# Enabling innovation in maritime ports and the need of the 6G candidate technologies: 5G-LOGINNOV showcase

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***Abstract*—5G-LOGINNOV is the best example about how to design an innovative framework addressing integration and validation of CAD/CAM technologies related to the industry 4.0 and ports domains by creating new opportunities for LOGistics value chain INNOVation. This paper is based on the experience of the European project 5G-LOGINOV presents a selection of future 6G candidates technologies and describes them in terms of their applicability in the maritime port transport sector and their implementation in two Living Labs. 5G-LOGINNOV will support the port application case by implementing 5G technological blocks, including new generation of 5G terminals notably for future Connected and Automated Mobility, new types of Internet of Things 5G devices, data analytics, next generation traffic management and emerging 5G networks, for city ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges.**

**Keywords—6G, maritime ports, vision, safety, sustainability, optimization**

## I. Introduction

Ports have a huge potential for job creation and investment, are essential for the European transport business, for Europe's competitiveness and for economic growth, 74% of goods exported or imported to the EU are transported via its seaports. Europe's ports represent the gateways to the European continent. 74% of extra-EU goods are shipped through ports. In the same time they are equally important for intra-European trade: 37% of the intra-EU freight traffic and 385 million passengers pass by ports every year [1] [3].

At this critical juncture 5G is the convergence technology for the new generation of mobile networks, expected to be massively deployed starting from 2023. 5G promises also to address the diverse and rather demanding performance requirements of a wide range of use cases, in terms of data rates, capacity, security, reliability, availability, latency and impact on battery life [2] [5] to build a new enhanced logistics system [7].

This paper aims to offer a vision for 6G innovation in ports to improve their sustainability [4], their security, optimizing the activities that have become more complex in a post-pandemic world facing complex socio-political and economic situations such as the conflict in Ukraine and the energy crisis.

## II. Project Framework

This paper aims to offer a vision for 6G innovation in ports to improve their sustainability, their security, optimizing the activities that have become more complex in a post-pandemic world facing complex socio-political and economic situations such as the conflict in Ukraine and the food and energy crisis.

## III. Preliminrary Results

In this section will be described four real-world use cases based on the future 6G candidate technologies. In particular, to test the potentiality of the 6G innovations to increase safety, sustainability and optimization in ports, two Living Labs are presented.

### *A. Athens Living Lab-Port of Piraeus*

As part of the 5G-LOGINNOV project [5], the Athens Living Lab (LL), at the Port of Piraeus (PCT), developed a set of use cases and platforms which communicate over the 5G NSA network with different types of end devices (5G-Trucks, 5G-Cranes, 5G-IoT, 5G UEs). 5G technology drives the use case innovations exploiting the eMBB service and low latency transmissions of 5G, including NFV-MANO based applications and service orchestration, pioneering extreme-edge computing solutions, computer vision and AI-enabled video analytics. Particularly, the use cases are focused on 5G&AI enabled services tailored to safety/security applications as well as for improving the efficiency of daily port operations (reduce costs, improve the utilization of human resources and automate logistics services). Figure 1 depicts the deployed 5G radio access network (based on the RRU 5639w) at Piraeus Port and mapping in the port area, operating in band n78 at 3.7GHz with 100 MHz bandwidth, providing 5G connectivity to a subset of the port Piers. Vodafone's Core network operates outside the port premises, at Vodafone's datacenter.


*Figure 1: Deployed 5G radio access network in Port of Piraeus*

**Experimentation Platform**. Our experimentation platform is located at PCT exploiting the 5G network deployed in the Port Pier. Within this area we have installed several IoT nodes that act as the extreme-edge devices. These nodes consist of three main components: (i) a 5G interface, namely

Teltonika's RUTX50 industrial 5G router that facilitates the cellular connectivity; (ii) an NVIDIA Jetson AGX Xavier (JAX) device for GPU based processing connected to the 5G modem via a gigabit Ethernet connection; (iii) a 4K camera also connected via gigabit Ethernet to the cellular interface. In addition, a Cloud server is deployed at the back-end system of PCT (residing beyond the NSA core), equipped with a GPU NVIDIA RTX 3090. Additionally, we create a virtual platform managed via a k8s system (based on Microk8s), where the extreme-edge and Cloud infrastructure nodes are added as k8s worker nodes that host the workload of containerized AI services. Particularly, we exploit the YOLOv5 convolutional neural network (CNN) family augmented with data from daily port operations. The various object detection models are prepared as docker images (i.e., container network functions, CNFs). The overview of the use case architecture and all relevant service components are shown in Figure 2.

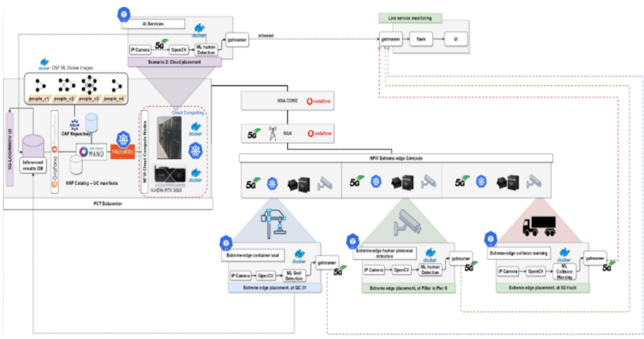

*Figure 2: The use case architecture and all relevant service components*

**5G Network Evaluation**. The following Figures (Figure 3-Figure 6) represent several 5G network KPIs including throughput and latency measurements. Particularly, the x-axis depicts samples from s1 to s12 aggregating in total 60 minutes of continuous monitoring. As illustrated, the average latency is about 16ms. Similarly, for the throughput measurements we observe maximum values of about 540Mbps in downlink and around 130 in uplink, whereas the average respective values are close to 440 and 95Mbps. Finally, the user experienced data rate is depicted in the last figure, that is, the required uplink bandwidth of a 4K camera integrated with the Port Internet of Things (IoT) nodes to provide the video analytics services.

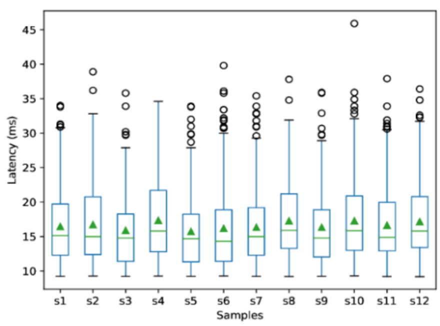


*Figure 3: Latency (ping) measurements*

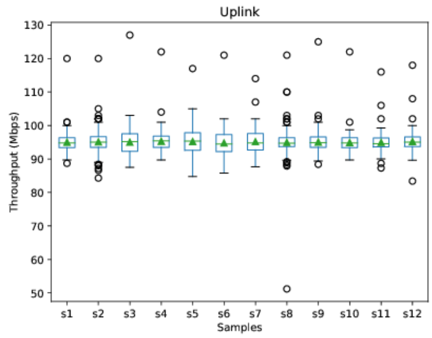


*Figure 4: Throughput Uplink (iperf)*

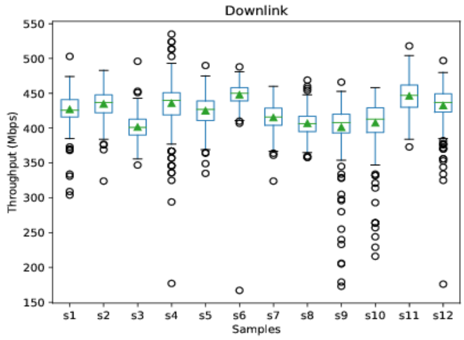


*Figure 5: Throughput Downlink (iperf)*

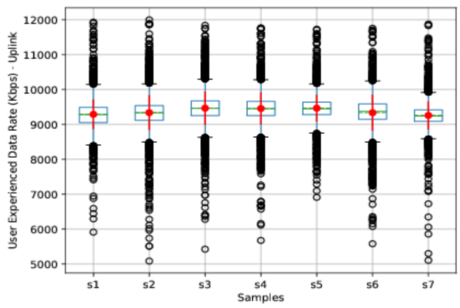


*Figure 6: 4K Uplink video streaming data rate*

**5G&AI enabled container seal detection evaluation**. For this use case we have a developed an AI-enabled video analytics service, exploiting 4K video streams from various cameras deployed at the Port quay side cranes, with aim to detect the presence (or absence) of container seals at the loading/unloading phase of vessels. The following two results depict the processing time that the developed algorithms require for inference, when the service is deployed at the Cloud or extreme-edge system and, the accuracy of the algorithm for predicting the presence/absence of container seals. We observe about 50ms (Figure 7) processing time per frame in extreme edge deployments, and about 20ms (right figure) when the service is operating at the Cloud. Additionally, with respect to accuracy (Figure 8), we observe zero false positive events, whereas only a few false negative cases are present, when evaluating about 30hours of video footage for the container seal service, spanning various working shifts and different light conditions.

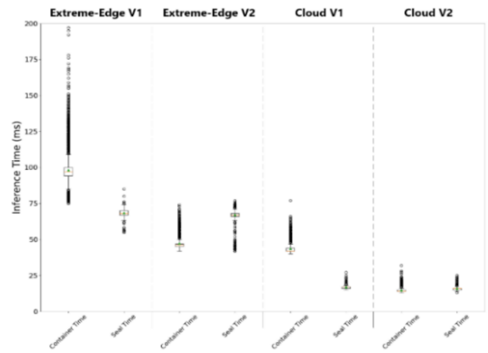


*Figure 7: Inference time for container seal detection -- extreme edge and cloud placement*

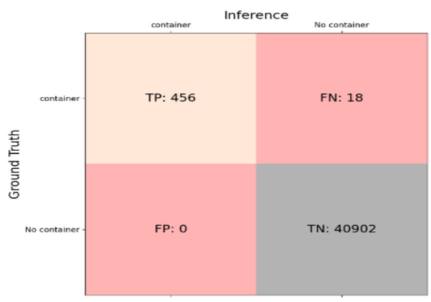


*Figure 8: Seal Detection (True/False Positives/Negatives)*

**5G&AI-enabled human presence detection evaluation**. For the following use case we focused on the development of a cloud native 5G&AI-enabled human presence detection service for safety applications (i.e., detecting the presence of people in high-risk areas, e.g., areas with intensive crane and/or truck operations). 4K video frames are exploited as sensors from Cloud or extreme edge containerized video analytics services to make the relevant inferences. The following four Figures (Figure 9-Figure 12) depict the processing time that the developed algorithms require for inference (including also the impact of the frame size in the algorithms performance), when the service is deployed at the Cloud or extreme-edge system and, the accuracy of the algorithm for predicting the presence/absence of people. Evidently, when the service is running at the extreme edge the processing time of each frame is slower when compared to the Cloud. Indicatively, processing full high definition (1080p) frames at the extreme edge requires a processing time of about 80ms per frame, whereas at cloud it is about 10ms. For the accuracy of the algorithm we observe very few false positive and false negative events, which indicates a very high (i.e., reliable) performance in the predictions. Finally, the last figure shows the cumulative distribution function (CDF) showing the (probability of) transmission delay for 4K frames in 5G and 4G networks, respectively, at Piraeus Port. Evidently, 5G shows a superior performance in terms of both transmission latency and steepness of the CDF.

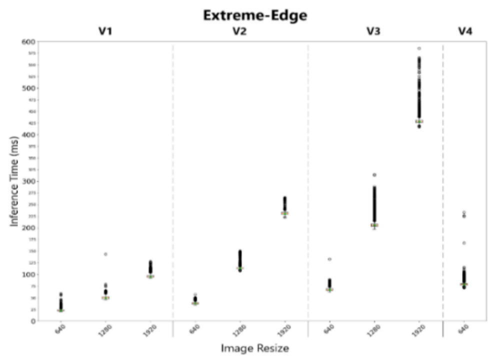


*Figure 9: Inference time for human presence detection*

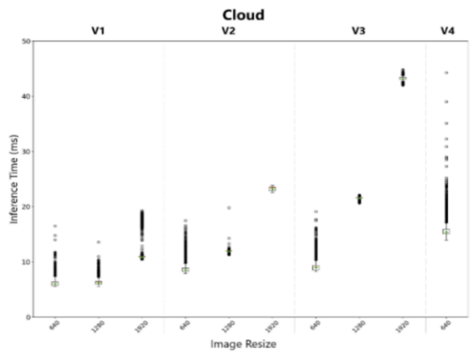


*Figure 10: Inference time for human presence detection*

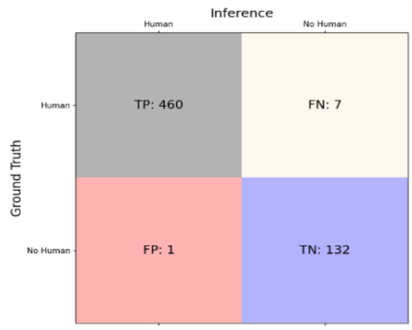


*Figure 11: People Detection (True/False Positives/Negatives)*

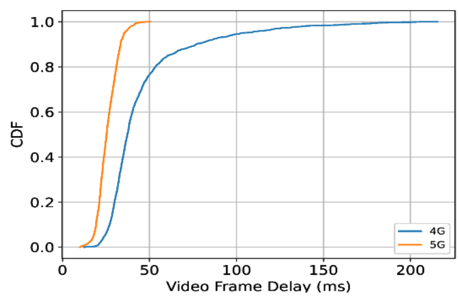


*Figure 12: 4K frame network transmission delay (ms)*

## *B. Hamburg Living Lab*

In Hamburg was built a test field available to all OEMs and mobility service providers for Car2X data exchange and other C-ITS functions. A total number of 50 traffic lights is currently available for Connected Automated Driving (CAD) test runs. The test field is located in the heart of the city close to the ferry boat terminals. In the context of 5G-Loginnov, highly innovative 5G use cases are built directly on top of this test track and link the 5G features such as Mobile Edge Computing, low latency communication (uRLLC) and advanced IoT, including massive Machine Type Communication (mMTC), to ITS functions implemented by the Hamburg traffic authorities. The Hamburg Port Authority (HPA) already traffic lights operated in the ferry port and cruise terminal area to guarantee a seamless traffic flow within the heart of Hamburg's tourist zone near "Landungsbrücken". The interaction between the logistics corridors connecting warehouses, motorways and shipping terminals with the busy road network inside the densely populated city center, that is the unique innovation highlight of the TAVF Hamburg test track.

**Connectivity in Hamburg.** Deutsche Telekom operates the public 5G network which covers the designated testfield for connected and automated driving (TAVF). Within this environment, Hamburg illustrates on one hand how new functionalities of 5G as MEC precise positioning as uRLLC can improve the efficiency of logistic operations, buton the other hand, also proves that improved 5G network functionalities as mMTC and eMBB are essential for stable service operation. The provision of an information system to enable an optimized trajectory planning for automated vehicle maneuvering across intersections requires a connection with high reliability and low latency below10ms.Having in mind an increasing population, several sensors, and connected devices in urban areas 5G connectivity will be essential for critical applications with strict connectivity requirements. Hereby, network slicing is one of the key aspects of 5G that will allow network and service operators to satisfy specific connectivity demands of specific use cases. By this, it can be ensured that each use case will always have the required resources. Each of the two slices will allow using the available network with the use-case specific required level of service quality, security, and reliability.

**6G-enabled Teleoperated Driving and Multi-Modal Platooning**. Platooning was piloted in Hamburg in several projects, as 5GLoginnov, where the focus was in setting up vehicle platoons in the context of urban logistics finding out corridor support measures for taxi-fleets and Amazon delivery. Special attention for these fleets is linked to the GLOSA speed advise ensuring that the driver has rest traffic light time available to adapt his speed. Therefore, the Platooning use case is safety and time critical as cellular V2X communication has to ensure that lead and follower vehicles receive the same speed recommendations avoiding that these recommendations lead to collisions. Vehicle platooning is part of Cooperative Connected Automated Mobility(CCAM) standard messages which are exchanges in hybrid communication mode, I.T.S.-G5 (WLAN 802.11p) and cellular V2X via Mobile Network. The advantage of 5G/6G lies in the scalability targeting the entire city, along-term necessity to extend the TAVF test track to a wider area. Besides vehicle platoons, Hamburg is targeting bicycle platooning reducing accidents and giving traffic signaling priority to eco-friendly modes of transport. A 6G-enabled multi-modal Platooning use case needs data fusion of multi-sensorial data input and standardized APP Interfaces. Vehicle platoons have to be informed whenever bicycle platoons are approaching the intersection and vice-versa. Due to the close cooperation with the local traffic authorities, feasibility tests for implementing 6G enabled traffic light prioritization based on existing technical standards, precise positioning, etc. will be included leading to uRLLC + eMBB + and mMTC+. The ISAC systemin the E-Band (71-73.4GHz) together with Multi-access Edge Computing (MEC) will be realized to support the GLOSA+ in city ATP(Automated Truck Platooning) use case.

**Multi-sensorial collision alerts and VRU Assistance beyond 5G**. The system optimizes the control of traffic signaling systems and detects vulnerable road users thanks to multi-sensorial traffic data, including anonymous video data. It combines a collision alert sent via Mobile Edge to cyclists, pedestrians and other vulnerable road users. Beyond-5G(6G) enables scaling up precise positioning of 1cm, the extension to covered areas (e.g., via UWB) and camera systems. Concerning camera systems, these need to consider existing GDPR and Cybersecurity aspects. The deployment of sensing capabilities from the infrastructure uses an Integrated Sensing and Communication (ISAC) system in the E-Band (71-73.4GHz) to enhance the perception of vehicles. The aim is to deploy the system in a road intersection to perceive the VRUs at the crossing. This integrated system will be able to perform the sensing or VRUs, and the communication with vehicles while meeting the stringent latency and reliability requirements typical of safety-critical applications. In-Vehicle Telematics Systems are considered Big Data sources (Advanced IoT) for automated driving requirements within uRLLC and low latency conditions. The Continental IoT Box is connected to CanBus vehicle data and smartphone APP alerts at selected TAVF intersections. XR/VR might be come powerful assistant technologies helping VRU protection. The VRU protection (especially for pedestrians and bicycles) is evaluated and simulated with AR/VR support to generate a real-time Digital Twin of a complex intersection. AI-supported examinations lead to a better prediction of dangerous situations to protect the VRUs.

**Hamburg Living Lab-preliminary results**

| KPI | Vehicle Mode | Results |
|---|---|---|
| Increase average truck speed | Single | > 5 % |
| Reduction of average acceleration activities | | > 5 % |
| Reduction of stillstand time | | > 5 % |
| Increase average truck speed | Platoon | Plus > 4 % |
| Reduction of average acceleration activities | | Plus > 4 % |
| Reduction of stillstand time | | Plus > 4 % |
| Reduction of fuel consumption | Single | 12 % |
| Reduction of $CO_2$ emission | | 12 % |
| Reduction of fuel consumption | Platoon | Plus 10 % |
| Reduction of $CO_2$ emission | | Plus 10 % |
| Increase energy performance index 'EPI - cl per ton and km' | Overall | 10 – 20 % |
| Increase acceleration performance index 'API - KWh per ton and km' | | 10 – 20 % |
| Extended cellular bandwidth on urban roads by 5G network | | Max. 800 Mbit/s |
| Positioning quality on urban road networks with 5G by 10 cm | | < 1 m |
| signal latency in the 5G environment | | avg. 20 ms |
| Average rate of packed errors during 5G data transmission | | 5 - 15 % |

## IV. THE NEED FOR 6G CANDIDATE TECHNOLOGIES-FUTURE WORKS

Although the B5G and 6G are in very early stage, 5G-LOGINNOV is already planned to test a number a B5G/6G candidate technologies as follows:

**AI-Enabled Networks**: it's expected to integrate also artificial intelligence (AI) and machine learning (ML) into network operations, enabling more efficient and intelligent network management, optimization, better network security and more advanced automation of network operations. AI-ML algorithms could be used to automatically adjust network parameters in real-time based on changing network conditions and user demand, as well as detect and mitigate security threats.

**Massive MIMO**: it's also expected to use massive MIMO (Multiple Input Multiple Output) technology, which uses a large number of antennas to transmit and receive data simultaneously. This could significantly increase network capacity and improve spectral efficiency, enabling more devices to be connected to the network simultaneously and reducing interference between devices.

**Dynamic Spectrum Access**: in the near future it's expected to support dynamic spectrum access, which enables flexible and efficient use of available spectrum resources. Dynamic spectrum access could enable networks to dynamically allocate spectrum resources to different users and applications based on changing demand, as well as enable more efficient coexistence of different wireless technologies and services.

**Network Slicing**: it's expected to support network slicing, which allows multiple virtual networks to be created within a single physical network infrastructure. This could enable network operators to offer more customized services to different types of users, with different performance and latency requirements.

**Edge Computing**: it's expected to support edge computing, which involves processing data and running applications at the network edge, closer to where the data is generated. This could reduce latency and enable new applications that require real-time data processing, such as autonomous vehicles.

**Integrated Satellite-Terrestrial Networks**: it's important to support seamless integration between satellite and terrestrial networks, which could enable global coverage and connectivity for a wide range of applications, including autonomous vehicles, remote sensing, and disaster response.

**Massive IoT connectivity**: if would like to connect seamless millions of IoT devices, enabling a range of applications in smart ports, autonomous vehicles, autonomous drones, vehicle robots and precision positioning then the Massive IoT is needed.

**Augmented reality (AR) and virtual reality (VR)**: B5G/6G could enable high-speed and low-latency communication, which could enhance the experience of AR and VR applications for seals & containers.

**Energy-Efficient Communication**: it's needed in order to support much higher data rates and more connected devices than 5G, which could lead to increased energy consumption and carbon emissions. To address this, researchers are exploring new techniques for energy-efficient communication, such as using machine learning algorithms to optimize network operation, or developing new power-efficient wireless transceivers.

**Environmental monitoring**: B5G/6G networks could be used to monitor the environment in real-time, providing insights into climate change, air quality, and other environmental factors using vehicles as IoT sensors on the road network.

## V. CONLCULSIONS

In this paper a number of potential 6 candidate technologies have been presented in order to improve security and safety and further optimize the maritime port and inland-related operations. Two Living Labs (Piraeus & Hamburg) described how were implemented these technologies from the activities currently taking place in the context of 5G-LOGINNOV. In this work there were presented only four use cases based on advanced IoT, AI and HPC to improve safety and enable connected and automated driving. Although in this paper have been only presented four use cases, it is possible to conclude that the combination of different technologies enabled by 6G can help to understand their real potentialities and limitations.

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