HD Maps in the 5G-MOBIX project

Tiago Dias, Jorge Ribeiro, Lara Moura
Research and Innovation
A-to-Be
Oeiras, Portugal
{tiago.delgado.dias, jorge.ribeiro, lara.moura}@a-to-be.com

Daniel Jáuregui, Marta Miranda
Centro Tecnológico de Automoción de Galicia
Porriño, Spain
{daniel.jauregui, marta.miranda}@ctag.com

João Almeida, Mohannad Jooriah, Joaquim Ferreira
Instituto de Telecomunicações
Universidade de Aveiro
Aveiro, Portugal
{jmpa, mohannad.jooriah, jjcf}@ua.pt

***Abstract*—**

***Keywords*—HD Maps; 5G; Connected Automated Vehicles (CAV); Connected and automated mobility (CAM);**

I. Introduction

The adoption of 5G cellular communications enables a series of advanced use cases involving vehicle, road infrastructure and cloud communications (V2X) that were previously not possible. For instance, the high bandwidths achievable by the 5G architecture enable the transfer of big chunks of data, enabling transmission of High-Definition Maps (HD Maps) between the road infrastructure and connected vehicles (CVs) offering near real-time road descriptions with centimetre-level accuracy. At the same time, the achievable low latencies enable the real-time position and status exchange between CVs and Autonomous Vehicles (AVs) and from legacy vehicles as seen by traffic radars.

HD Maps and their use in the Spain-Portugal cross-border corridor (ES-PT CBC) of the 5G-MOBIX Project [1] are precisely the focus of this paper.

II. HD Maps in the 5G-MOBIX Project and the ES-PT Cross-Border Trial

HD Maps provide a detailed description of road topology, precise vertical signs and road-marks locations and can even contain a detailed point-cloud of the road surroundings. This information is essential for the navigation of AVs and it can be highly dynamic when considering events like vehicle accidents and road works.

The ES-PT CBC includes a specific HD Maps scenario that explores the update of HD Maps from live sensor data sent through the 5G network to the cloud.

In the HD Maps scenario, an autonomous vehicle (blue vehicle in Fig**.** 1) approaches an uncharted obstruction zone. For this reason, and to ensure vehicle safety, it switches to manual driving mode but uses its' sensors to collect information about the obstructed area and sends it to the cloud where an HD Map is then built using artificial intelligence techniques. With the updated map delivered to other AVs (exemplified by the white AD vehicle in Fig**.** 1) on time they can remain autonomous while driving through temporary obstacles such as roadworks, minimizing human intervention. CVs (exemplified by the silver vehicle in Fig**.** 1) can also use the HD Map to warn the driver about the situation and present the obstruction in detail, helping the driver plan a safe diversion manoeuvre.

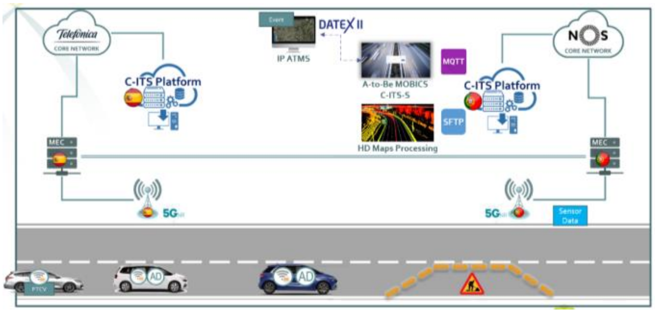

Fig. 1 – Schematic of the HD Maps scenario

III. HD Maps Infrastructure

A. Architecture

The ES-PT 5G-MOBIX Cross Border Corridor will provide a fully working 5G V2X architecture going from cloud Cooperative-Intelligent Transport Systems (C-ITS) Centres to 5G .AVs and CVs, including 5G roadside units (RSUs), Radars and Message Queuing Telemetry Transport (MQTT) brokers hosted at 5G Multi-Access Edge Computers (MECs) [3]. The HD Maps scenario will involve the AVs and CVs, the MQTT brokers and the C-ITS Centres, which will have a pivotal role by processing vehicle sensor data and serving updated HD Maps to AVs to guarantee safety.

The HD Maps scenario starts with a Decentralized Notification Message (DENM) message regarding road works at the trial location. This message is either composed on the C-ITS Centre or converted from the Operational Traffic Management System from Datex II. Then it is disseminated to the MEC MQTT brokers in the proximity of the event. Vehicles are subscribing to topics at these MEC MQTT brokers and receive the DENM event over the 5G network.

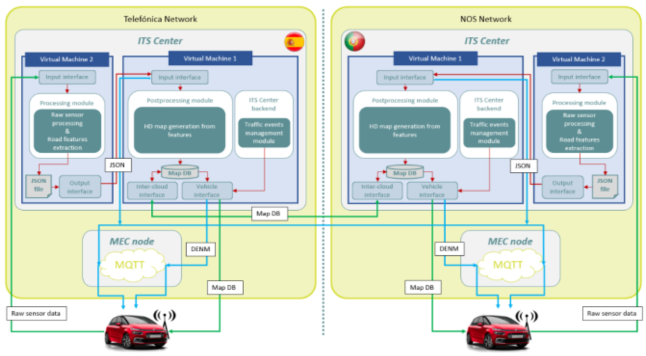

Fig. 2 – Architecture of the HD Maps Scenario

After receiving this event, the Autonomous Vehicle (AV) will check its' internal map registry. Since the first AV to pass the location will not have an updated registry, it will switch to manual driving and collect sensor data throughout the length of the roadwork event.

The sensor data is packed in an ADTF file [4] holding time-synchronized LIDAR, video, GPS and IMU data. Depending on the length of the obstruction, the size of this file easily reaches a few Gigabytes. It is uploaded directly to the ITS Centre from the autonomous vehicle using SFTP over 5G.

The ITS Centre unpacks the file, decodes the sensor data, and processes it to extract road features such as road-signs, obstructions and lane markings. With this, the ITS Centre produces a JSON file summarizing the road features which were detected.

Another ITS Centre component uses this JSON file to update an HD Map database and distribute it to the AVs. This is done directly using SFTP over 5G too.

The HD Map update JSON file will also be distributed to the MEC MQTT brokers, so it reaches the CVs which will use it to display updated information to drivers.

With this solution it is possible to test two different approaches to HD Map distribution: an integral one, that is used with the AVs and distributes the entire updated HD Map; and an incremental one, used with the CV, that only distributes the updates (as JSON messages) and is potentially compatible with different HD Map technologies used in different vehicles.

Both the vehicle sensor data upload and the distribution of the integral HD Map database to the AVs are high bandwidth tasks which will help trial the performance of the 5G network.

B. *Autonomous Vehicles*

The HD maps scenario requires the generation of a set of data about the road collected by vehicle's sensors. This data is uploaded to the ITS Center in order to be processed, and to generate a new HD map, updated with the new features of the road which are obtained from processing the data recorded by AVs. For this purpose, AVs are equipped with a set of sensors, such as a LIDAR, a D-GPS receiver, a video camera and an IMU. Furthermore, some data from the vehicle odometry (vehicle CAN) is extracted too for composing the recorded data.

Fig. 3 – Autonomous vehicles from CTAG

AVs from CTAG count on a Map Unit which implements map recognition and usage. This Map Unit is prepared to receive new map databases with updated information about the roads.

Apart from the sensors and the maps unit, CTAG's AVs are equipped with a 5G OBU which uploads the recorded sensor data and downloads the updated map from the ITS Centre, and is also in charge of sharing CAM messages with the MQTT brokers in order to keep other vehicles and managers (C-ITS Platforms) aware of its position, speed and other relevant attributes.

C. *Connected Vehicle*

The connected vehicle is equipped with a 5G OBU and a V2X App running in a smartphone. Instituto de Telecomunicações's (IT's) 5G OBU publishes awareness messages (CAM) to the MEC broker and consumes information from it. A Wi-Fi dongle is used to create a hotspot that enables the wireless connection of the 5G OBU with smartphone devices. This allows the communications between the OBU and the V2X App, including both the exchange of C-ITS messages in XML / XER format (converted from the binary one used at MEC level), as well as the HD Maps information updates. Another MQTT Broker is hosted by the OBU to support all communication between the OBU and the V2X App.

A-to-Be's V2X App is Android-based and provides drivers with a live map where it represents DENM and IVIM situations, HD Map updates, as well as other vehicles (using CAM and CPM). It also alerts the driver when approaching relevant situations and allows the reporting of relevant road situations (using DENM).

The HD Map update consist of a JSON message that includes detailed information about temporary road signs, their location, and the 3D geometry of road obstructions. This information is represented in A-to-Be's V2X App in 2D with the road signs and obstruction lines that will help drivers know when and where to expect obstacles. The App decodes the JSON message and represents it on the dynamic map.

D. *Time synchronization*

Both the AVs and CV are connected to a Time Server machine with the sole propose of providing a precise source for clock synchronization, using the Pulse Per Second signal available in an independent GNSS receiver. This accurate time synchronization is very important for the logging and evaluation measurements of KPI metrics, such as communications latency in a 5G setup. The Precision Time Protocol (PTP) is used to synchronize the 5G OBU to the Time Server.

E. *MEC Broker*

MQTT brokers are hosted at MECs in the Spanish and Portuguese sides of the border as shown in Fig. 4. The brokers are used to exchange binary C-ITS messages (CAM, DENM, CPM and MCM) and JSON HD Maps updates between all connected devices.

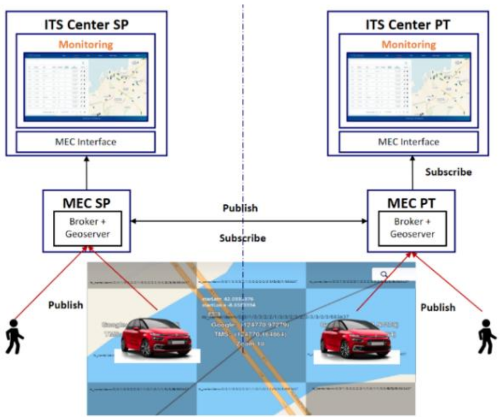

Fig. 4 - MEC Brokers and GeoServers in ES-PT CBC

Messages are organized with a topic structure that includes a level to identify the message type and another set of levels to identify the physical location of the message content using a geo-tiling scheme [5][6], as follows:

```
<general_topic_header>/<message_type>/<tilelevel1>/…/<tilelevelN>/<StationID>
```

The geo-tiling / quadtree scheme is used to distribute only the relevant information to each subscriber. To do this there is a GeoServer application running in each MEC node. The GeoServer is responsible for handling the messages published by all connected elements. It republishes messages to the relevant adjacent tiles. To provide service continuity in the cross-border areas, the GeoServer publishes messages that are relevant on the other side of the border to a special topic at the adjacent country's MEC.

The option of using a GeoServer was selected instead of relying on vehicles' subscriptions to the tiles they judge of interest because the GeoServer has a more general overview of the traffic system and thus can better manage the publishing tiles to fulfil specific message dissemination purposes.

F. ITS Centre

The ITS Centres in Spain and Portugal will support the Advanced Driving and HD Maps use cases by monitoring AVs and CVs, processing sensor data for generating new maps, and distributing updated HD Maps between vehicles involved.

In the ES-PT CBC, two similar mirrored ITS Centres have been deployed, each one intended to serve vehicles traveling on its side of the border.

1) Spanish Side – CTAG

The Spanish ITS Centre is composed of the following modules:

- ***Monitoring and Traffic Management module:*** aims to be the control centre of the cooperative ecosystem, allowing for the management, monitoring, and actuation of the different connected and cooperative elements. This module allows monitoring AVs and CVs' states, as well as triggering traffic events for vehicles that can receive them. This module has been developed by CTAG, and the same one is used for each ITS Centre.
- ***HD Maps module:*** aims to add new functionality to the ITS Centre, enabling it to support the HD maps generation for AVs. This module has been developed by CTAG. The HD maps module works as follows: the module receives a package with raw sensor data from a vehicle. This data is processed to extract the features of the road which are then inserted into a JSON file. This JSON file is used in two ways: it is published over the network, in order to be accessed from any vehicle able to generate its own proprietary HD map; and is used too as an input in a second phase of processing in the cloud, which generates an updated HD map, that is later distributed to vehicles using this kind of map format. The component that uses the JSON file to produce and distribute an updated HD Map in the cloud is the same both in Portugal and Spain and is provided by CTAG.

2) Portuguese Side – A-to-Be and CTAG

A-to-Be's MOBICS C-ITS Centre already managed ITS-G5 RSUs. In 5G-MOBIX, it was extended to connect to the 5G MEC MQTT Broker to receive C-ITS messages and send these as well as HD Map JSON messages. A-to-Be's MOBICS was also integrated with Traffic Management Systems (TMS), using the Datex II standard, so it is possible to disseminate DENM from incidents generated at the TMS. This is used in the Portuguese side of the HD Maps Scenario to trigger the DENM message using the TMS from Infraestruturas de Portugal, bringing this scenario as close to reality as possible.

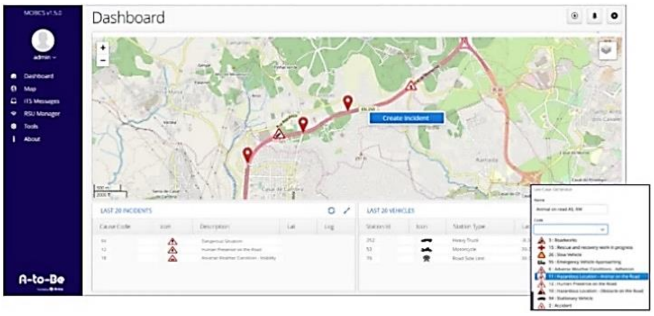

Fig. 5 – A-to-Be MOBICS dashboard view with events

The ITS Centre on the Portuguese side also includes a component developed by A-to-Be that produces an HD Maps update from the AV collected sensor data.

Processing sensor data can be a very complex task which requires several combinations of different approaches from the fields of Artificial Intelligence, image processing and others. But the focus of the 5G-MOBIX project is not on developing advanced CAM solutions, but on the exploitation of the 5G network to support complex CAM scenarios. As such, we devised a simplified approach to process sensor data and produce the respective HD Map update.

First, we split the problem into three parts: one, the extraction of the road signs; two, the extraction of the road boundary; three, putting it all back together.

For the extraction of the road signs, the video stream will be used. Each frame will be processed to identify road signs using a pre-trained neural network. It is necessary to identify the most adequate training data set and neural network type and architecture [7][5]. As a result, we will get a list of signs detected, associated probability and coordinates for a rectangle bounding each sign. At this point we will still need to convert the sign bounding box into a 3D shape in the real geographic space. For this, we will use the camera lens property values fused with the GPS data stream to produce a geolocated bounding box for the identified road signs.

As for the extraction of the road boundary, the LIDAR stream will be used in conjunction with the GPS stream, IMU and information regarding the assembled position and orientation of the LIDAR sensor. We will produce a 2D occupancy map [8] at a specific band (out of the 16 vertical bands collected by the VPL-16 LIDAR sensor) relative to a specific observation height. As part of the production of the 2D occupancy map we will remove noise and moving objects from the data collected. We will then filter the 2D occupancy map for points inside driveable lanes only, for this, we will use an a priori map based on Open Street Maps (OSM). Finally, we will be able to produce the obstruction lines by connecting the points in the occupancy map. The height of the obstruction will be a fixed constant for now.

Finally, the output of each part is put together in a single JSON file and distributed.

Monitoring, HD Map composition and dissemination to the AVs is handled by CTAG's ITS Centre already described previously.

IV. Trials and Evaluation

The main purpose of the 5G-MOBIX project is not focused on the CAM technology itself, but on the 5G network that supports it. In particular, in the ES-PT cross-border, trials and evaluation are focused on the analysis of the impact of roaming and handover processes on the behaviour of the CAM services by means of the network level performance evaluation of every data flow involved in the system architecture. This means that the degree of safety when performing the trials is directly linked to the continuity of connectivity when sharing C-ITS messages by the MQTT Broker and the HD Maps update in the ITS Centre. In the ES-PT cross-border, achieving the desired seamless roaming means searching for the configuration that gets as little roaming interruption time as possible.

This use case allows a 5G evaluation in two complementing ways: CAM, DENM and CPM communications are directly involved in the latency-critical applications that autonomous driving demands while the key indicators in the HD Maps module are those related to the data rate of the files transferred.

Cross-border trials planned for 2021 will be executed in the new international bridge that connects Spain and Portugal. The design of these trials serves specific evaluation purposes: different Spanish and Portuguese SIM combinations will be used to test the roaming mechanisms; tests are planned both in Spain-Portugal and Portugal-Spain directions to assess the different transitions between both NSA networks. Finally, the network will also be stressed to test its boundaries.

National trials will also take place in Spain (A55) and Portugal (A28) involving vehicles from both sides in each.

The trials will be tightly time-limited and will involve road closures due to the participation of the AVs. Testing prior to the trials is essential. Currently tests are taking place at CTAG's facilities which are covered by Telefonica's NSA 5G network. This is allowing fine tuning the HD Maps processing algorithms and tackling several identified issues and limitations, contributing to a more robust solution.

Fig. 6 –LIDAR and CCTV data next to the V2X App HD Maps representation for CTAG's test track

V. Conclusion

Creating Spain-Portugal cross-border 5G CAM infrastructure and vehicles involved adapting existing solutions like the AVs and CVs, the OBUs and the C-ITS Centre, but also integrating and creating new ones like the HD Maps processing and distribution components or the 5G RSU and Radar integration.

With this 5G CAM architecture ready for the 5G-MOBIX ES-PT CBC trials we are now focusing on the project most relevant aspects. It is now possible to evaluate the usage of the trial 5G network for this set of demanding CAM applications with a series of technical and functional KPIs that will allow a much deeper understanding of the behaviour of 5G and the technical solutions that were used in the trial deployments. Comparison and benchmarking will also be possible by trialling solutions from other 5G-MOBIX country sites at the ES-PT CBC and comparing results. The ES-PT CBC will also assimilate the most relevant results from other countries trial sites to optimize the overall solution in a way no independent effort would be able to do.

As a result, we aim to have a 5G architecture comprising all the necessary technical solutions to be able to further promote the deployment of effective cross-border 5G CAM solutions across Europe. We also plan to initiate further trials of the resulting 5G CAM architecture in other areas and accompany the ongoing adoption of 5G in Europe.

Acknowledgment

The work presented in this paper is part of the European Project 5G-MOBIX. This project is funded by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement Nº 825496. The content reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

References

[1] 5G-MOBIX Consortium. "5G-MOBIX Description of Action", 5G-MOBIX, 21 May 2019

[2] 5G-MOBIX Consortium. "5G-MOBIX D2.1 - 5G-enabled CAM use cases specifications", 5G-MOBIX, [Online]. Available: https://5g-mobix.com/hub/deliverables, 28 October 2019

[3] J. Almeida *et al.* "CAM Infrastructure Support for 5G Advanced Driving Scenarios", Virtual ITS European Congress, 9-10 November 2020

[4] EB Assist. "ADTF DAT File Format", EB Assist ADTF, [Online]. Available: https://support.digitalwerk.net/adtf_libraries/adtf-streaming-library/v2/DATFileFormatSpecification.pdf, 2010

[5] InterCor Project. "Milestone 4 - Common set of upgraded specifications for hybrid communication" section 5.3 Filtering, version 2.1, [Online]. Available: https://intercor-project.eu/wp-content/uploads/sites/15/2019/01/InterCor_M4-Upgraded-Specifications-Hybrid_v2.1-final_INEA.pdf , 17/01/2019

[6] Microsoft Azure. "Zoom levels and tile grid". [Online]. Available: https://docs.microsoft.com/en-us/azure/azure-maps/zoom-levels-and-tile-grid

[7] E. Forson. "Recognising Traffic Signs With 98% Accuracy Using Deep Learning", Towards Data Science, [Online]. Available: https://towardsdatascience.com/recognizing-traffic-signs-with-over-98-accuracy-using-deep-learning-86737aedc2ab, 24 August 2017

[8] University of Toronto. "Lesson 1: Occupancy Grids, Motion Planning for Self-Driving Cars", [Online]. Available: https://www.coursera.org/lecture/motion-planning-self-driving-cars/lesson-1-occupancy-grids-oJcwU