Enabling innovation in Transport & Logistics: a 5G approach

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***Abstract* — The Transport & Logistics sector has been one of the leading examples of adopting 5G technologies to address various challenges stemming from the evolving societal needs for fast and reliable supply chain management and last-mile delivery. The optimization of such challenging end-to-end operations can be highly reinforced via the adoption of 5G enabling technology, which can at the same time accelerate innovation. Both, the infrastructure optimization aspects, alongside the various involved sites' performance are equally important for the successful implementation of 5G technologies for any T&L sector. The paper offers the unique perspectives of 5 EU-funded projects, namely 5G-BLUEPRINT, VITAL-5G, FOR-FREIGHT, FENIX and 5G-LOGINNOV, and how they combine their consortia's expertise in both providing a complete 5G-based system for seamless connectivity between the various projects' trial sites as well as how the use cases/developed infrastructure can empower innovation in the Transport & Logistics sector.**

Keywords* — *Transport & Logistics; 5G; Logistics 4.0; Multi-modality; Sustainability

I. INTRODUCTION

The introduction of digital and automation technologies has revolutionized the way of managing assets, materials, and workforce in the supply chain sector [1]. In this context, the combination of the Internet of Things (IoT), Big Data, Cloud Computing, and Artificial Intelligence (AI) for enabling improved logistics processes claim for advanced and stable instantaneous communication. This integration of digital technologies in logistics is commonly mentioned under the term of "Logistics 4.0" or "Smart Logistics" [2, 3].

Logistics 4.0 can be seen as the response of the logistics field to Industry 4.0, which envisions the digitization of activities and processes for enabling cooperation, connectivity, adaptiveness, integration, autonomy, and cognition [3]. Smart logistics rely strongly on the latest ICT, software systems and the IoT for providing (i) better control of logistics processes; (ii) realization of commodity flows, and; (iii) realization of information flows [4]. Towards this direction, the 5th generation cellular networks (5G) are considered to provide the required and necessary connectivity, compute capacity, as well as trustworthiness and security of information exchange between supply chain stakeholders [5-7].

Particularly, 5G is envisioned to increase the intelligence in managing and coordinating material flows, meanwhile enhancing visibility and transparency through (i) higher data speeds (in uplink and downlink communications); (ii) ultra-reliable low-latency communication; (iii) increased connection density, and; (iv) enlarged spectrum bands [1, 8, 9]. However, despite the obvious upgrades expected in Transport & Logistics (T&L), there are currently only few applications currently present, as the integration of 5G with other technologies is still immature in terms of research [1].

In the above context, the scope of this paper is to highlight the multi-perspective impact of 5G connectivity on improving the operations and the whole end-to-end processing in T&L. More specifically, the aim is to present an intersection of EU-funded projects oriented to cover different complementary domains of the complete value chain of communications within the T&L arena, such as federated-model infrastructures, finetuned technical architectures and business models for optimizing multi-modal/multi-stakeholder logistics in terms of improved resource management, freight tracking/monitoring, remote operation, and sustainability.

The remaining of the paper is organized as follows: Section II provides the expected impact of the involvement of 5G in the T&L sector and highlights the barriers that hinder the adoption of 5G-enabled technologies in modern logistics. On the sequel, Section III gives a brief intersection between relevant running or recently completed EU (HORIZON, CEF) projects and reports their up-to-day findings. Finally, Section IV summarizes the topic and outlines the added value of the presented projects.

II. 5G IN TRANSPORT & LOGISTICS (T&L)

A. Transition to Logistics 4.0

After the systematization of logistics management and the use of IT systems, e.g., Warehouse Management System (WMS), Transportation Management System (TMS), during the Logistics 3.0 era, the fourth logistics' revolution is currently progressing [10]. Logistics 4.0 was introduced amid the rapid expansion of Industry 4.0, aiming to digitize and automate the logistics operations [2]. In this context, the objective of this transition is to increase the efficiency of logistics processes by leveraging modern information technologies in demand and supply management, logistics platforms, transportation of goods, and delivery operations [11]. Big data, IoT, Cloud Computing, Wireless Sensors, Augmented Reality, Blockchain, Robotics, Automatic Guided Vehicles (AGVs) and Unmanned Aerial Vehicles (UAVs) constitute the main components enhancing this evolution [2, 12].

The utilization of these technologies in Logistics 4.0 is expected to transform the current logistic practices by: (i) enabling the sharing of data and information between companies (cooperation); (ii) integrating and enhancing transparency in the supply chains (connectivity), (iii) having the flexibility to meet diverse market requirements (adaptiveness), (iv) coordinating logistics flows in a holistic manner (integration), (v) allowing independent decision making (autonomy), and; (vi) automating tasks based on human capabilities (cognition) [12].

Connectivity remains an underdeveloped domain in logistics operations despite the possibilities offered by recent advances in digital infrastructure. Considering that 5G technology offers significantly faster speeds compared to 4G (up to 20 times faster) [13], it is critical to explore its potential utilization in the enabling technologies of Logistics by implementing practical applications, such as in European projects.

B. 5G Connectivity in the T&L sector

The requirements of reconfigurability and modularity in modern supply chains has urged a more and more increasing interest towards a shift from traditional wired communications (e.g., EtherNet, PROFINET, Modbus, TCP) to wireless technologies [1]. However, current 4G technologies are incapable of fulfilling the vision of Logistics 4.0 adequately, due to that many applications are characterized by very restrictive latency and reliability requirements, and moreover are very bandwidth demanding [1, 5].

To meet the required performance standards for reliability and speedy exchange of data, 5G networking is considered as a global unified multiple-device connectivity solution for T&L [5, 8], offering key features to advance the sector, such as (i) data speed up to 10 Gbps; (ii) ultra-responsive and ultra-reliable connections; (iii) higher network availability; (iv) lower power consumption; (v) enhanced mobile broadband and; (vi) machine-type communication [1, 5, 13]. Considering these, 5G has a unique value towards the creation of resilient and intelligent supply chain management, by providing proper information flow between multiple stakeholders in logistics, enhanced visibility and process transparency, thus enabling better control of material flows.

C. Expectations & Barriers

5G technology can ensure reliable, mission-critical and real-time data exchange among different logistics actors, including assets, carriers, shippers, and receivers. The envisioned ecosystem of the "*always connected assets and cargo*" focuses on providing to such a multi-stakeholder community unprecedented visibility on every stage of the logistics supply chain. Key benefits include (i) the breakdown of barriers between different logistics systems by providing secure, trusted and distributed communications; (ii) improvement in the efficiency of logistics operations and massive reduction of costs through (remote) real-time telemetry and service automation/digitalization (reducing labor, management and transportation costs for in/out-warehouse operations), as well as; (iii) provisions on inherent risk mitigation mechanisms, forecasts and agile planning, putting in the center of attention the sustainability of Smart Logistics [1]

Even though the benefits of exploiting the portfolio of technologies that constitute the 5G ecosystem are undeniable [1, 14], there are still many critical issues including governance and business aspects that delay the massive rollout of 5G in enterprises. 5G constitutes a relatively novel concept in modern logistics and industrial applications occur only to a minor extent, thus requiring further investigation. A major issue unfolds in the integration of 5G technology with legacy systems, which translates to increased costs not only for the installation of critical network infrastructure, but also investments in learning and development initiatives for the employees to fully utilize the 5G-enabled logistics ecosystem [14]. Other issues include the privacy of sensitive logistics data and AI. Although 5G and Multi-access Edge Computing (MEC) can provide increased compute capacity with low latency, it also compromises data security if the local breakout occurs outside the local premises. Other challenges include (telco and Country) handovers in cross-border corridors for 5G connected vehicles/trucks that has been investigated in other HORIZON activities [15]. Finally, privacy risks for drivers could be raised [16] and thus requires careful consideration. However, it's evident that due to the limitations of current wireless technologies, there's a need for development work on 5G to support logistics applications and address all critical factors that impede its widespread adoption.

III. EUROPEAN PROJECTS (HORIZON, CEF)

A. The "5G-Blueprint" project

The 5G-Blueprint project is focused on creating, testing, and validating, a comprehensive 5G-based system for seamless cross-border teleoperated transport. In the project, the seamless teleoperation over 5G Standalone (SA) based on 3GPP Release 16 technology is tackling cross-border challenges in terms of advancements in 5G network design and implementation that minimize the service interruption time while teleoperated vehicles/barges are crossing the Dutch-Belgian border. To validate effective teleoperation mechanisms on vehicles, trucks, and skid steers, over the 5G SA, 5G-Blueprint offers two in-country pilot sites located in port environments (Vlissingen in NL, Antwerp in BE), and to achieve seamless cross-border teleoperation, 5G-Blueprint created Zelzate pilot site (BE-NL).

The 5G-Blueprint project defines four use cases in total: (i) Automated Barge Control, focused on improving the port entry efficiency by reducing crew requirements for barging in busy port environments; (ii) Automated driver-in-loop docking, providing the yard tractors and skid steers with optimized docking and maneuvering operation in safety-critical situations; (iii) CACC based platooning, leveraging 5G connectivity on the highways to combine platooning with teleoperation and full automation, and; (iv) Remote take-over, which is entirely focused on the teleoperation mechanisms that are later applied to other use cases. The use cases are further enhanced with the help of so-called enabling functions, whose objective is to improve safety and efficiency of teleoperated transport, thereby increasing awareness of vulnerable road users, enhancing distributed perception, and enabling intelligent traffic lights, among others. Some of the preliminary findings are listed:

- A driver-in-the-loop docking test in the Vlissingen pilot site, with a scaled truck trailer combination and 5G equipment, resulted in a maximum value of tracking error is 1.3cm (average of 0.4cm), meeting the requirements of less than 2.5cm.
- Tests including 5G-enhanced CACC-based platooning integrated with the enabling functions, performed in shadow-mode (sending teleoperation commands to the teleoperated vehicle, without application to the UE side) were possible with a maximum achievable speed of 90km/h, with an extended awareness to the teleoperator that increases safety with less than 5% error between lead and follower vehicle.
- Remote takeover tests, where remote driving enhanced by enabling functions was tested over 5G connectivity, resulted in improved values for throttle (obtained error 3%, required less than 6%), and brake accuracy (obtained error 5%, required less than 6%).
- A promising cellular-based automated barge control system proved that 5G outperforms 4G both in terms of latency (~15ms vs. 27ms), and bandwidth on the uplink (24Mbps vs. 36Mbps).

All results obtained so far show good consistency between the target performance values and data measured in the pilot sites using the 5G network. One of the critical testing and validation aspects is on the challenging cross-border scenarios, thereby testing and validating the impact of enhancements on the 5G SA roaming on achieving the service continuity for cross-border teleoperation.

B. The "VITAL-5G" project

The extended adoption of 5G technology in the T&L industry is among Europe's top priorities for the next few years. For the successful deployment of 5G-powered services in this sector, it is crucial to have access to flexible and user-friendly tools and APIs that can enable the design, management, and orchestration of these services from the trial stage to production.

The VITAL-5G consortium is focused on addressing these challenges and advancing the deployment of 5G services for the T&L industry. It aims to achieve this by developing an intuitive and production-ready service orchestration and validation platform with an open catalogue of Network Applications, helping to overcome the existing limitations for industry verticals eager to design and deploy T&L virtualized services on a 5G network.

Several key challenges that need to be addressed for the successful adoption of 5G technology in production services offered by the T&L industry have been identified including: (i) Lack of user-friendly tools and APIs; (ii) Limited interoperability between 5G systems and technologies that can lead to fragmentation and inefficiencies in service delivery; (iii) Security and privacy concerns, and; (iv) Limited availability of 5G infrastructure and 5G-enabled services for the T&L industry. By addressing these key challenges, the VITAL-5G consortium aims to support adopting 5G technology in the T&L industry and facilitate the successful deployment of 5G-powered services from the trial stage to production.

Through the VITAL-5G platform, users can easily create their own T&L-specific as well as vertical-agnostic Network Applications and deploy them in the platform, regardless of their technical expertise. This can be easily achieved through the user-friendly interface provided, which aims to simplify the application development process and provides access to a wide range of pre-built templates and building blocks that can be used to create complex services to meet the specific needs of different service providers and verticals.

The VITAL-5G platform offers powerful tools and features that enable internal or third-party experimenters to design, develop and deploy custom network applications in the T&L industry, with a comprehensive validation process ensuring their reliability and performance. Once the Network Applications are validated, they can be onboarded into the VITAL-5G catalogue, making them available to other third-party service providers and other verticals. The VITAL-5G platform is addressed to both internal and third-party experimenters, such as software developers, network engineers, and researchers. Experimenters can use the VITAL-5G Portal to manage the creation, instantiation, life-cycle actions, and monitoring of T&L services and related 5G network slices, experimenting with different service and network configurations.

The project's use cases (UCs) were selected aiming to address the specific needs of the T&L industry and demonstrate the practical applications of 5G technology across three testbeds located in the Sea Port of Antwerp (BE), the River Port of Galati (RO), and a warehouse in Athens (EL). The "Assisted vessel transport" UC trialed in the BE node, leverages on 5G to improve the efficiency and safety of vessel transport operations in the port, whereas the "Automation and remote operation of freight logistics" UC (EL node) enables the remote control and monitoring of complex logistics operations with the use of AGVs. Finally, the "data-enabled assisted navigation using IoT sensing and video cameras" UC (RO node) enables safer port operations even in severe weather and water conditions.

C. The "FOR-FREIGHT" project

The FOR-FREIGHT project engineers the development of flexible, multi-modal, and robust freight transport, aiming to modernize the T&L sector and reduce costs by (i) designing and developing novel interoperable solutions for T&L stakeholders and; (ii) validating the proposed solutions into real-world multi-stakeholder use cases. The project foresees to supply T&L stakeholders with State-of-the-Art technologies, such as

5G/IoT connectivity, AI/Machine Learning (ML) and Big Data analytics towards approaching an end-to-end optimization of multimodal/multi-stakeholder logistics processes, meanwhile enabling access to transshipment services. The solutions will enable more capacity-effective, cost-efficient, trustworthy, and sustainable management of goods and freight flows in multiple transfer nodes, such as ports, airports, or inland terminals.

FOR-FREIGHT aims to validate its solutions into three multimodal T&L trial sites located in real-world operational environments and to integrate their functionalities and legacy systems involved under a common cloud-based 5G-enabled experimentation platform, offering access, monitoring, and evaluation capabilities. The three multimodal use cases that will be demonstrated in real-life T&L environments namely are:

- "Blockchain & Digital Twins supporting Decision Making Process in multimodal transport combined with a Subway-Based Network for sustainable last-mile distribution."
- "End-to-end optimization with Decision Support Systems (DSS), real-time monitoring & control capabilities of Port-to-Airport multimodal freight transport."
- "IoT and data processing solutions (5G, Internet of Containers, etc.) for accessible information on transport flow in river port to warehouse hub via railway network."

The main idea is to ease (i) door-to-door tracking based on Digital Twin concepts; (ii) offer DSS for the optimization of resource utilization (labor power, vehicles, equipment) and real-time scheduling, based on advanced AI/ML techniques, as well as provide; (iii) resilience against large-scale disruptive events (e.g., pandemic); (iv) secure information exchange using Blockchain, and; (iv) achieve sustainability by adopting a carbon footprint assessment framework for reducing CO_2 emissions. To achieve these Unique Value Propositions, commercial 5G networks will be utilized to enable proper data exchange among existing and newly developed hardware and software equipment, including stakeholders' legacy systems, vehicles, or even personal devices (e.g., tablets, smartphones).

D. The "FENIX" project

The current lack of interoperable and interconnected data sharing in the supply and logistics chains is an important barrier to the improvement of the efficiency of T&L operations. Concerted efforts have been initiated to address this issue and improve system interoperability and connectivity by linking the existing legacy systems and information silos across Europe. FENIX (A European FEderated Network of Information eXchange in LogistiX) aimed at developing the FENIX Federated Network, the first pan-European federated network of interoperable platforms as an enabler of Business-to-Business (B2B) and Business-to-Administration (B2A) data exchange and sharing between transport and logistics platforms in Europe.

The federation comprises a distributed format, like a data space, of linked platforms that utilize a FENIX Connector to communicate. The connector is a fundamental component of the federation architecture that is integrated into each participating platform to enable identity management, service brokering, and data exchange capabilities. By means of the federation, participating organizations share and utilize services throughout Europe, with minimal adjustments required in their operational systems, all while retaining complete ownership of their data. This decentralized approach minimizes entry cost barriers and reduces governance conflicts by creating a framework for digital service interoperability and data exchange standardization.

The ultimate objective is to provide interoperable data leveraging real-time streams (e.g., physical internet devices, IoT, etc.) delivered via cloud services, resulting in real-time awareness and visibility for stakeholders across the logistics chain. FENIX carried out under the guidance and coordination of the Digital Transport & Logistics Forum (DTLF) across 11 pilot sites in nine European countries (AT, BE, DE, EL, ESP, FR, IT, NL, and SK), in all corridors of the Trans-European Transport Network (TEN-T) [17].

Notable improvements from the application of FENIX have been recorded in the overall supply chain operational efficiency, sustainability, process digitalization, and service levels. Higher load factors (up by 9%) have been achieved in road and rail shipments, matched with significant increases in modal shift (up to 4.34%), while delivery reliability has increased by 32.71%. This also affected the operational externalities, reducing the overall CO2 emissions by 16% and NOx emissions by 7.32%. Digitalization accelerated reaching end-to-end automation in many cases, with fewer documents being exchanged physically (70.43% increase in digital exchanges). Consequently, widespread automation resulted in decreased (12.5-95.5%) operational process times (i.e., fulfillment, customs, turnaround, (un)loading, related to administration, automation, and travel).

E. The "5G-LOGINNOV" project

5G-LOGINNOV's vision is to optimize freight and traffic operations at Ports and Logistics hubs via innovative concepts, applications and devices supported by 5G technology, the IoT, AI-enabled data analytics, next generation traffic management systems, Cooperative, Connected and Automated Mobility (CCAM). The project's scope with focus on large scale trials and pilots has been verified in real operating conditions in three Living Lab (LL) environments, namely, Athens (EL), Hamburg (DE) and Koper (SI). While Athens and Koper LLs are focused on 5G applications and Smart Logistics within the Port premises, in Hamburg, the focus resides in the hinterland, i.e., the interconnection of the Port with the road transport network. In more detail, following the compute continuum paradigm various AI-service placement options have been considered (extreme-edge, edge and cloud) given the various requirements of the developed use cases (e.g., latency sensitive, or throughput intensive), creating a 5G system of cloud native interconnected Port assets (5G Trucks, 5G cranes, 5G drones, 5G IoT).

The main objectives of the project include: (i) the support of the "Green" Port Industry vision by reducing the hub's operation

emissions. Particularly, a 5G based Green Light Optimum Speed Advisory (GLOSA) system has been developed coupled with precise positioning technology and MEC, for combined coordination of vehicle platoon movements and traffic light infrastructure; (ii) enhance safety and security operations by developing a 5G & AI enabled collision warning system between trucks and personnel, as well as mission-critical AI-assisted drone surveillance; (iii) improve the efficiency of logistics operations via 5G&AI enabled video analytics related to port control, logistics and remote automation. The portfolio of 5G-LOGINNOV use cases were evaluated in various deployment options, i.e., 5G-NSA private network (Athens LL), public 5G-NSA network (Koper and Hamburg LLs), as well as private 5G SA network (Koper LL). Some key findings include:

- Main advantage of using public NSA-assured infrastructure is in the large commercially available spectrum, allowing applications to benefit from a high download speeds. With the current 5G UEs, speeds can easily go above 1 Gbps, but due to regulatory enforced TDD splits profiles, it currently limits uplink throughput up to 150 Mbps. To fulfill the strict cybersecurity requirements of port critical infrastructure, MEC mechanism with local core can be integrated into public infrastructure. This enables local port traffic breakout, which can also benefit from communication resilience, lower latency and higher throughputs, as port-generated traffic doesn't need to travel to the remote centralized telco core.
- Utilizing Private 5G assured with cloud-native mechanisms, deployment flexibility and its speed present a major benefit for the ports. In the case of pre-prepared and operational compute and baseline RAN infrastructure (e.g., RRU with CPRI), the initial deployment of virtual BBU and 5G CN is less than 2 minutes. This provides significant flexibility for private 5G system optimization and reconfiguration tailored to different operational needs. SA mode also allows for lower latency compared to NSA, with an average RTT of 17ms. Furthermore, there is inherited flexibility in the assignment of TDD NR profiles, enabling optimization of uplink throughput to go beyond 150 Mbps even with limited spectrum (e.g., 190 Mbps in the case of 50 MHz spectrum).

IV. Conclusions

This paper provided an overview of five (5) European-funded projects, namely: (i) 5G-Blueprint; (ii) VITAL-5G; (iii) FOR-FREIGHT; (iv) FENIX, and; (v) 5G-LOGINNOV, which are focused on the multi-perspective impact of 5G for the optimization of end-to-end T&L processes. Particularly, the paper presented an intersection between the abovementioned projects as they cover different complementary domains of the complete value chain of the communications arena in the sector, such as business models, technical architectures, federation concepts, multimodality, flexibility, and sustainability. The projects' concepts are presented, alongside their objectives and use cases. Moreover, their latest findings are briefly reported. The current works reflect representatively the attempts of the EU Commission to modernize logistics operations within its territory, as well as for removing the barriers, which are currently blocking the full-wide adoption of 5G connectivity in the T&L sector.

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