., Platform for monitoring different datasets related to warehouses' status, arrivals prediction, truck/vessel/cargo position and cargo status/condition, as well as matching the supply and demand of storage space for logistics service providers and users, etc.), and AI/ML.

Finally, the third UC, the Romanian Trial Site located in Galati Port, combines river port and rail transport. For a more effective transport flow, this UC will be collecting information from all individual management systems, and therefore, state-of-the-art IoT and data processing solutions such as 5G, Internet of Containers, etc., will be used. In more depth, the unloading and reloading of cargo from the Danube Galati Port on to trains, and its further transport towards central Europe via rail, will be addressed. A unique identification code will be used every time a container is transported, unloaded in Galati port, and loaded as rail cargo. The combination of historical and real-time tracking data will allow ETA to automatically update and provide a complete picture of the end-to-end procedure to the end-users. With this intention, DSS will inform port authorities, logistics operator and custom agencies on resources needs, as well as rail freight operators on required storage space and resources, according to the updated ETA. In addition, a possible scenario is to provide automatic reservations for railway companies. The technologies that will be used for UC3 are Digital Twins, Blockchain, IoT sensors for real-time tracking, 4G/5G network, as well as AI/ML.

IV. Analysis

A. *Connectivity Pain Points and Impementation Barriers*

A key issue in the T&L industry that significantly affects the FOR-FREIGHT use cases is the low level of digitalization and automation leading to suboptimal resource planning of the processes and connectivity challenges.

An important aspect is that the analyzed use cases have been found to be characterized by information silos across different operational domains, which prevent interaction between various systems and lead to a lack of prior knowledge on key information. Insufficient investment in new technologies hinders real-time tracking and tracing of goods and shipments, while additional delays are caused due to the reason that communication between stakeholders is primarily facilitated via phone calls, emails and paper-based documentation.

Similar to the findings of previous research [15], the absence of interoperability and compatibility between systems results in the exchange of unreliable data. The unreliability of the data adversely affects the quality and availability of data, resulting in data fragmentation and inaccessibility. This lack of standardization creates a gap in ensuring efficient communication among stakeholders and their systems, and limits operational effectiveness in multimodal operations.

As a consequence, the inability to use real time data and simulate potential alternative scenarios results in longer delivery times, congested ports and hubs, and lack of visibility along the supply chain.

Addressing these challenges is essential for fully realizing the benefits that come with the application of novel, state-of-the-art technologies like 5G technology or platform federation in the project’s use cases, and, by extension, the transport and logistics industry.

B. *Boosting Connectivity: Areas of Application, Technologies and the Expected Benefits*

To boost system connectivity and achieve seamless data exchange (interoperability) it is required to establish the appropriate connectivity infrastructure and to ensure connectivity protocols (standardization and governance) that are agreed upon by all stakeholders involved.

Optimizing the overall transport and logistics system, shall not necessarily entail optimizing all of its processes, but rather identifying these areas that the application of new technologies and/ or business models will bear the highest benefits for the system and achieve “quick wins”. For instance, in the case of FOR-FREIGHT, the focus could be on the intermodal and multimodal interfaces. As described in section III, the project use cases deal with multimodal transport cases such as Port-to-Airport, Riverport-to-Rail, Port-to-Railway, Port-to-Road and Road-to-Metro. These scenarios consist of a wide variety of T&L stakeholders that cover end-to-end operations using a combination of different modes (e.g., air, land, sea), operational/ legacy systems (e.g., ERP, TMS, TOS, PCS, added-value services, etc.) and devices (e.g., IoT, physical internet) to facilitate physical T&L service implementation.

The application of 5G technology in the FOR-FREIGHT use cases is expected to fill many of the identified connectivity gaps and enhance the overall supply chain processes.

The 5G network coverage will allow for door-to-door tracking of the entire process via commonly agreed interfaces (e.g., APIs), providing an accurate real-time position of the cargo and containers, as well as complete remote monitoring capabilities for logistics operators and users. This notion of a common governance, which is implied by the commonly agreed interfaces, calls for sophisticated federated solutions that facilitate multi-stakeholder collaboration with minimum entry costs for the involved parties. Models like the federation (as proposed by the Digital Transport & Logistics Forum/ DTLF) that have been successfully piloted in industrial cases recently (i.e., through projects like FENIX or FEDeRATED) can be applied to facilitate seamless, safe and secure B2B system communication.

Visibility of the end-to-end process can provide important details about the location and status of the cargo (temperature, humidity, vibrations, luminosity, etc.) resulting in increased safety and road transport efficiency. Real time updates are also feasible with the tracking of a specific container using a unique identification code along with automated updates of vehicle ETA. The use of IoT solutions, feeding real-time operations or Digital Twins, can improve the decision-making process and reduce the inefficiencies in order to optimize the transport routes according to multiple real-time and historical factors.

Enabling 5G technology and federation in FOR-FREIGHT project is expected to address gaps related to the timely exchange of information from multiple sources, positively impacting end-to-end shipment and cargo visibility, safety and overall system performance.

C. *Links with other Projects*

To facilitate platform connectivity and ensure seamless flow of information, FOR-FREIGHT leverages the technological outputs of relevant active or finished EU research and innovation actions such as VITAL-5G, 5G-Blueprint, 5G-MOBIX, iNGENIOUS, FENIX, 5G-LOGINNOV, etc. The aim is to successfully integrate extant 5G based solutions and toolkits (e.g., open testing environments), as well as innovative B2A and B2B network technologies (e.g., federative approaches) to the existing project use cases and further develop assets to increased technology readiness levels. Some examples of specific technologies could be the following:

1) The VA1 Network Application for data ingestion and two-way communication with on-site equipment, decision-support using rules and inferences, container monitoring and infield assistance. The early version of the application includes the following features: (i) Core IoT Controller; (ii) MQTT/HTTP protocols; (iii) a Reasoning Engine and; (iv) a Persistence Engine [16].

2) The VITAL 5G Portal for the lifecycle management of various network applications and the creation of multimodal services. The portal is a frontend for aggregating individual components in the following subparts: (i) Vertical Service Lifecycle Manager; (ii) Service Testing & Experiment Manager; (iii) Intent-based Interface for Experiment Requests; (iv) Service Monitoring; (v) Automated Service Performance Diagnostic, and; (vi) AI/ML in support of lifecycle management and diagnostics [16].

3) The Open Online Repository serves as a catalogue of multimodal services, which provides access to outside users to download experimentation functions for testing [16].

4) The Access Control of VITAL-5G enables authentication and authorization of all requested actions received from the backend. It is responsible for the management of the users' roles (create, merge, update, delete user), as well as for providing access to a single user to fetch specific resources and services from the portal backend [16].

5) The FENIX Federated Network allows various end-user platforms equipped with a FENIX Connector to connect to a federated architecture model for exchanging and sharing real-time data and information seamlessly through the FENIX Federated Network. The FENIX Connector facilitated the following core functionalities: (i)Authentication/ authorization; (ii) service brokering; (iii) safe and secure data exchange thus allowing various end-user platforms to connect (one-to-many, many-to-many) [15, 17]. More specifically, some of the FENIX Connector features could be employed in the Athens (GR) use case to facilitate the mutual data exchange between the legacy systems of the various stakeholders and resources involved in the transport procedure of cargo from the Port to the Airport, such as port authorities, custom brokers, transport vehicles/trucks, warehouse handlers, airport authorities and various airlines systems.

V. Conclusions & Next Steps

Freight transport is a concept that requires regular developments and improved solutions. Due to inadequate resource planning and connectivity, modern logistics have various stakeholders and end-users dealing with the need to shift their operations to 5G technology for more efficient and reliable interconnectivity, management, and control. Henceforth, T&L stakeholders need to invest in employees' development and offer training on several domains of the multimodal logistics chain to strengthen their knowledge and skills and advance their operational environments. To overcome challenges in the T&L sector, FOR-FREIGHT aims to provide a platform that connects multimodal transport stakeholders who use a combination of devices, modes, and legacy systems, with the main intention to improve their everyday processes, and better monitor their logistics operations, and users. This B2B system communication and connectivity infrastructure aims to lead to a means of more efficient freight transport by deploying, in relation to the project's UCs, different domains of multimodal logistics such as AI/ML, Blockchain, IoT sensors, Digital Twins, 4G/5G network, and Big Data and Cloud Computing.

As next steps in that direction, the FOR-FREIGHT consortium foresee to pursue the following: (i) the identification of connectivity standards to support seamless adoption across varied application scenarios; (ii) the detailed design of the implementations in the trial sites (in the form of to-be situations); (iii) the identification of applications that are quick to develop, integrate and test, and promise great potential for immediate benefits at the same time ("quick win" solutions); (iv) the start of the integration activities between the legacy systems of the involved stakeholders, and external systems and databases; (v) the definition of business models to ensure plug-and-play functionalities to generalize FOR-FREIGHT outcomes and transfer results to similar settings.

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