5G-Blueprint: Next Generation Connectivity for Enhanced, Safe, Efficient Transport & Logistics

Invited Paper

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***Abstract*—The H2020 project 5G-Blueprint aims to exceed the limits of current 5G rollouts, which have been mainly focused on enhanced broadband by implementing, deploying, and evaluating the newest 5G features as enablers towards an ecosystem for highly advanced Connected and Automated Mobility (CAM) use cases, with an emphasis on teleoperation of vehicles and vessels. Cross-border challenges will be tackled in terms of 5G network design and implementation on the field to reduce outage time when performing handovers between multi-operator and multi-domain networks across the Dutch-Belgian border, continuously fulfilling the service requirements by providing ultra-reliable and low latency communications. The main outcome of 5G-Blueprint will result in a blueprint for the future cooperation between public, private, and semi-private parties (e.g., ports) enhanced by 5G technologies and the insights associated with business models, policies, and regulation of teleoperation and other CAM services.**

***Index Terms*—5G communications; teleoperated transport; logistics; vehicular communications; remotely operated vessels and trucks**

I. Introduction

The "International Mobile Telecommunications (IMT) for 2020 and beyond" specifications proposed by the International Telecommunications Union - Radiocommunication Sector (ITU-R) have been officially published as the new Recommendation ITU-R M.2150 in February 2021 [1]. This recommendation specifies the technical requirements that 5G communications should fulfill to provide enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC) and massive machine-type communications (mMTC). The initial 5G deployments have addressed eMBB solutions. The next step towards the provision of URLLC connectivity is being researched and tested while the latest Release 16 is being deployed, which aims to explore the URLLC solutions to address the requirements defined in the M.2150 recommendation. Current and future applications such as connected and autonomous vehicles and verticals such as Connected Intelligent Transportation Systems (CITSs) require URLLC connectivity in order to properly function and to deliver the expected performance to users, where safety is critical and highly dependable of the URLLC communications.

The industry believes that autonomous vehicles will become part of the transportation network in the upcoming years. Driverless vehicles will impact businesses and professionals [2]. However, despite their great potential and high expectations, fully autonomous vehicles are not widely available, as the technology is not yet considered mature enough for safe public introduction.

The concept of teleoperation could provide an interesting alternative. Compared to fully autonomous vehicles, it relaxes the requirements imposed upon the artificial intelligence that controls the vehicle [3]. It strengthens the requirements on the mobile network but these should align well with the URLLC design goals of 5G. It also enables the gradual addition of automation on specific parts of the trajectory over time in situations where the corresponding operational design domain is considered suitable (e.g., driving in traffic jams, docking of trucks, etc.). This opens the door for an evolutionary approach to CAM adoption, which could be more feasible than a big-bang change from fully manual to fully autonomous vehicle operation. The introduction of teleoperated autonomous commercial vehicles can change the business models in the logistics sector in several ways but solutions that can handle those without disrupting the business case for the involved stakeholders must be found. Firstly, the replacement of the driver by a teleoperator (TO) eliminates the formal representative of the logistics service provider. Physical and administrative tasks will have to be taken over by other parties in the chain (e.g., recipient of the goods, subcontractor for the list mile) or technological solutions. Secondly, the traditional relationship between Original Equipment Manufacturer (OEM) and logistics service provider may change. The OEMs of teleoperated vehicles or the teleoperation software developers could become disruptive players in the logistics market because of the reduced dependency of traditional driver resources. Einride and Airlift are examples of companies already positioning themselves as capacity providers and logistics service providers instead of OEMs. This means that logistics service providers might need to overhaul their accents

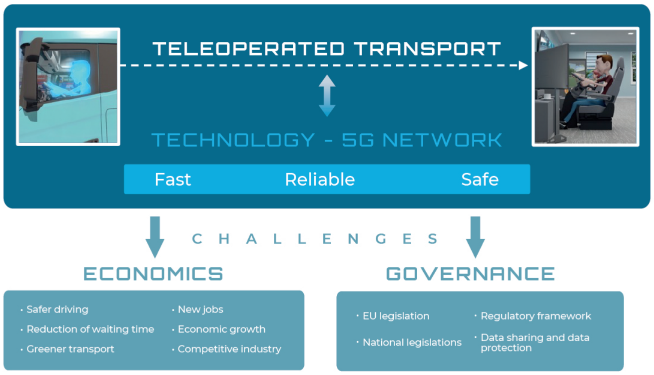

Fig. 1. 5G-Blueprint in a nutshell

in terms of value creation with their operations. Moreover, the development of (partially) automated transport with teleoperation as a foundation, will accelerate the step towards 24/7 logistics and the development of physical internet (PI) since the development of a hub network might be needed to support this type of operation. These developments indicate that it is necessary to develop new business models for logistics.

The European funded project 5G-Blueprint[1] designing and validating a technical architecture, business and governance models for uninterrupted cross-border teleoperated transport based on 5G connectivity, for subsequent operational pan-European deployment of teleoperated transport solutions in the logistics sector and beyond [4]. In this paper we present an overview of the 5G-Blueprint approach.

II. The 5G-Blueprint outlook

The project will serve as the blueprint for the subsequent operational pan-European deployment of teleoperated transport solutions in the logistics sector and beyond.

The overall project objectives can be broken down into three core areas:

1) *Technology-related objectives*:

- *Design and implement a 5G network for CAM services:* 5G-Blueprint is designing and implementing a 5G network system that can support advanced CAM services with stringent requirements on latency, handover time, reliability, packet loss and throughput. In fact, teleoperation where the remote operator is directly performing all steering, braking, and acceleration commands (defined as direct control teleoperation), is considered one of the most challenging CAM services for the network to support, pushing the URLLC capabilities to its limits to guarantee safe control of the vehicle and adding eMBB characteristics to the mix because of the intense use of video streams.
- *Tailor and implement the prototype of a teleoperated system:* : 5G-Blueprint is designing and developing the main technological elements that will enable the use of teleoperated system architecture such as seamless cross-border teleoperation, human factors of teleoperating trucks and barges, and efficiency increasing elements, such as automated docking and cooperative adaptive cruise control where the operator of the trailing vehicle can be swapped to another vehicle while platooning.
- *Implement and deploy enabling functions guaranteeing the safety of teleoperated transport:* : 5G-Blueprint is designing and implementing the enablers needed to set up a viable teleoperated transport solution, such as enhanced awareness functions and solutions to increase the safety and efficiency of the logistic operations.
- *Validation of the end-to-end teleoperated transport solution supported by 5G in real-life scenarios, including cross-border conditions:* 55G-Blueprint is integrating, evaluating, and validating the end-to-end teleoperated transport solution in real life (including cross-border conditions) and confirming its technical feasibility.

2) *Business and Regulation-related objectives*:

- *5G tele-operated transport market analysis:*Provide an understanding of the needs in the logistics market and define how teleoperated transport based on 5G connectivity can tackle existing challenges, such as shortage on the labor market or economic loss due to waiting times at port terminalsDefine business and governance models for teleoperated transport based on 5G connectivity supported by all involved stakeholders. The qualitative description of the developed value network configurations, business models, and identified barriers, as well as the quantitative benefits, costs, and allocation models will be validated via dedicated in-depth interviews and workshops.
- *Commercial possibilities:*Define a business model and a governance model for tele-operated transport based on 5G connectivity and supported by all involved stakeholder types. Both the qualitative description of the developed value network configurations, business models, identified barriers and the quantitative benefits, costs and allocation models will be validated and iterated upon by all partners. This will be done via dedicated in depth interviews and workshops.
- *Position the possible role of teleoperated transport based on 5G based on 5G connectivity:* in the evolutionary transition from L1 to L5 autonomous driving.
- *Tele-operated transport based on 5G connectivity market adoption:* Promote teleoperated transport based on 5G connectivity market adoption through demonstrations at large showcasing events
- *Identify regulatory issues regarding the deployment of cross-border tele-operated transport based on 5G connectivity, and identify recommended actions:* TVerify if any legal/regulatory aspects hinder the large scale deployment, both from the connected perspective (spectrum allocation, co-existence of technologies in the 5.9 GHz band, C-V2X mode 3 coordination of the same 5.9 GHz spectrum by multiple MNO's, etc.) and from the automated perspective (regulation to allow teleoperated

[1] www.5gblueprint.eu

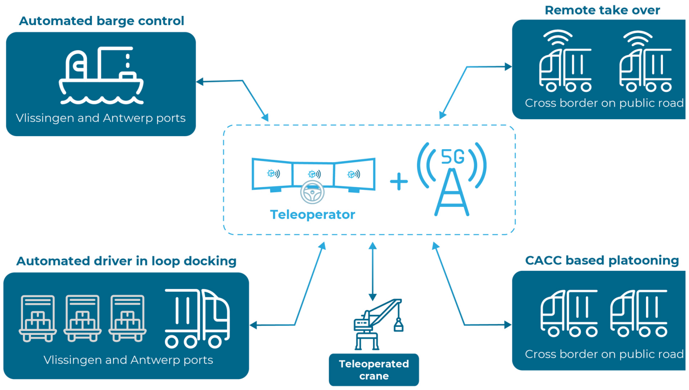

Fig. 2. Use cases

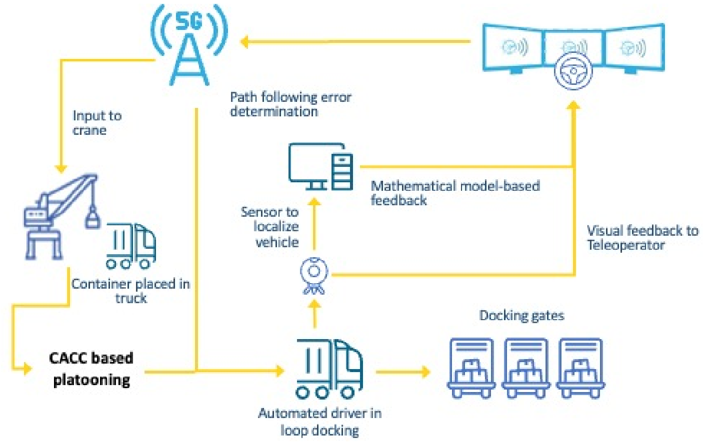

Fig. 3. UC2 sequence including automated docking and teleoperation of a crane.

vehicles with a human fallback driver present beyond experimentation purposes, etc.).

Figure 1 presents 5G-Blueprint in a nutshell, illustrating the main goal of the project, as well as the challenges that the project must face to provide feasible solutions.

III. 5G-Blueprint Framework

A. Teleoperation Use cases

As previously mentioned, 5G-Blueprint is focused on implementing the URLLC capabilities of the 5G network thereby achieving low latency and ultra-reliable communication to develop innovative use cases with new governance and business models. To accommodate the 5G technology within the mobility domain, several use cases and enabling functions are being addressed within the project as shown in Figure 2.

1) UC1. Automated barge control: Port entry efficiency will be increased by reducing crew requirements for barging. Vessel navigation during barging will be performed entirely by the vessel captain in collaboration with the teleoperating captain in the shore control center, eliminating further crew interventions. The channel navigation of the barges will be teleoperated along with partial automation. Moreover, cross-border pilots will be given priority. Pilots will be located in the ports of Antwerp and Vlissingen while the Zelzate site will provide the validation in the cross-border area.

2) UC2. Automated driver in the loop docking: Trucks will be equipped with standardized connectivity solutions for an optimized docking operation with respect to time and space requirements. Positioning of these yard trucks will be performed via camera-based RTLS, either stationary or via drones. Next to this, a mobile harbor crane will be retrofitted with teleoperation functionality, allowing for operation by a remote control center resources. Communicating optimal driving paths to the tractor and maneuvering the crane in safety-critical situations will be time-critical. Pilots will be located in the ports of Antwerp and Vlissingen. Figure 3 describes the events and interactions involved in UC2.

3) UC3. Cooperative Adaptive Cruise Control based platooning: Truck platooning is the linking of two or more trucks in a convoy that follow one another while maintaining a close distance on dedicated stretches of the highway. Platooning makes combined use of adaptive cruise control, lane-keeping system, and CV2X communication. The cost savings due to the reduced aerodynamic drag leading to lower fuel costs and emissions have been established by many studies in the past [4]. Platooning of trucks has been widely discussed in the area of logistics. The European truck platooning challenge was one of the main highlights of this technology wherein multiple truck OEMs participated in driving from their respective countries to the port of Rotterdam in platoons. However, most companies failed to see a business case with this technology as the following trucks still required drivers on board, ready to take over at any point in time. The trucking industry has been facing the challenge of the shortage of skilled drivers for a while now. The platooning technology does not solve the issue of driver shortage nor adds significant savings in costs, with the driver still being the most expensive part of the operation. Within 5G-Blueprint, we aim to upscale this existing technology with the use of 5G connectivity along with providing an interesting business case that revolves around the fundamental strategy of platooning, upgraded by teleoperation and automation, with the following options: a) The leading vehicle is physically driven while the following vehicles are teleoperated or automated. b) The leading vehicle is teleoperated while the following vehicles are automated with the dynamic takeover functionality for the automated system. Adding teleoperation to these solutions will allow for a greater cost reduction than in the initial idea of platooning.

4) UC4. Remote takeover: Remote takeover is a process in which a TO takes control of a vehicle from a remote location. This use-case provides the teleoperation functionality on which use cases 2 and 3 build further. To enable remote takeover, it is necessary to adjust the vehicles to steer and drive remotely from a control center. Subsequently, the vehicle must be equipped with an onboard unit and cameras providing teleoperation functionality. Another essential component is the teleoperation center, which must provide the technical means to manage vehicles, remote operators, ensure connectivity, and control vehicles' access. Remote takeover operations will be tested as one of the crucial activities of a real deployment of teleoperation. The tests will verify both static (stationary vehicle) and dynamic (vehicle in motion) scenarios. It is expected that the dynamic scenario is technically more challenging, but it also has the potential to greatly influence the business case on long-haul transport based on teleoperation. If the vehicle does not need to stop to transfer from one operator to another, it becomes possible to plan the takeover exactly at the end of the shift of the first operator since there is no dependency of an available parking space in the vicinity of the vehicle. This optimizes the driving time of the operator and reduces the idle time of the vehicle. Both of them are important parameters for the business case. Within the project, takeover operations will be tested within harbor environments followed by a public road test case. Network stability and latency will be highly safety-critical in this use case. The validation will be performed for both human and autonomous pilots. The handover between several remote operators will be performed and verified.

B. Connectivity and Enabling Functions

1) Connectivity: The teleoperation use cases addressed in the context of the project demand strict requirements to the communication network, in particular demanding eMBB and URLLC in critical scenarios in cross-border scenarios. Focus is needed on i) providing performance guarantees (e.g., with 5G slicing [5]), ii) predicting when the performance lowers so that preventive measures can be taken while maneuvering, iii) providing performance guarantees upon traversing the borders and switching operators. Currently, the focus in cross-border areas is on minimizing connectivity interruptions when crossing borders and during handovers. Work is needed to design and test out possible handover relations between cross-border mobile infrastructures. This needs to cover both the technical and governance issues to keep the implemented solutions in a working condition. 5G-Blueprint will study whether hybrid communication (5G-NR CV2X long- and short-range communication) can be used to enhance specific CAM use cases. Moreover, coexistence among 3GPP-based CV2X (PC5) and IEEE ITS-G5 communications will be explored concerning short-range communications [6], [7]. Besides, the use of public/private fiber infrastructure in a 5G landscape will be technically investigated, targeting the reduction of deployment and operational costs of 5G networks. Currently, an analysis is being carried out mapping the functional requirements of the use cases and enabling functions into networking requirements, analyzing networking functionalities and capabilities from User Equipment, Radio Access Network up to CORE functionalities, including a function to expose network capabilities and network slicing.

2) Enabling Functions: : This subsection describes the various enabling functions that are being developed and validated in the context of 5G-Blueprint. Some of the enabling functions developed within the project are a first important step towards increasing operator efficiency by providing better and up-to-date information and reducing operator waiting times.

5G-Blueprint foresees in the development of 8 enabling functions:

- EF1 – Enhanced Awareness Dashboard foresees clear and concise on-trip information about the situation on the road/waterway via a dashboard. This will present a consolidated view of all safety-related information to the TO, increasing their situational awareness without creating information overload.
- EF2 – Vulnerable Road User Warnings provide warnings to TOs and vulnerable road users (e.g., pedestrians or cyclists) about potential conflicts between teleoperated vehicles and vulnerable road users.
- EF3 – Time Slot Reservation ensures a conflictless crossing of intersections by teleoperated vehicles by providing a time slot for a "green-lighted" passage. This will reduce the likelihood of collisions on intersections, as well as ensure smooth navigation of the intersection (which is especially important for truck platoons).
- EF4 – Distributed perception extends the perceptive range of the TO (currently limited to cameras and sensors installed on the teleoperated vehicle) by making use of cameras and sensors on other vehicles and road-side or water-side units. This will lead to safer teleoperated transport.
- EF5 – Active collision avoidance provides safety measures that actively protect teleoperated vehicles from colliding with other road uses. This integral function will further ensure the safe deployment of teleoperation in a production environment.
- EF6 – Container ID recognition provides the capability to identify the unique shipping container ID number using the camera images. This will allow for visual confirmation of the container ID in the absence of the truck/crane/barge operator, increasing efficiency and reducing the risk of errors.
- EF7 – ETA sharing provides real-time ETA and routing information to the TO and other interested partners, as well as sets up an exchange of data with terminal systems to dynamically organize the container pick-up or drop-off time at the terminal.
- EF8 – Logistics chain optimization foresees in continuous monitoring (through IP cameras and sound sensors) and anomaly detection of several key areas relevant to teleoperation: inspection of the teleoperated vehicle (TOV) at the start and end of a trip, security breach of parked TOV, entry queue length at terminal, buffer parking occupancy, etc. This will make teleoperation safer and more efficient.

C. Pilot sites

Pilot sites are located in three locations, two in port areas (Antwerp and Vlissingen) and one in a cross-border area between Belgium and Netherlands (Zelzate). On a bigger scale, these pilot sites will serve the busy logistic area between the Netherlands and Belgium, expanding from the North Sea Port, Antwerp, and Rotterdam Transport corridor (see Figure 4).

On the Antwerp site, the demonstration of the UC1, UC3, UC4, along with EF1, EF4, EF4, EF7, and EF8 will take

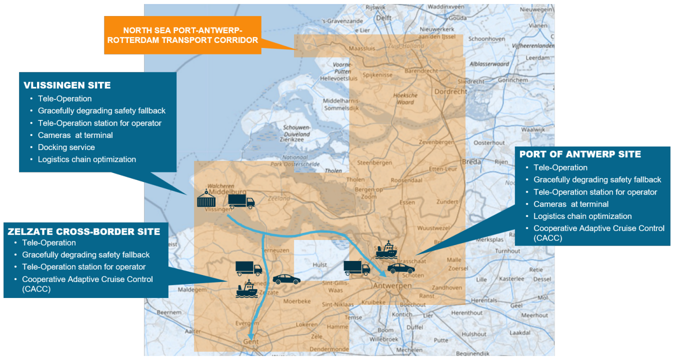

Fig. 4. Pilot sites located in Belgium and the Netherlands

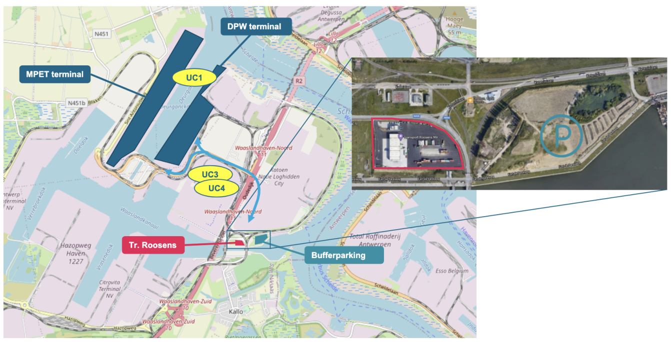

Fig. 5. Antwerp site

place in Kallo, having the trajectory from the terminal to the Transport Roosen office, as shown as in Figure 5. Transport Roosen office will be the departure point where trucks can pick up containers to be transported to the terminal. Once the container is loaded with the help of a reach stacker, the truck will leave the office to start its journey towards the terminal. Three UCs will be demonstrated on this site. During the milk run (a short trajectory of just a few kilometers, driven very regularly, e.g., from a factory to a nearby port terminal) CACC based platooning will be performed in addition to remote takeover operations. On the terminal side, teleoperated barge control will be performed, where the barge will pick up the container transported by the truck. Along the way, six EFs will also be demonstrated.

On the Vlissingen site, UC2, UC3, UC4, along with EF1, EF2, EF3, EF4, EF5, EF6, EF7, and EF8 will be demonstrated. On this site, we have a milk run consisting of a trajectory from the Kloosterboer terminal towards the MSP Onions warehouse, as shown in Figure 6. CACC based platooning and remote takeover UC will be performed during this milk run. An additional UC, which is an automated driver in the loop docking will be performed. This UC consists of picking up a container with a crane, as well as docking the truck to the warehouse. The crane operations will take place at a nearby terminal, operated by the project beneficiary Verbrugge. VRU interaction EF will be demonstrated on the warehouse site with the aim of giving the awareness to the truck about the warehouse staff presence, so that accidents can be avoided. In addition, to ease the journey of the truck, time slot reservation

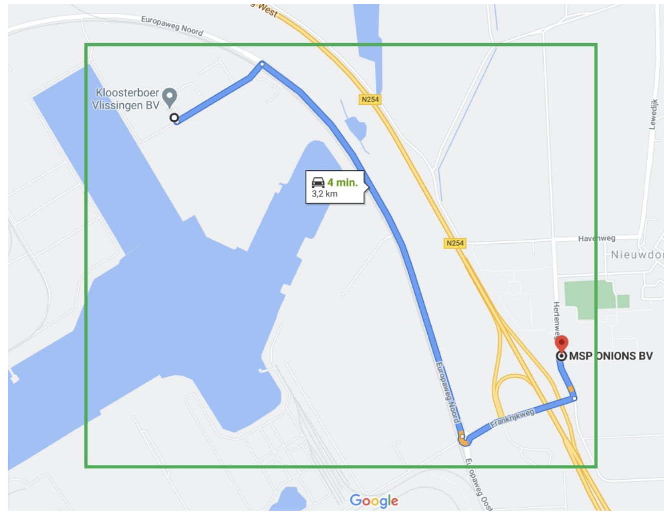

Fig. 6. Vlissingen site

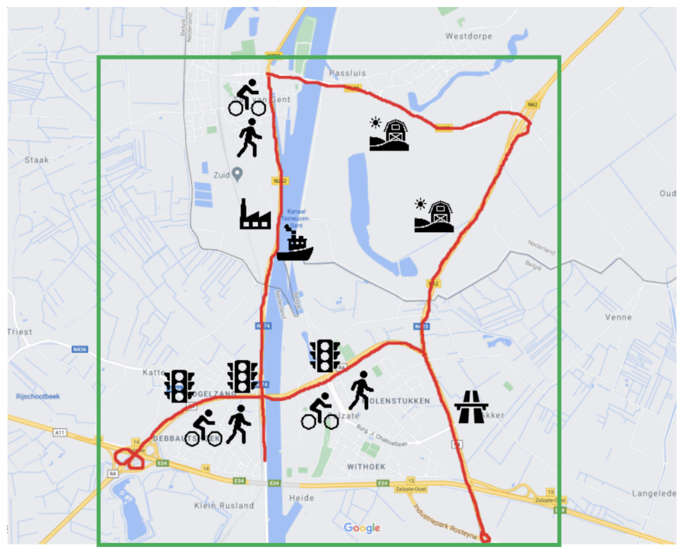

Fig. 7. Zelzate site

of traffic lights will also be performed.

UC1, UC3 and UC4 enhanced by EF1, EF2, EF3, EF4, EF5 and EF7 will be fully demonstrated on the Zelzate site. We will perform cross border scenarios of both on the road and waterway. We will also showcase the EFs performed in the city area near the border. This consists of reserving the traffic light in order to bypass the trucks from the highway towards the border. In addition, as VRUs might be present in the area, we will also demonstrate the VRU interaction EF, only the automated driver in the loop docking will not be shown here, since the UC is suitable for port scenarios. As shown in the figure 7, two roads will be used for the cross border scenario.

An overview of the UCs and EFs showcased in the project is depicted in Figure 8. This matrix describes at a glance how the UCs and EFs will be demonstrated for each site. Grey diamonds presented in the matrix signify that the EF will not perform with its full feature. For example, the EF2 VRU interaction feature is available on the Antwerp site, but will

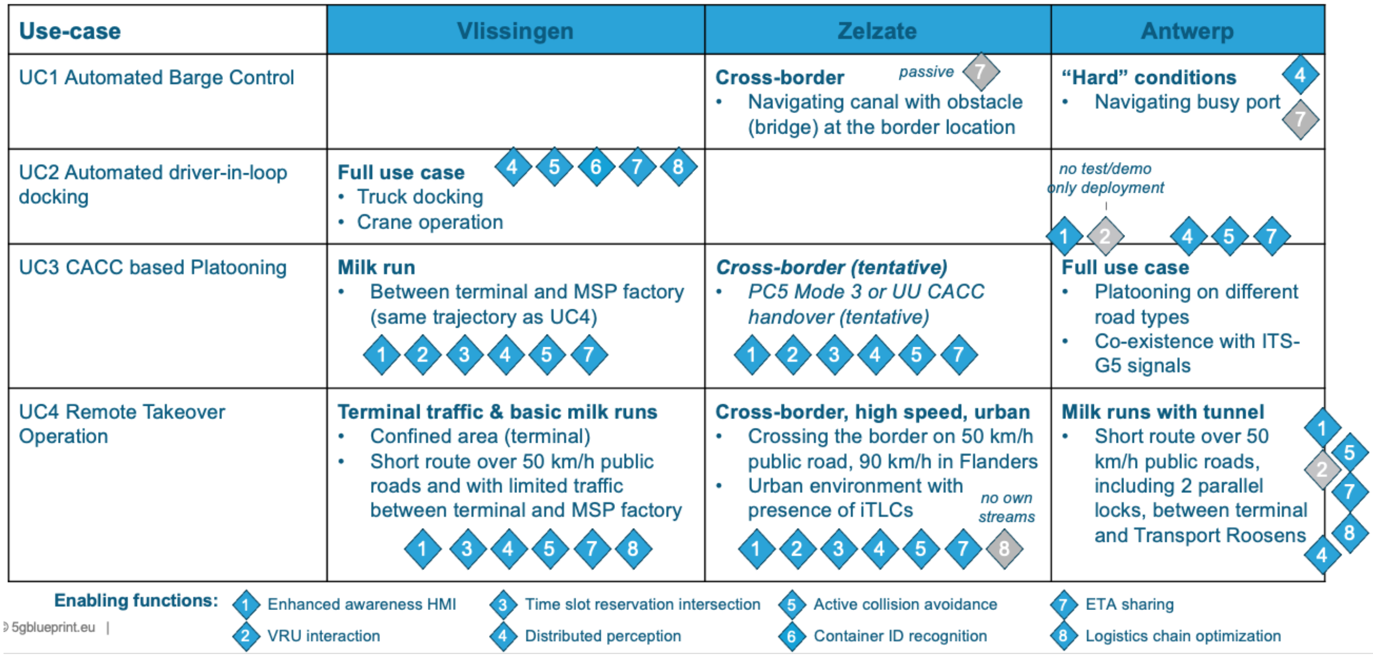

Fig. 8. 5G-Blueprint sites, function and use cases matrix

not be performed for the demonstration. On the other hand, blue diamonds signify that the EFs will be fully demonstrated and showing their full feature.

IV. Conclusions

5G-Blueprint is tackling challenging teleoperation-related use cases, exploring the capabilities of 5G regarding not only eMBB but also URLLC requirements. Moreover, the project explores the feasibility of teleoperation in the context of transport and logistics from a technical, business and governance perspective, aiming to deliver a clear understanding of the requirements and the proper techno-economical solutions as well as provide a roadmap to enable future deployments in Europe.

V. Acknowledgments

This work was carried out with the support of the 5G-Blueprint project, funded by the European Commission through the Horizon 2020 programme under agreement No. 952189. The views expressed are those of the authors and do not necessarily represent the project. The Commission is not liable for any use that may be made of any of the information contained therein.

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