(INVITED) 5G-MoBiX ES-PT Cross-Border Corridor

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***Abstract*—*5G Technology is becoming a reality that will impact all existing connected domains, including the automotive sector, and providing support to the deployment of new autonomous functionalities in the near future mobility. As a key challenge of this new horizon, the deployment of safety-related applications in the vehicles, which depend on low latency and high-volume bandwidth, in cross-border (roaming and handover) environments is a very important focus of study. This document aims to provide an overview of the Spanish-Portuguese Cross-Border Corridor (ES-PT CBC) in the 5G MOBIX Project framework, which aims to show all the benefits of 5G technology for CCAM applications*.**

Keywords—CCAM, 5G Network, Cross-Border Corridor (CB), Trial Site (TS), RSI, Cloud, Remote control.

I. INTRODUCTION (*HEADING 1*)

Within the evolution of Automated Driving vehicles (1), the concept of Cooperative, Connected and Automated Mobility (CCAM) is a crucial element, which understands that isolated automated vehicles have an important lack of information. This data gap can be fulfilled with the integration of connectivity technologies as non-physical perception sensors, providing access to a new domain of data sometimes challenging for the common vehicle sensors for the different ADAS&AD algorithms to reach.

In this sense, communication between vehicles, infrastructure and other road users is crucial to increase the future automated vehicles' safety and their full integration into the overall transport system. In this way, connectivity does not only rely on the vehicles' capabilities to receive and transmit information, but the infrastructure also has an important role, and it must be prepared for the different scenarios for the successful deployment of CCAM.

For all the above, 5G technology provides three main advantages: more transmission capacity, much less latency and greater reliability. Nevertheless, there are many challenges to be addressed by this new communication technology, including the ones that take place when speaking about cross-border scenarios, synchronization of different Mobile Network Operators (MNOs), Edge Computing, Handover, etc.

5G-MOBIX will develop and test automated vehicle functionalities using 5G technological innovations along different cross-border corridors and urban trial sites, under conditions of vehicular traffic, network coverage, and service demand. It will also consider the inherently distinct legal, business, and local social aspects.

The ES-PT Cross Border Corridor (CBC) is one of the two corridors of the 5G MOBIX project, connecting the cities of Vigo and Porto. The corridor consortium covers the complete value chain of 5G technology for CCAM, including car manufactures, telecommunication companies, Public Administrations, and research institutions. This corridor, led by CTAG, will support use cases in 4 of the five categories set out in the project: Advanced Driving, Remote Control, QoS and Extended Sensors.

II. 5G MOBIX OBJECTIVES

5G-MOBIX aims to match the benefits of 5G technology with advanced CCAM use cases to enable innovative, previously unfeasible, automated driving applications with high automation levels, both from a technical and a business perspective.
The goal of 5G-MOBIX will be achieved through the following objectives:

- To formulate comprehensive requirements for CCAM using 5G.
- To deploy 5G road infrastructure and CCAM use cases and vehicles on x-border corridors and at local trial sites.
- To use the data and experiences for cost-benefit analysis and assess the commercial impact of technologies and deployment. This will allow to explore and evaluate new business opportunities for CCAM with 5G.
- To scale up and replicate it to provide global 5G deployment scenarios and recommendations for EU-wide 5G corridor deployment and beyond.

III. THE ES-PT CBC

This section describes the Spanish-Portuguese Cross-Border Corridor in 5G MOBIX Project.

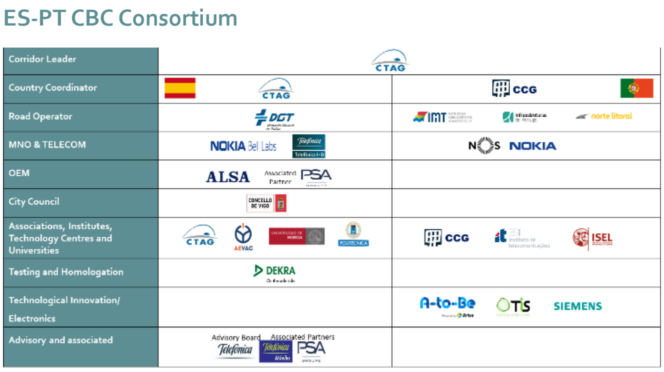
A. Location

The ES-PT CBC connects the cities of Vigo and Porto (250 Km). The cross border is between the north of Portugal and Spain, crossing the Minho/Miño river through two international bridges (New Bridge and Old Bridge), providing the road infrastructure for trucks, cars, and pedestrians.

International trade and large passenger commuting flows are of great importance and provide ideal conditions for the execution of diversified trials to showcase the advantages offered by the 5G connectivity to CCAM user stories.

B. ES-PT CBC Partners

The consortium of the ES-PT CBC comprises 23 partners and has 3 more partners belonging to the Advisory Board and Associated Partners. It includes the main companies of the sector in different areas that will contribute to the success of the ES-PT CBC.



The ES-PT consortium, therefore, counts with the participation of:

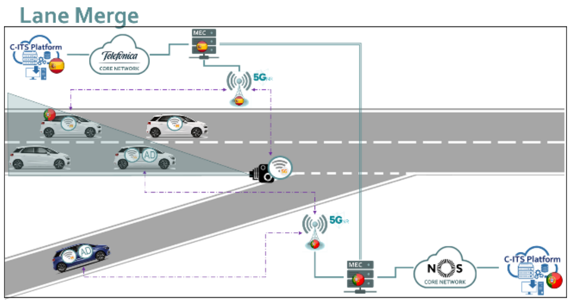
- ***Road operators*** from both countries and city councils to advise on the best way to execute the tests.
- ***MNOs and telecommunication partners*** to enable the deployment of the 5G network.
- ***OEMs*** that supply vehicles.
- ***Institutes, Technological Centres and Universities*** to allow to go off the hand to the state-of-the-art of the most advanced technology.
- ***Testing and homologation companies*** to provide an objective vision for the evaluation of the project.
- ***Technological companies*** to contribute to the deployment of user stories at different levels.

IV. USER STORIES

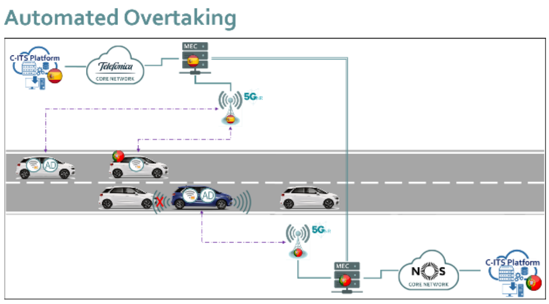
According to the goals of the project, which focus on 5G connectivity to improve CCAM services, a set of scenarios have been defined to experiment and analyse the impact of the 5G technology in cross-border environments. These scenarios may be classified in 4 of the 5 categories described in the Project (1).

A. Advanced Driving Category

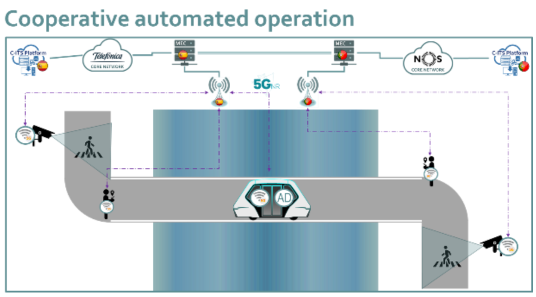
- ***Lane merge:*** perception data shared by vehicles and roadside sensors through ultra-low latency communication channels allows autonomous cars entering highways to build an extra perception layer with real-time information about the environment in the lane to be merged in, increasing the manoeuvre's safety.



- ***Automated overtaking:*** when performing an overtaking manoeuvre, 5G technologies provide non-interrupted low latency communications, which allow autonomous vehicles to complement their perception layer with real-time data from other connected cars, even in cross-border environments.



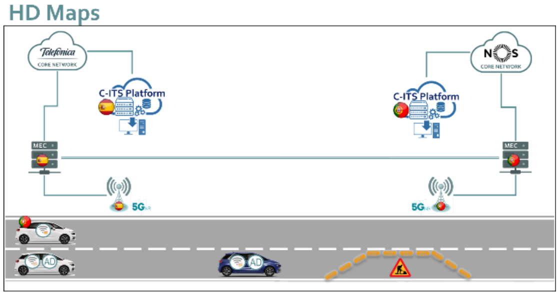
- ***Cooperative automated operation:*** last-mile autonomous shuttles operating in interurban areas are likely to constitute a hazard to vulnerable urban users. 5G allows uninterrupted, low latency communications that enable the vehicle to be notified in real-time of the presence of users at risk of collision.



B. Extended Sensors Category

- ***HD Maps:*** higher levels of autonomous driving in vehicles are often compromised when an unknown event is found on the road. In order to guarantee the level of autonomy and improve road safety, vehicles are able to record the dynamic events they encounter and send large amounts of information to the cloud via 5G to update the HD map of the other vehicles in the nearby area.

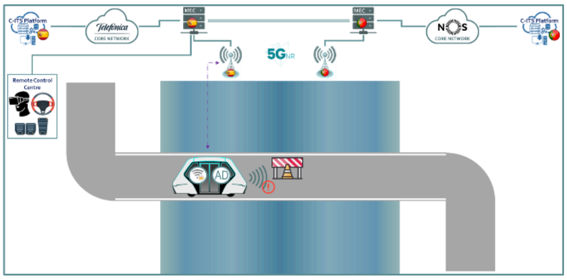
HD Maps



C. Remote Driving Category

- ***Remote control:*** driving a last-mile automated shuttle remotely when its route is obstructed or deviated is a sensitive task. 5G connectivity provides the necessary ultra-low latency and continuity in communications to do it, even in cross-border environments.

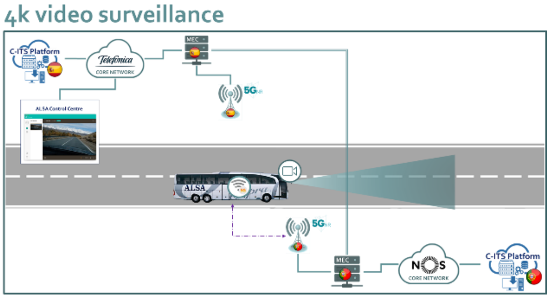
Remote Control



D. *Quality of Service Category.*

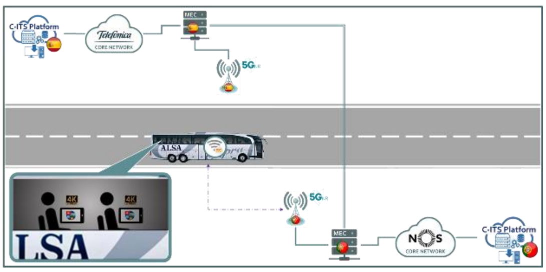
- ***4K bus monitoring*****:** the ability to transfer high-quality content with low latency allowed by 5G is key to giving bus companies a real-time monitoring system of vehicles' visual environment.

4k video surveillance



- ***Multimedia services for passengers:*** passengers on a commercial bus line can enjoy a wide variety of high-quality online content with the greatest smoothness during the journey due to the large capacity offered by 5G communications.

Multimedia service for passengers



V. 5G Network

This section (2) presents some details of the 5G networks in Portugal and Spain within the project framework.

On the Spanish side, the architecture is based on the 3GPP non-standalone 3X option. The core is centrally located in Madrid, which is around 500km away from the test area. This large distance results in high latency, and therefore, it was necessary to deploy an edge site with the MEC platform, where the most critical services can run closer to the final users. This edge site is in Vigo, 20 km away from the border, and it allows to reduce the latency drastically. All the nodes involved in the test have a direct connection to the MEC services through the transport network.

On the Portuguese side, a dedicated network is used, independent from NOS commercial network. This network is initially being operated based on NR NSA option 3x mode and is intended to be upgraded to NR SA option 2 mode at a later stage.

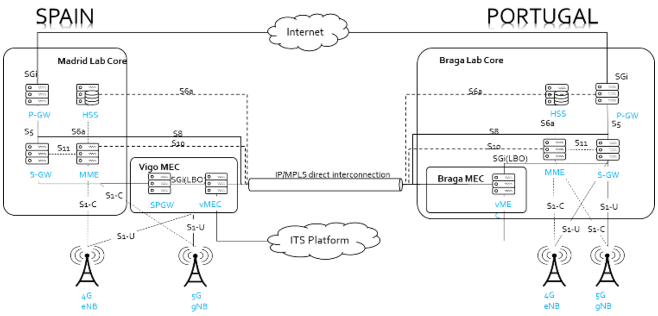
There are two axial sites deployed in Porto corridor at A28 (Corvo and Leça) and an axial site covering A3 motorway over the New Bridge. Two small cells will provide dedicated coverage on the Old Bridge. These locations will be remotely connected to the NOS baseband in Valença.

The centralized 5G core is placed in Lisbon where one CMM and one CMG have been deployed. Additionally, a distributed CMGa-2 working as SGW/PGW is allocated in Riba de Ave, Braga.

For the PT Core, there are two CMG deployed in combo mode (SGW/PGW together): One CMG in Lisbon is dedicated to a different APN, Internet Access only (SGW/PGW), and one CMG-a2 in Braga is dedicated to handling the Control and User Plane traffic (SGW/PGW) of 5G Applications. There is one CMM in the PT Core working as MME.

The Portuguese MEC is in Braga and is directly connected to the Spanish MEC.

ES-PT CBC. 5G Network overview



VI. Roadside, Cloud and Remote-Control Infrastructure

5G MOBIX project is compounded by different roadside and cloud infrastructure (3), listed below:

- ***Traffic Radars*** are used to provide connected vehicles with information about legacy vehicles on the road. The radars used are provided by CTAG and IT.
- ***Anticollision systems*** are used to provide connected vehicles with information about vulnerable users crossing roads. The anticollision systems used are provided by CTAG and Siemens.
- ***5G RSUs*** are used as a connectivity link to other sensors (like radars or anticollision systems) to provide them with

5G capabilities. 5G RSUs used are provided by CTAG and IT.

- ***5G smartphones*** are used as an anticollision system to protect users by warning near vehicles about possible collision situation. CCG provides the 5G smartphones.
- ***ITS Centres*** are used as an ITS platform in the cloud with different objectives: to monitor connected vehicles, to generate road events and notify connected vehicles about them, and to generate updates of the vehicle's HD map. The cloud platform (HW and SW) is provided by several partners: A-to-Be, CTAG and Infrastruturas de Portugal.
- ***Remote driving equipment*** recreates a vehicle cockpit used as a tool for driving vehicles remotely in specific situations. This equipment (HW and SW) is provided by CTAG and Nokia Bell Labs.
- ***MEC applications*** are some applications such as a Message Queuing Telemetry Transport (MQTT) broker, which is the core of almost every communication in the common architecture of the user stories, the Remote Driving application for enabling the communication between the vehicle and the Remote Control Centre, or the Collision Detection application, which warns user's smartphones about possible collision risks with vehicles nearby, are developed and integrated into the MECs for complementing the CCAM infrastructure. These software modules are provided by Nokia Bell Labs, CTAG, IT and CCG.

VII. Vehicles

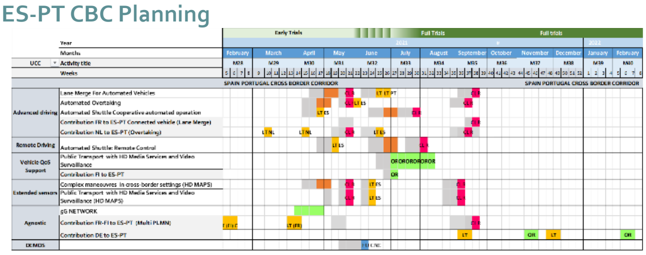
The vehicle fleet for ES-PT CBC (4) is composed by 3 autonomous vehicles (2 Citroen C4 Picasso provided by PSA and 1 Vw Golf provided by CTAG), 1 Autonomous Shuttle provided by CTAG, 1 premium bus provided by ALSA and 1 connected Renault Clio Station Wagon provided by AtoBe.

- ***The Automated Test Prototypes*** are equipped with a CTAG automated driving system, based on a constellation of sensors that provide a perception of the vehicle's surroundings, processing equipment to analyse sensor data and deploy the different automated function in the vehicle, and a CTAG Hybrid Modular Communication Unit (HMCU). CTAG HMCU counts with different communication channels: ITS-G5, Cellular 4G/LTE, PC5 and 5G, of particular interest to 5G-MOBIX. This communication unit can also communicate with the vehicle through CAN and Automotive Ethernet standards, exchanging information with different vehicle units (including automated driving systems).
- ***The Alsa Bus*** is equipped with a sensors collection to get information about the road and its status. It has available one tablet by seat to broadcast streaming content to passengers and two 4K cameras. This bus is also equipped with a CTAG HMCU to exchange data.
- ***The Portuguese connected vehicle*** (AtoBe) is retrofitted with a 5G OBU (IT), a dashboard smartphone and a GNSS receiver. The vehicle's OBU integrates a 5G Quectel module for V2N/N2V communications.

VIII. Trialling Phase

The trials are divided into an initial phase at the national level, both in Spain and Portugal, and a second phase to be held at the borders. In this second phase, the work done by different TS (Finland, France, Netherlands, and Germany) will be integrated into the ES-PT CBC trials, which will add value at the technological and interoperability level.

ES-PT CBC Planning



IX. Evaluation Methodology.

Evaluation methodology aims to capture the new business opportunities for the 5G enabled CCAM and recommendations and options for the deployment. It is structured in three areas:

- ***Technical Evaluation*** focused on capturing the impact of CBC mobility on CCAM user-perceived performance and comprehensively evaluating the technologies and solutions implemented.
- ***Impact Assessment*** assesses the potential business and societal impacts of the systems and applications in the following metrics: personal mobility, traffic efficiency, traffic safety, environment, and business.
- ***User Acceptance*** based on the evaluation of the performance experienced by the vehicle occupant with the HMI systems in four different dimensions: acceptability, trust and perceived safety, system usability and the ability of the system to deal with user error and misuse. Moreover, acceptance of the general public to the CBCs user-stories will also be assessed.

X. Conclusions

Following the deployment of the network, roadside infrastructure, cloud, remote control, and the vehicles needed to execute the use cases, the ES-PT CBC is in the verification phase that will allow trials to begin in the different locations mid-Q2 2021.

XI. Acknowledgment

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