Leveraging 5G to Enable Automated Barge Control: 5G-Blueprint Perspectives and Insights

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Abstract—The shipping sector has become one of the corner-stone aspects of modern production systems, which has been impacting economic growth over the past decades. Its digitalization is expected to make significant improvements in ship control safety and reliability by enabling autonomous operations. Nonetheless, there are still many challenges that need to be thoroughly studied, and in this paper, we focus on one of them, i.e., the communication between barges, ports, and services, as the increased network latency and the limitations on the bandwidth imposed by satellite communications could result in significant risks for accident occurrence. Thus, we present one of the first attempts to leverage the potential of 5G systems for automating barge operations, starting from teleoperation as an enabler of automation, toward creating and validating a cellular-based automated barge control system in a real-life environment.

Index Terms—5G, automated ships, teleoperation, shipping operations, 5G ports, real-life experimentation environments

Fig. 1: A high-level overview of the 5G-Blueprint pilot sites.

I. INTRODUCTION

The Transport & Logistics (T&L) sector is becoming step-wise one of the cornerstone aspects of modern production systems, as it has a large impact on macroeconomic development [1]. However, performing T&L processes in an automated and optimized manner becomes a must for keeping up the pace with the development of such production systems and their load. The inefficiency and delayed response from T&L operations could highly affect the efficiency and safety of the overall T&L chains, and it is important to carefully study all aspects that could be improved and automated in such T&L systems. Thus, in this paper, we present our work-in-progress on enhancing T&L operations with the help of 5G technology. In particular, we study automating barge control, thereby focusing on a particular sector within T&L industry, i.e., the T&L operations in the river/sea ports.

The trends over the past few decades are showing that around 74% of the goods in Europe are being transported via ships/barges. This makes the shipping sector one of the huge impact factors on economic growth and prosperity [2]. As digitalization is affecting almost all industrial areas, the full benefit of digitalizing the shipping processes is expected to be reached once full automation of barges reaches sufficient technological maturity, thereby making sailing and other shipping processes significantly safer and more reliable [3]. Such an increase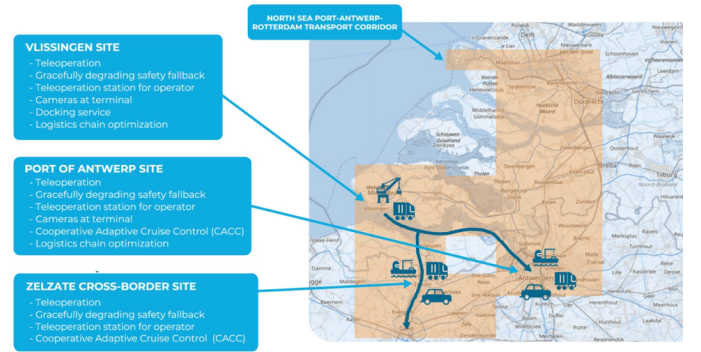d safety and reliability of autonomous and/or remotely controlled ships are expected to reduce the risk of human mistakes, thus, improving safety levels by minimizing the risks of both injuries/fatalities for the onboard crew, and also the damage to the ships.

However, one of the major challenges in achieving an efficient remote or autonomous control is related to inefficient communication between barges and ports. In addition, the lack of efficient navigation systems imposes considerable risks for accident occurrence, thereby leading to delays in barge sailing that pose a great risk of hindering all port operations. Based on the thorough survey of the so-called Internet of Ships (IoS) systems, presented by Aslam et al. [2], the communication between barges and ports as well as between barges themselves is entirely based on satellite communication. Nonetheless, satellite networks are expensive to deploy and involve significant delays in communication between the sender and receiver, providing insufficient bandwidth for most of the automation operations. Due to that reason, 5G technology is being investigated as one of the principal technologies for achieving ultra-low latencies and enhanced throughput for various vertical industries. One of the primary goals of 5G and beyond networks is to provide reliable connectivity for any connected entity. The quality of service offered by such cellular systems as 5G and beyond networks is measured in terms of ultra-low latency (1-10 ms), ultra-high reliability (99.999%), and high data rates (up to 20 Gbps) [4], and it achieved by creating logical and virtualized networks, i.e., network slices,

over the common network infrastructure. Therefore, by deploying Ultra-Reliable Low-Latency Communication (URLLC), enhanced Mobile Broadband (eMBB), and massive Machine Type Communication (mMTC), 5G is providing enormous opportunities to improve the operation and efficiency of many industry verticals, creating new use cases and applications whose stringent connectivity requirements could not have been met with the previous generations of mobile communications systems [5].

In addition, compared to all previous generations of mobile communication systems, 5G technology is designed as a vertical-oriented technology that is transforming network infrastructure into various virtualized networks, so that each of them can be tailored to meet the needs of specific verticals by applying concepts of network slicing. Coming back to autonomous and/or remote control of ships, the teleoperation network requirements might need to combine elements of both eMBB and URLLC slices at the same time, while also emphasizing the uplink communication instead of downlink bandwidth consumption. Given the lack of research on the true potential of leveraging 5G systems in the context of industry verticals such as T&L, in this paper, we introduce one of the first attempts to create a cellular-based system for enabling teleoperation and automated barge control, designed and driven within the 5G-Blueprint project.

As illustrated in Fig. 1, we have created three pilot sites in the 5G-Blueprint project, in order to test the impact of 5G and the benefits it brings to the teleoperation of barges, trucks, cars, and skid steers. In this work-in-progress paper, we focus on the Antwerp pilot site that has been built in the utmost busy area of Port of Antwerp Bruges (Belgium). This pilot site is a real-life environment used for testing and validating the impact of the 5G system on the automation of barge control operations, in which the barge is sailing along the predefined trajectory while being connected to the 5G network. Since even for 5G technology, a combination of different network slices might be challenging to realize, we need to validate in depth how 5G can provide the connectivity needed for teleoperation and/or automated barge control. Also, the challenges of leveraging 5G on the open seas still persist due to the lack of cellular infrastructure. Therefore, this work inspects the potential of 5G for inland waterways, thus, studying the teleoperation of barges as an enabler of automation.

II. AUTOMATED BARGE CONTROL SYSTEM

Within the scope of the H2020 5G-Blueprint project, one of the main goals is to implement the 5G network slicing capabilities, i.e., to deliver URLLC and eMBB slices, which make the development and testing of innovative 5G-enhanced teleoperation services a reality. To leverage an ultra-reliable, low-latency, and high-bandwidth network connectivity by using such network slices, and to validate their true impact in the real-world environment such as busy seaports in Europe, we have defined four main use cases, i.e., automated barge control, automated driver-in-loop docking, Cooperative Adaptive Cruise Control (CACC)-based platooning, and remote takeover [5]. In this work-in-progress paper, we entirely focus on the first use case, and in this section, we describe the 5G system and its architecture designed in the pilot site, as well as the control system used for automated barge control.

A. 5G ecosystem

In Fig. 2, we show the 5G-Blueprint network architecture for the pilot site in Antwerp, developed for testing and validating
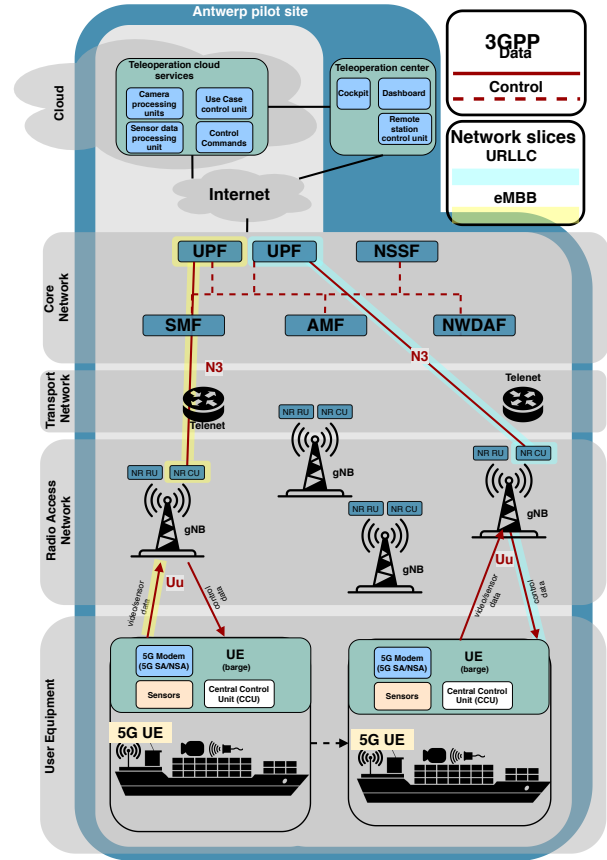

Fig. 2: 5G-Blueprint Network Architecture for Antwerp Pilot Site.

automated barge control. Starting from the User Equipment (UE), which is a commercial barge, the overall system is equipped with various sensors and several cameras that are installed on board and used for improving environmental perception and hence situational awareness. To be able to communicate via cellular networks, this barge has a 5G modem installed, including the antennas necessary for signal transmission/reception.

The data such as video from different cameras is being transferred on the uplink, through the Radio Access Network (RAN), transport, and core network, from where it is further routed through the public internet towards the Control services running on the cloud to which both the teleoperation center and the barge are connected. Concerning the core network, two deployments are possible, i.e., 5G Non-Standalone (NSA) based on the 4G Evolved Packet Core (EPC), and 5G Standalone (SA) with 5G Core functions (illustrated in Fig. 2) that, among the other features, enable network slicing as well. The cloud services are being used both by the barge and the operator in the control center, who is further making decisions on the barge maneuvering, thereby generating the control commands. Such control commands are transferred back to the barge over the 5G infrastructure (downlink), and once the commands are translated into electrical signals on the Programmable Logic Controller (PLC) of the barge control unit, the remote operation is achieved. The overall network infrastructure used in the Antwerp pilot site is deployed by the mobile network operator Telenet.

TABLE I: Network requirements for automated barge control [5].

Description	HD camera stream	HD video screens	Ship control interface
From/To	barge → control center	barge → control center	control center → barge
Service type	Uplink	Downlink	End-to-end
Ideal latency	<22ms	<22ms	<35ms
Service interuption	<30s	<30s	<150ms
Bandwidth requirement	>5Mbps, <25Mbps	>5Mbps, <25Mbps	<2Mbps
Device scenario	Outdoor mobile	Outdoor stationary	Outdoor mobile + Outdoor stationary
Slice type	eMBB	eMBB	URLLC
Number of flows	10 per ship	6 per operator	1 per ship

To provide a clear understanding of network requirements in this type of use case, and to grasp the potential of applying the 5G network slicing concept, in Table I we present particular requirements for High Definition (HD) camera streams, video screens, and ship control interface. These requirements are derived in the scope of the 5G-Blueprint project, after a thorough study of network capabilities and operational requirements for barge control.

Given that automated control of barges requires a bandwidth of 5-25Mbps in the uplink, and latency lower than 22ms, per HD video camera stream, and latency lower than 35ms for vessel control interface, the potential of leveraging the eMBB type of slice for the uplink traffic and the URLLC for the downlink is evident. For the uplink, such a use case requires efficient data collection and encoding from sensors and cameras, so that advanced processing of such data could be performed on the cloud prior to decision-making that would affect the maneuver of the barge. However, with an increased number of barges in busy ports such as Port of Antwerp Bruges, where the traffic load would be extremely heavy when all barges are connected, the bandwidth requirement on the uplink becomes even more stringent (leveraging on eMBB slice), pushing the need for 5G deployment. On the other hand, for the downlink connection with the barge, where control commands are being transferred, the end-to-end latency needs to be lower than 35ms so that the remote operation, i.e., control commands can be applied in an efficient and safe manner (leveraging on URLLC slice).

By studying such requirements, one can see spot an enormous potential for leveraging 5G technology toward providing both faster and safer operations with ms-level end-to-end latency, and data rates above 100Mbps. This is particularly promising as such network capabilities are usually not available in current 4G systems, and the impact of such network capabilities will be even increased in case of future scaled-up systems with a large number of barges being simultaneously connected over the network.

B. Barge control system

In Fig. 3, we demonstrate the components of the overall control system used in our testing scenarios. On the barge side, there are controllers and PLCs installed and connected with the sensor and camera processing units, which are further capable to transfer the signals toward remote control centers via a 5G antenna onboard. In our testing environment, we use the commercial barge, i.e., Tercofin II, and thus there is a limitation in terms of autonomous operations that could be achieved. Instead, the testing is currently being performed in a so-called *shadow-mode*, which means that the control commands sent from the control center over the 5G network to the barge are not translated to local control commands onboard that will execute

the real actions on the barge (as marked in the system illustrated in Fig. 3).

To mitigate the limitations and increase the level of autonomy, as well as the opportunities for testing the benefits of autonomous shipping and teleoperation, Seafar[1] is working closely with the Port of Antwerp Bruges towards obtaining the required permissions to navigate the barge from distance, thereby ensuring the safety of operation and the environment. During this test, the network performance of the 5G infrastructure has been monitored and recorded for detailed analysis. Thus, the impact of the network on the teleoperation, as an enabler of the automated operation of barges, needs to be assessed and thoroughly studied first, thereby measuring the performance of the network at the barge side.

III. INITIAL RESULTS FROM THE ANTWERP PILOT SITE

Here we present and discuss some of the initial results obtained during the *shadow-mode* testing, with the goal to assess the 5G capabilities in the real-life port scenarios for achieving automated barge control, with reference to the network requirements indicated in Table I.

We performed the tests with the barge connecting it to the 4G and 5G networks. Due to the larger 4G coverage in the testing area, i.e., with more base stations commercially deployed, we collected more measurements of the 4G signal. In Fig. 4, the obtained results of the latency are shown, where latency is measured as the time an Internet Protocol (IP) packet takes to arrive at its destination. The gain in latency achieved by 5G compared to 4G is evident, where the average latency of 26.62ms is achieved using 4G, and 15.06ms with 5G. The values of jitter for both 4G and 5G can be considered negligible, since the achieved values are 2.34ms, and 3.57ms, respectively.

Taking into account the requirements listed in Table I, the performance over 4G might not be sufficient for the uplink traffic (<22ms), i.e., HD camera feeds transferred from the barge to the control services on the cloud. It could be reasonably expected that such performance could be even more hindered when more barges are simultaneously connected to the remote cloud services. On the other side, both 4G and 5G results comply with the requirements on the ship control interface (<35ms). Concerning the bandwidth, as the maximum amount of data that could be transferred over the network per second, our measurements show that up to 24Mbps could be achieved over 4G connectivity, and up to 36Mbps over 5G. Although both results suffice the bandwidth requirements, the testing included only simple Iperf[2] measurements, whereas more tests

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[1] Seafar NV is an independent ship management company, offering services to operate unmanned and crew-reduced vessels for ship owners and shipping companies.

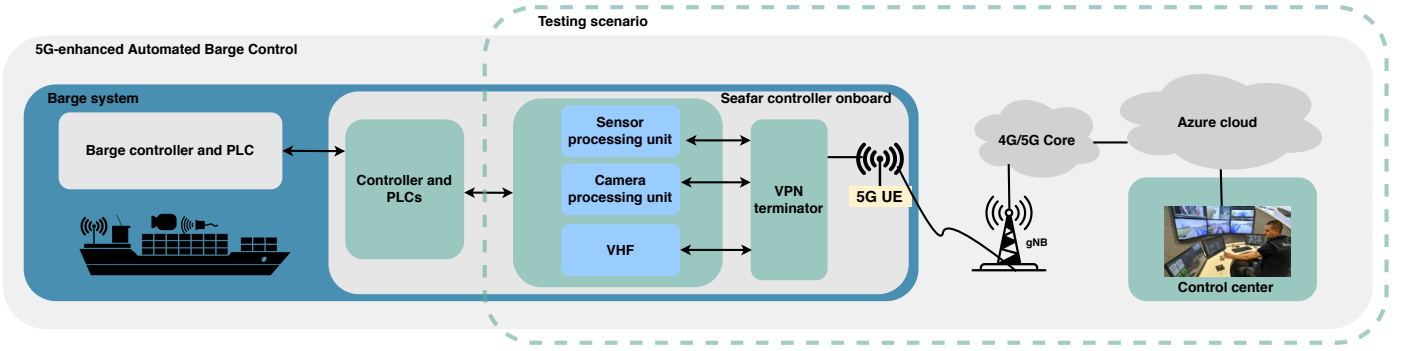[2] Iperf is a tool for network performance measurement and tuning.
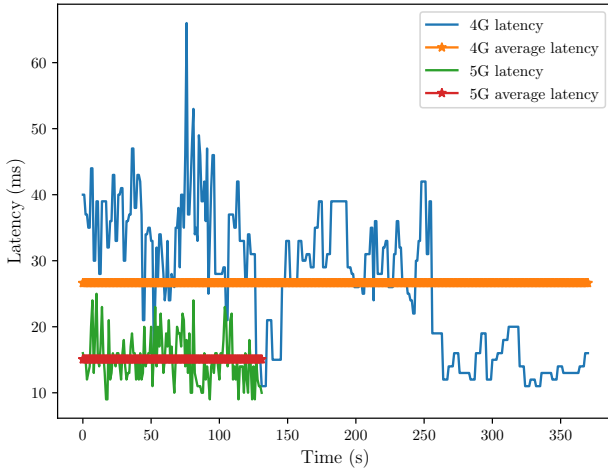
Fig. 3: Test environment.

Fig. 4: Latency measurements.

need to be performed to evaluate the bandwidth improvements with e.g., 10 HD camera streams on the uplink and 6 video screens per operator (as indicated in Table I).

We can see from the results that the 5G signal is more stable and robust compared to the noise and interference, however, the testing scenario for 5G included a limited area in close proximity to the canal through barge was sailing, thus more testing needs to be performed to derive more insights. In the scope of the 5G-Blueprint project, we are planning to further extend the testing to include more scenarios with higher traffic load (more camera feeds simultaneously), including cross-border scenarios for a barge sailing between Belgium and the Netherlands, and extending it to different weather conditions, in order to test possible bottlenecks in the setup. The results presented in this paper indicate the performance of 5G NSA, which is already promising, while the tests and further measurements on the 5G SA are planned as well, with the main goal to study the true impact of network slicing capabilities.

IV. CONCLUSION

Automation of ship operations should be considered one of the major cornerstones in the digital era, as increased safety and efficiency of ship operations will become an inevitable part of the emerging IoS systems. Nonetheless, there is a lack of studying the network performance and the impact of network connectivity on autonomous ship operations. In general, there is also a lack of performance assessments in real-life environments as most of the studies are based on simulations or scaled ship setups. Therefore, in this work-in-progress paper, we provided insights into one of the seminal approaches to automating barge control with the help of 5G systems. We presented a cellular-based automated barge control system, which is deployed in a real-life environment with the barge sailing in the Port of Antwerp Bruges, and connecting dynamically to the available 5G network. Based on the initial results we presented, 5G is showing promising behavior compared to 4G in terms of latency, thereby meeting the network requirements that are carefully defined in the scope of the 5G-Blueprint project. Due to the limitation of the work-in-progress paper, more tests will be conducted in the real-life environment, testing both 5G SA and eMBB and URLLC network slices, and as such, they will be presented in our future work.

V. ACKNOWLEDGEMENT

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