Designing a 5G architecture to overcome the challenges of the teleoperated transport and logistics

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***Abstract*—One of the aims of the H2020 5G Blueprint project is to enable seamless cross border teleoperation use cases with 5G technology. The explored use cases are automated barge control, automated drive-in-loop docking, cooperative adaptive cruise control based platooning, and remote take-over operations. In this paper, we present an analysis of the network requirements of such use cases, and we present an end-to-end 5G architecture (with a focus on network slicing and seamless cross-border roaming) for the trial network based on lasted standardization work and implementation tools, from user equipment, radio, transport, core network to exposed network APIs. This work will be used as guideline for further network deployment and feature implementation in test labs and project pilot area within the project.**

***Index Terms*—teleoperated transport, 5G connectivity, logistics, vehicular communications, network requirements**

I. Introduction

Being the next generation of cellular network technology, 5G is considered as the mobile system that meets the stringent requirements of enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), massive Machine Type Communications (mMTC). These characteristics, together with 3GPP C-V2X (sidelink), made 5G technology a game changer of teleoperation, Cooperative Adaptive Cruise Control (CACC) platooning and related enabling functions. In this paper, the defined piloting use cases (automated drive-in-loop docking, CACC based platooning, remote takeover operations) and enabling functions (enhance awareness dashboard, vulnerable road user warnings, slot reservation, distributed perception, active collision avoidance, container ID recognition, ETA sharing, scene analytics) are analysed to discuss network architectural components and to define the network architecture of 5G Blueprint project [1]. In large scale 5G deployment, 5G network still faces challenges from cross boarder coverage and cross Mobile Network Operators (MNO) service continuity. Thus the research and design of the 5G architecture focus on both end-to-end service guarantee with network slicing, and cross border roaming with two operator networks. In this paper we perform a functional analysis of uses cases, enabling functions and corresponding application requirements, resulting in connectivity requirements of 5G network, to finally present an end-to-end design of 5G network architecture capable to fulfill the demanding requirements of our uses addressed. As future step, within the 5G Blueprint project, work lab and pilot area network deployment and feature implementation of such architecture will be validated

The result shows that the selected use cases and enabling functions have very specific and high requirements on latency, bandwidth, reliability and service continuity of 5G network. Simplified as three main challenges: i) uplink bandwidth requirement of uploading raw video or lidar data from a mobile unit to cloud servers, ii) ecosystem readiness and the critical end-to-end service stability of URLLC and Vehicle to Vehicle (V2V) services, and iii) complexity of large-scale deployment of seamless cross-border roaming features. These challenges can be partially solved by the network design in this work (such as optimization of radio resource for uplink with limited bandwidth), or by coordinating use cases and enabling functions (such as adaptively change video quality based on teleoperator's behaviour and scheduling of raw/compressed data upload circles based on movement). Some challenges require continuous further work with ecosystem partners on testing validating the lasted equipment and features, also governance and data exchange between of cross boarder network providers.

II. Use cases, functionality and requirements

The purpose of the 5G Blueprint project is to deliver a blueprint for a 5G based infrastructure which enables seamless teleoperated transport across Europe. The seamless cross boarder teleoperation in 5G Blueprint project is demonstrated and piloted with four selected Use Cases (UC) to be realized in Belgium and The Netherlands, please see Figure 2, in the locations of Port of Antwerp (Belgium), Vlissingen (The Netherlands), and Zelzate (cross-border between Belgium and The Netherlands), please refer to Figure 1. Next to the UCs there are eight Enabling Functions (EF) defined to further enhance or supplement the UCs. In a previous paper we have described these UCs and EFs [2]. Before describing the requirements of the UCs, we will describe the extra enhanced functionality that the project is developing in order to enable such use cases and have a direct influence on the network requirements, and therefore the 5G architecture needed.

- **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 Teleoperator (TO), increasing his/her situational awareness without creating information overload.
- **EF2 Vulnerable Road User (VRU) interaction** - provide warnings to TOs and VRUs (e.g., pedestrians or cyclists) about potential conflicts between teleoperated vehicles (TOV) and vulnerable road users.
- **EF3 Time Slot Reservation at Intersections** - ensures a conflict-less crossing of intersections by teleoperated vehicles, by guaranteeing 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 Estimated Time of Arrival 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 Scene Analytics** - foresees in continuous monitoring (through IP cameras and sound sensors) and anomaly detection of several key areas relevant to teleoperation: inspection of the 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.

A. Use case 1: Automated barge control

In this use case, the port entry efficiency is 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 are teleoperated along with partial automation. Moreover, pilots are located in the ports of Antwerp (Belgium) and Vlissingen (The Netherlands) while the Zelzate site provides the validation in the cross-border area, which are highly relevant for understanding both the 5G network and teleoperation performance when there are cross-border handovers between operators including cross-border regulation among the countries involved.

In this use case a barge will be teleoperated from a central location on the shore. Each Teleoperated Vehicle (TOC), i.e., barge, will be equipped with i) 10 HD-Video Cameras which can be controlled remotely, ii) one PLC which is used to control the vessel (rudder, engines, thrusters), iii) sensors to continuously measure the distance to the shore, the depth below the waterline, iv) at least two independent 4G/5G modems.

On the shore the Teleoperation Centres (TOC) will be equipped with i) 6 HD-Video screens, ii) joysticks, iii) radio Communication devices, iv) small screens for additional camera views and ship status information

The most important technical measures of success are i) maximum number of HD-Video streams, ii) latency, iii) availability (e.g., Radio Coverage and reliability of Session Continuity).

The result of the use case requirements analysis is described in Table I. We consider that the metrics values contained in this requirements Table (presented at each UC) are a valuable contribution to our community, since they are the outcome of an analysis done by key experts in both industry and academia domain. Furthermore, in our analysis we have realized that there is a lack of such analysis coming from applied sources (e.g. industry or field trials). To futher enhance the requirements analysis, an overview of the EFs and UCs and in which location they will be deployed and tested is illustrated by Figure 3.

B. Use case 2: Automated driver in the loop docking

Trucks are equipped with standardized connectivity solutions for an optimized docking operation with respect to time and space requirements. Positioning of these trucks are performed via camera-based RTLS. Next to this, a mobile harbor

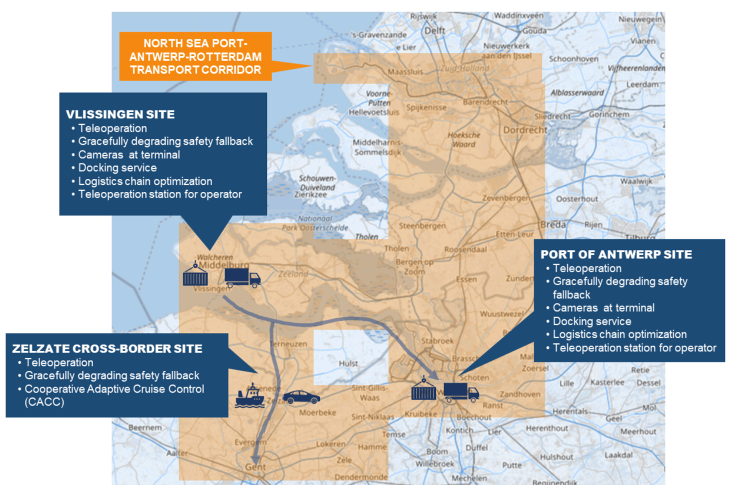


Fig. 1. 5G Blueprint pilot locations

TABLE I
USE CASE 1 REQUIREMENTS

Description	HD Camera stream	HD Video screens	Ship control interface	Distance/depth sensor in ship
From/To	TOV→ TOC	TOV→TOC	TOC→TOV	TOV→TOC
Service Type	Uplink	Downlink	E2E	Uplink
Ideal Latency	<22ms	<22ms	<35ms	<100ms
Service Interruption	<30s	<30s	<150ms	<1s
Bandwidth Requirement	>5Mbps <25Mbps	>5Mbps <25Mbps	<2Mbps	<1Mbps
Device Scenario	Outdoor mobile	Outdoor stationary	Outdoor mobile + Outdoor stationary	Indoor mobile
Slice Type	eMBB	eMBB	URLLC/ hMTC	V2X
No. Flow	10 per ship	6 per operator	1 per ship	1 per ship

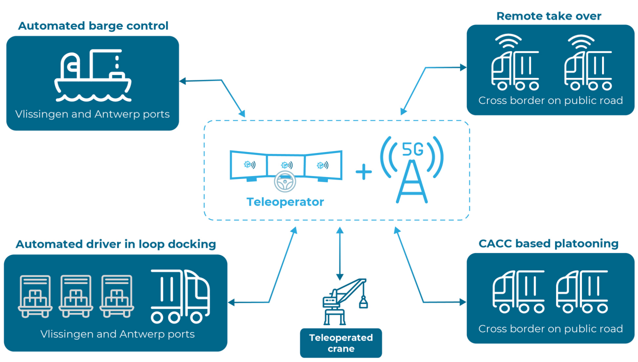
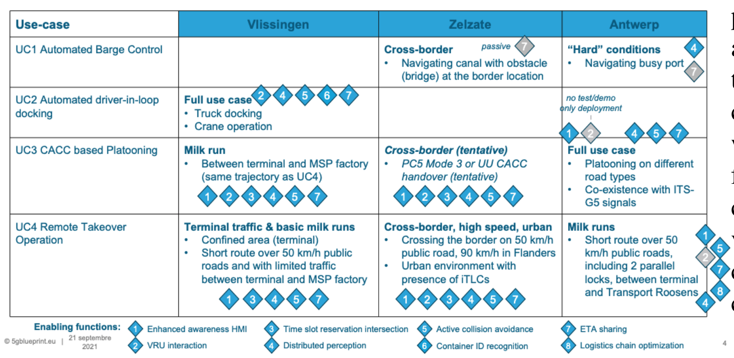


Fig. 2. 5G Blueprint use cases



Use-case	Vlissingen	Zelzate	Antwerp
UC1 Automated Barge Control		**Cross-border** *passive* 7 • Navigating canal with obstacle (bridge) at the border location	**"Hard" conditions** 4 • Navigating busy port 7
UC2 Automated driver-in-loop docking	**Full use case** 2 4 5 6 7 • Truck docking • Crane operation		*no test/demo only deployment* 1 2 4 5 7
UC3 CACC based Platooning	**Milk run** • Between terminal and MSP factory (same trajectory as UC4) 1 2 3 4 5 7	***Cross-border (tentative)*** • *PC5 Mode 3 or UU CACC handover (tentative)* 1 2 3 4 5 7	**Full use case** • Platooning on different road types • Co-existence with ITS-G5 signals
UC4 Remote Takeover Operation	**Terminal traffic & basic milk runs** • Confined area (terminal) • Short route over 50 km/h public roads and with limited traffic between terminal and MSP factory 1 3 4 5 7	**Cross-border, high speed, urban** • Crossing the border on 50 km/h public road, 90 km/h in Flanders • Urban environment with presence of iTLCs 1 2 3 4 5 7	**Milk runs** • Short route over 50 km/h public roads, including 2 parallel locks, between terminal and Transport Roosens 1 5 2 7 8 4

Fig. 3. 5G-Blueprint sites, function and use cases at a glance

crane is 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, therefore a strong emphazis on 5G ultra-low latencies is put into this use case. Pilots are located in the ports of Antwerp and Vlissingen. The result of the use case requirements analysis is described in Table II.

C. Use case 3: Cooperative adaptive cruise control (CAAC) based platooning

This platooning use case makes combined use of adaptive cruise control, lane-keeping system, and CV2X communication. Platooning of trucks has been widely discussed in the area of logistics. 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, where the leading vehicle is teleoperated while the following vehicles are automated with the dynamic takeover functionality for the automated system. The result of the use case requirements analysis is described in Table III.

D. Use case 4: Remote takeover

Remote takeover is a process in which a teleoperator 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 access to control vehicles. Network stability and latency is highly safety-critical in this use case.

As aforementioned, the remote take over operation shares the same hardware setup as UC3. Thus, the analysis result of UC4 is combined with UC3 and described in section II-C

III. 5G Blueprint Architecture Overview

After a detailed and thorough analysis and discussion presented and available in [3], Figure 4 presents the 5G network architecture capable to provide connectivity to support the strict requirements of the use cases. On the user equipment side at each UC, data generated from vessels or vehicles that are on mobile and have a cross-border service continuity requirement should be connected to a specific use case device. if one 5G modem (hardware or software version) does not fulfil the requirement of all network slices simultaneously, 5G device can be separated according to service type. If the use case device deployment scenario does not allow full aggregation of all data needed for the use case, e.g. data from one sensor cannot be collected with camera data at the same location of the ship, then multiple 5G device is mandatory. As conclusion the device solution will be further

TABLE II
USE CASE 2 REQUIREMENTS

Description	HD Camera stream	HD Video screens (as fallback)	Vehicle control interface	Telemetry sources
From/To	TOV→TOC	TOV→TOC	TOC→TOV	TOV→TOC
Service Type	Uplink	Downlink	E2E	Uplink
Ideal Latency	<50ms	<50ms	<35ms	<100ms
Service Interruption	<150ms	<150ms	<150ms	<1s
Bandwidth Requirement	>5Mbps <25Mbps	>5Mbps <25Mbps	<2Mbps	<1Mbps
Device Scenario	Indoor mobile	Outdoor stationary	Indoor mobile + Outdoor stationary	Indoor mobile
Slice Type	eMBB	eMBB	URLLC/ hMTC	V2X
No. Flow	3 per vehicle	3 per vehicle	1 per vehicle	1 per vehicle

TABLE III
USE CASE 3 REQUIREMENTS

Description	HD Camera stream	HD Video screens	Vehicle control interface	Telemetry sources	LiDAR data stream
From/To	TOV→TOC	TOV→TOC	TOC→TOV	TOV→TOC	TOV→TOV
Service Type	Uplink	Downlink	E2E	Uplink	V2V
Ideal latency	<50ms	<50ms	<35ms	<100ms	<100ms
Service Interruption	<150ms	<150ms	<150ms	<1s	<1s
Bandwidth Requirement	>5Mbps <25Mbps	>5Mbps <25Mbps	<2Mbps	<1Mbps	>20Mbps <100Mbps
UE Scenario	Outdoor mobile	Outdoor stationary	Outdoor mobile	Outdoor mobile	Outdoor mobile
Slice Type	eMBB	eMBB	URLLC/ hMTC	V2N	V2V sidelink
No. Flow	3 per vehicle	3 per vehicle	1 per vehicle	1 per vehicle	2 per vehicle

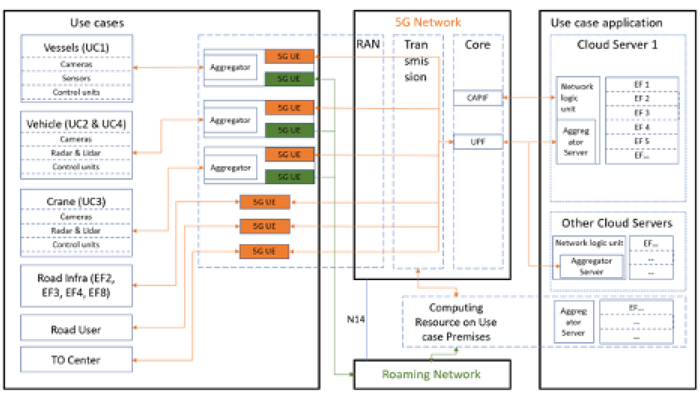


Fig. 4. 5G Blueprint Architecture Overview

changed and refined during field trails. Moreover, cross MNO roaming with N14 interface is key feature for validating seamless roaming. For edge computing on use case premises, as illustrated in Figure 4, there will be a breakout point from transmission network directly to computing resource. For edge computing in MNO data center, the computing resource is in the same environment as the virtualized 5G core. Regarding the application side at each UC, the application could be located on cloud environment, or on edge solution. There is a logical unit on application side to connected with network APIs. This logical unit also includes the data aggregator server is an aggregator is used on use case device side.

IV. CONCLUSIONS

In this paper, all input from use cases, enabling functions and trial environment are analysed and processed together with standardization work, MNO resource, regulatory and ecosystem info to understand network requirements for teleoperation and to provide the architecture design of 5G Blueprint. During this process each network function and component (user equipment, radio network, transport network, core network, E2E slicing, multi-edge solution, V2X, roaming and network API) was considered individually with listed further study for field trails within 5G Blueprint. In the soon future the trials to be executed within the 5G Blueprint project will validate the findings of the analysis exercise done in this paper.

V. ACKNOWLEDGMENTS

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