Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2022) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

"HD Mapping supporting Autonomous Driving with Cross-border 5G"

Tiago Dias[a]*, Ana V. Silva[a], Lara Moura[a]

[a]*A-to-Be Mobility Technology S.A., Lagoas Park, Ed. 15, Piso 4, 2740-267 Porto Salvo, Portugal*

Abstract

This paper is focused on A-to-Be's contributions to the 5G-MOBIX Project. 5G-MOBIX provides a proving ground for the application of 5G technology to demanding ITS and CAV/CCAM use cases that cannot be supported by previous communication technologies such as 4G/LTE. A-to-Be is contributing with sensor data processing to produce live HD Map updates in a 5G-MOBIX trial in the Spanish-Portuguese border. This trial tests the 5G network with connected and automated vehicles using a cloud produced and updated HD Map. This paper presents the 5G-MOBIX project, the HD Map portion of the trial in the Spanish-Portuguese border and explores the sensor data processing technical solution that produces updates to the HD Map.

Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference
Keywords: HD Maps; 5G; CCAM; Connected, Cooperative and Automated Mobility; C-ITS; Cooperative Intelligent Transport Systems;

1. Introduction

Recently, investment in Autonomous Vehicles (AVs) has become more focused on motorway driving and other scenarios that are easier to tackle and can become profitable sooner than full self-driving solutions, according to Laviv et al. (2021). Meanwhile, the ongoing deployment of 5G cellular networks comes at a critical time to allow a higher degree of interaction between AVs and cloud services.

It is in this context that the 5G-MOBIX project sets a proving ground for the application of 5G technology to the most demanding ITS and Connected Automated Vehicles (CAV) / Cooperative Connect Automated Mobility (CCAM) applications, that cannot be supported by previous communication technologies. This is done in real European roads, highways and two selected cross-border corridors. 5G-MOBIX is developing two 5G-enabled cross-country corridors between the borders of Spain-Portugal (ES-PT) and Greece-Turkey (GR-TR) and includes national trials in France, Netherlands, Germany, Finland, China and Korea, refer to Martin et al. (2019). The national trials have developed, tested and demonstrated 5G CCAM solutions like remote driving, refer to KPN (2020), and Service Discovery, refer

* Corresponding author. Tel.: +351 214 233 400.
E-mail address: tiago.delgado.dias@a-to-be.com

2352-1465
Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference

to Dang et al. (2021). A wider set of 5G CCAM solutions are now being tested together at the cross-border trials, including knowledge, results and the actual solutions from the national trials, allowing for solutions comparisons and benchmarking.

One of the CCAM aspects studied in the Spain-Portugal cross-border corridor is the enhancement of AVs driving autonomy using cloud-based HD (High Definition) Maps. This is trialled in 5G-MOBIX for a specific scenario where a roadworks event is occupying a driving lane. AVs typically require drivers to take over for such unexpected situations. To avoid this, the first AV that passes the roadworks situation will collect sensor data which will be uploaded to the cloud. Subsequent AVs won't exit autonomous mode because they will use an updated HD Map which includes the detailed roadworks obstruction 3D geometry. This trial is done at a cross-border location to include tests on handover between 5G networks and interaction between ITS centres in both sides of the border. The 5G network is pivotal for these trials because both the sensor data and the actual HD Maps are large sets of data which need to be transferred to and from the cloud in a short amount of time. Other lower-bandwidth technologies would not make the solution viable for AVs driving at motorway speeds.

The main challenge for HD maps is the on-time availability of up-to-date information before the vehicle enters a specific area. 5G enables this type of mapping solution by supporting the combination of high-performance data rates, seamless coverage and low latency.

According to the 5G PPP 2021 brochure on "Trials and Pilots for connected and automated mobility", from the seven UE initiatives dedicated to 5G for CCAM, there are only three with HD Maps use cases: 5G-MOBIX, 5GCroCo and VITAL-5G. Kousaridas et al. (2020) present an overview of the technical requirements for vehicles and telco operators to support this advanced manoeuvre. Hetzler et al. (2021) present the HD map generation and distribution solution in the 5GCroCo project, whereas Muehleisen et al. (2021) describe performance and service continuity of HD Maps in MEC-enabled cross-border scenarios for 5GCroCo. According to Sultanoiu et al. (2021), the VITAL-5G initiative will provide a virtualized experimentation facility, composed of a secure service environment platform and three distributed 5G-testbeds, for testing and validating a set of vertical transport and logistics applications. One of its use cases aims at creating a more accurate electronic navigation map using distributed sensor data ingestion, fusion and post-processing, according to the project proposal, refer to VITAL-5G (2022).

Through its findings on technical and operational conditions, 5G-MOBIX is expected to actively contribute to produce sustainable business models for the deployment of 5G for the road transport sector, as well as to standardisation and spectrum allocation activities.

2. The HD Maps Scenario in the Spain-Portugal border

The ES-PT corridor stretches from Vigo to Porto and is comprised of roads and highways in Spain and Portugal. Cross-border activities in this corridor are centred around the northern border of Portugal with Spain, near the cities of Valença and Tui.

In particular, the HD Maps scenario in the ES-PT cross-border trial is focused on disseminating detailed dynamic geographic information to vehicles, namely to autonomous ones. Typically, autonomous vehicles will require human intervention when knowing of unpredicted obstacles ahead. This is because the autonomous vehicles require detailed information on the geometry of the obstacle and how it obstructs the road to automatically avoid it. But, in most cases, it is not even known where the obstacle starts and ends precisely. This is where the HD Map solution comes into play. The first autonomous vehicle to come across an obstruction 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 an updated map delivered to other autonomous vehicles on time, they may remain autonomous while driving through temporary obstacles such as roadworks (studied scenario), accidents and other hazards, minimizing human intervention. This is because the detailed 3D geometry of the obstruction is available to the vehicle, so it can plan and execute a diversion manoeuvre to avoid the obstacle without the need for human intervention while maintaining or even increasing safety.

This scenario focuses on the capability of the cloud infrastructure to map changes in the road in detail and update the HD-Map used for autonomous driving. In the cloud processing component, sensor data like Lidar, camera and GPS information collected by the autonomous vehicles, is fused and processed to extract road features, such as traffic signals, barriers and so on. These features are used for updating the HD Map. Finally, the obtained data (updated HD

Map) is shared with an ITS-Centre to be processed, stored and shared with other vehicles, ensuring the information reaches all the relevant vehicles.

The scenario starts with the dissemination from the ITS-Centre of a roadworks event. The information will be disseminated to several vehicles driving towards the roadwork situation (Step 1 - Alert). The alert consists of a C-ITS message notifying the basic information about the event (the type of event, start location of the event, end location of the event). In the case of the Portuguese ITS-Centre, operated by Infraestruturas de Portugal, it uses DATEX II to internally encode this message and deliver it to A-to-Be's C-ITS centre where it is translated. This message is then encoded using the DENM standard, refer to ETSI (2014), and sent to MQTT brokers at the MEC sites serving the relevant 5G geographic locations where the message shall be disseminated. Finally, the brokers distribute the DENM message over the 5G network to all the subscribing vehicles.

Please note that, in the future, it is expected that autonomous vehicles will not depend upon this alert to detect obstructions to the road and can detect these themselves, this scenario could then be applied from that point onwards.

In possession of the basic information about the event, the first autonomous vehicle passing through the roadwork checks if the event is already registered in more detail in its internal HD map. If not, the vehicle assumes the HD map is outdated, asks the driver to take manual control and deal with the road works situation on his own. While passing the obstruction event in manual drive, the autonomous vehicle collects sensor data from its GPS, Lidar, Camera and other sensors for the duration of the event (Step 2 – Sensor Data Collection, see Fig. 1). As described by according to Elektrobit (2010), after passing the event, the vehicle synchronizes and packs the distinct sensor data streams using the ADTF format, and uploads it, using 5G, to the ITS Centre where it will be processed (Step 3 – Processing).

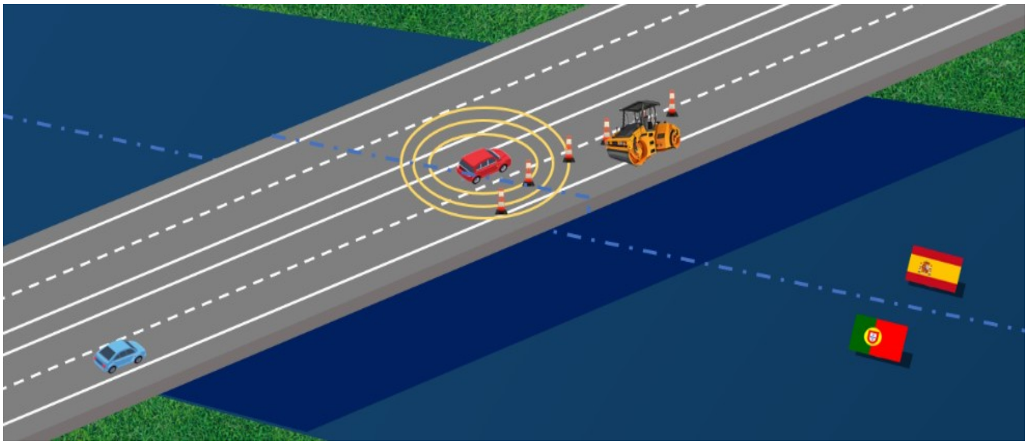

Fig. 1 - Representation of the HD Maps scenario in the ES-PT border during sensor data collection (Step 2 of HD Maps use case)

The sensor data will amount to the most massive quantity of data transferred in this scenario. This is the most demanding part from the 5G infrastructure and only an adequate 5G network will allow cloud processing of this amount of vehicle sensor data. 4G and other slower networks will not be able to cope with this scenario effectively in time, due to the longer duration of sensor data transfer to the cloud.

The Sensor Data Processing phase is detailed further ahead in this article. This phase results in an update to the HD Map. This update is encoded using a custom JSON format. Once the HD map update is available in one of the ITS-Centres it is used to update an HD Map database. Both the JSON HD Map update and the updated HD Map database are distributed to the ITS-Centre of the other country and to vehicles, namely those that drive towards the roadwork (Step 4 – HD Map provision). The JSON file is distributed using the MQTT brokers at the MECs, but the updated HD Map database is distributed directly to the autonomous vehicles using SFTP.

Autonomous vehicles driving towards the roadworks will then receive the updated HD map. After that, vehicles will have enough information to safely divert, in autonomous mode, the obstructions caused by the road work (Step 5 – Autonomous Driving through Road Works).

Although this scenario was developed around the needs of autonomous vehicles, we considered that the resulting HD Map updates have importance for the drivers of connected vehicles too. Road warnings regarding events like roadworks or accidents usually convey the type and point location of the event and not much more detail, as usually it is not available. This leaves the driver unknowing whether the obstruction caused by a roadwork event is on the left lane, the right lane or elsewhere, and that information is very important to help the driver deal with the situation in an optimized fashion. The HD Map allows just that, by showing the exact location of the obstruction geometry and even to be able to guide the diversion manoeuvre of the human driver.

This way, A-to-Be and Instituto de Telecomunicações from Universidade de Aveiro (IT) introduced a Portuguese 5G connected vehicle to this 5G-MOBIX scenario, allowing the visualization of crucial details from other vehicles and the infrastructure. This highly increases safety in complex manoeuvres by showing occluded vehicles and detailing dynamic obstructions ahead. The 5G connected vehicle is comprised of a 5G OBU developed by IT and a V2X App that serves as the Human Machine Interface (HMI) developed by A-to-Be.

While the wider adoption of autonomous driving might take a long time still, with 5G technology it is already possible to connect existing vehicles and benefit from these safety enhancements today. That is why we consider the role of the 5G Connected Vehicle crucial in maximizing the benefits from 5G technology as it is deployed.

The HD Map updates consist of JSON messages that include 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, to help drivers know when and where to expect obstacles (see Fig. 2). The JSON messages are delivered to the V2X App using an MQTT broker hosted by the 5G OBU. The App decodes the JSON messages and represents them on a dynamic map.

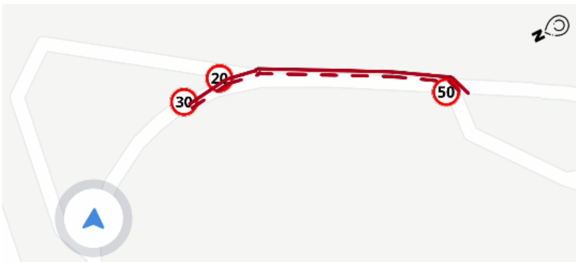

Fig. 2 - A-to-Be V2X App displaying an HD Map update for an obstacle on a test track

3. Production of HD Maps Updates

The HD Map Production consists of two main steps. First, the received sensor data (ADTF package) is unpacked, and the information contained in it is decoded and fused. Then, the fused data is analysed and processed into relevant features of the road, like road-signs and the geometry of temporary obstructions. The ADTF file format is an automated driving industry standard used to package timestamped sensor data together. It can be used for streaming but, in our case, a single DAT file is transferred with all the collected sensor data, once the obstruction is passed by the vehicle collecting the data. A-to-Be's solution receives and unpacks this ADTF DAT file. The DAT file is in a binary format, it has a header with metadata about the entire file, a data section made up of data chunks, each with its' header and data section, a file extensions section and an extensions table (index) at the end of the file. This format supports multiple synchronized data streams, one for each sensor source. It does this by identifying the stream each data chunk belongs to and by mixing chunks from all streams together in the data section, order according to their timestamps, see Fig. 3. A file extension is then used to index each distinct data stream in the file, providing information such as stream name or data size and associating it with the stream identifier that is used for each chunk of data.

For the HD Maps scenario in the ES-PT cross-border trials, the ADTF files include a VPL-16 LIDAR data stream, a CCTV pixel matrix sequence data stream and GPS, IMU and EGO data streams. These streams are extracted from the respective ADTF file chunks, put back together and then each stream is processed. The GPS, IMU and EGO streams are struct-based binary formats, so they are directly extracted into in-memory data structures for processing. The CCTV pixel matrix sequence stream is a series of pixel matrixes taken by a specific camera at subsequent instants, they are read into images, next to their metadata and kept for processing. Finally, the LIDAR stream is extracted using a VPL-16 format library so it can then be processed also. By using the timestamps associated with the sensor samples it is then possible to synchronize LIDAR, video and the other data streams. An example of the resulting visualization for the LIDAR and video stream is shown in along with a visualization of the produced HD Map update, which is actually only produced at the end of this entire process.

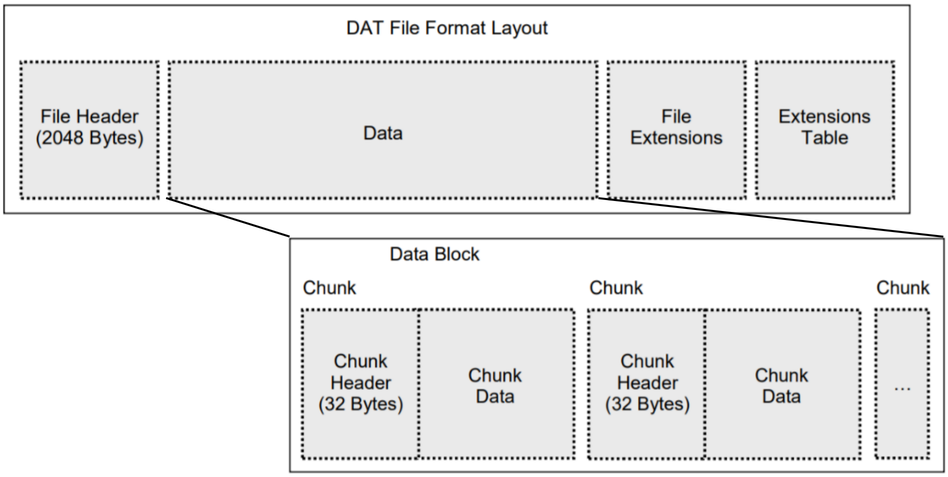

Fig. 3 - Layout of the ADTF DAT file format. Adapted from Elektrobit (2010).

Processing sensor data can be a very complex task which requires the combination of different approaches from the fields of AI and image processing. The focus of 5G-MOBIX is not on developing advanced CCAM solutions, but on the exploitation of the 5G network to support complex CCAM 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 (Fig. 4).

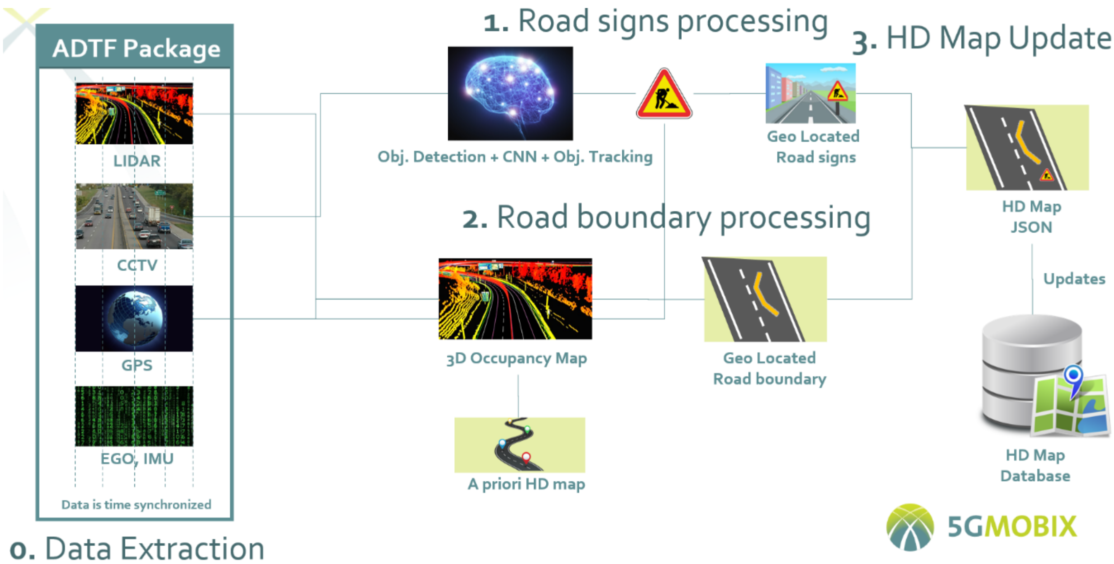

Fig. 4 - The three stages of sensor data processing.

For the extraction of the road signs, the data from the video stream is used. First, the contrast and sharpness of each frame is optimized. The sharpening level is dependent on whether the image is daytime or not, as applying stronger sharpening for night-time images yields better results in the following processing stages. Then, each frame is analysed to detect and classify road signs, using two pre-trained neural networks YOLO for detection, following the work of Karovalia (2021) and a custom CNN, for classification. The end result is a list of signs detected in each frame, associated with the most probable classification category and with the coordinates corresponding to a rectangular bounding box for each sign. The road signs are processed for each frame of the stream and tracked with our own algorithm, that matches the signs which were found closer between frames. From the tracked signs we elect the most common sign identification for each distinct sign. Finally, we still need to convert the sign bounding box into a 3D shape in the real geographic space. For this, we use the camera lens parameters along with GPS data, to produce a geolocated bounding box for the identified road signs, using the last frame the sign was detected at. This process is illustrated in Fig. 5.

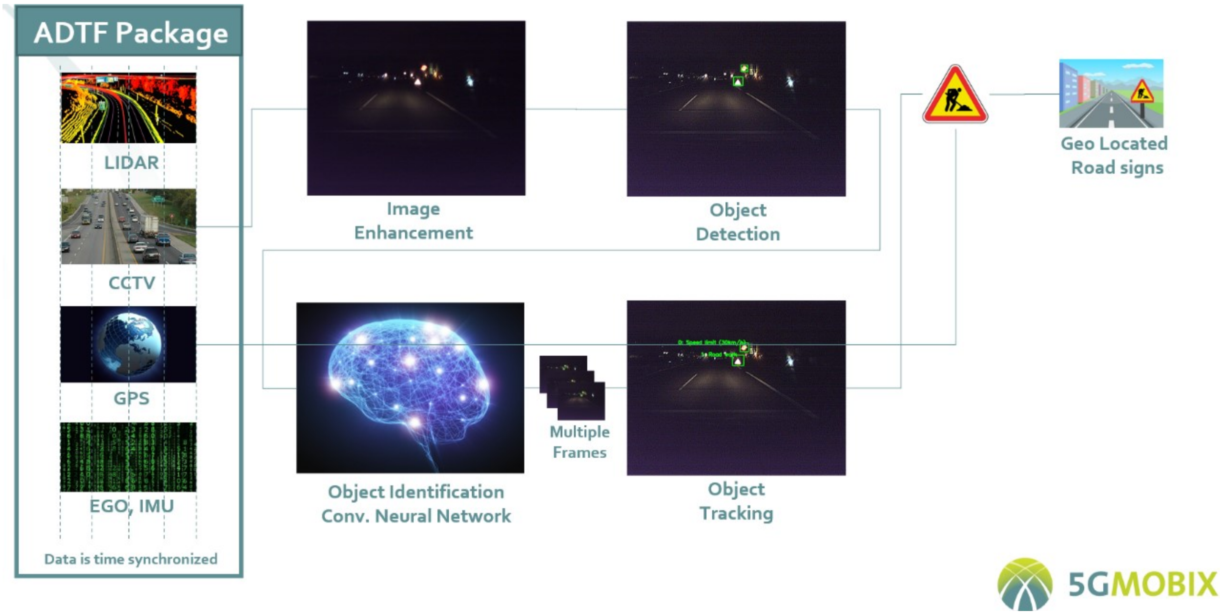

Fig. 5 - The road sign extraction process applied to the video data stream

As for the extraction of the road boundary, the LIDAR stream is used in conjunction with GPS stream, inertial measurement unit data and other information regarding the vehicle-assembly position and orientation of the LIDAR sensor. We produce a 3D occupancy map, following the work of Koide et al. (2019). The 3D occupancy map is basically a 3D point cloud where each point is georeferenced. This is produced from the processing of a series of LIDAR scans along a period of time. The production of the 3D occupancy map will also remove noise and moving objects from the data collected. We then filter the 3D 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 produce the obstruction lines by connecting the points in the occupancy map (see Fig. 6).

Finally, the output of each processing stage is put together in a single JSON file and distributed to connected vehicles as previously described (see Fig. 7 bottom right).

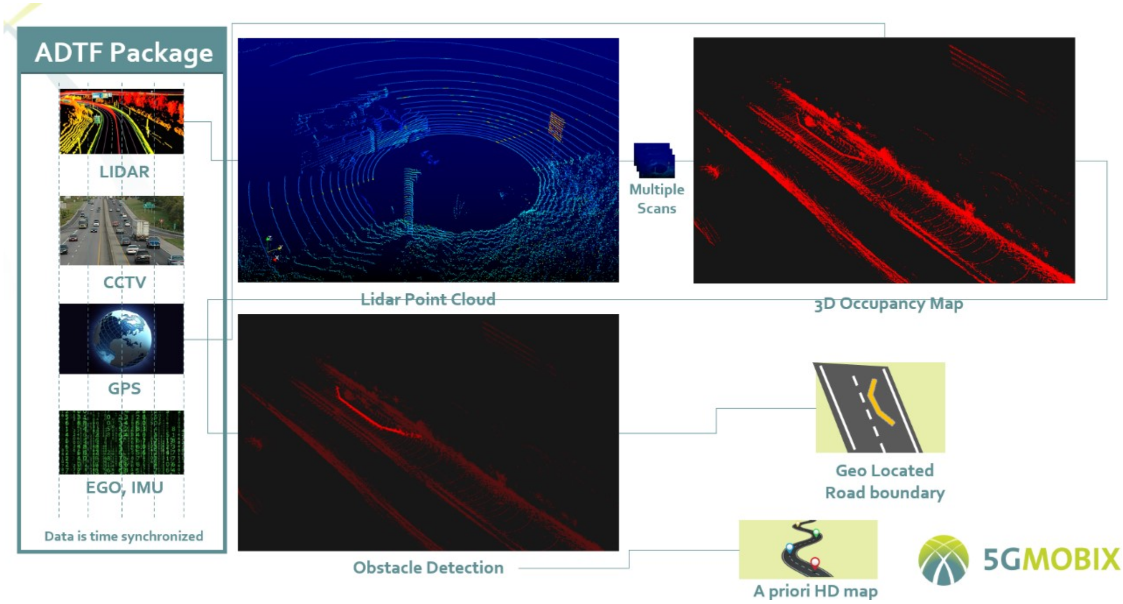

Fig. 6 - The road boundary extraction process

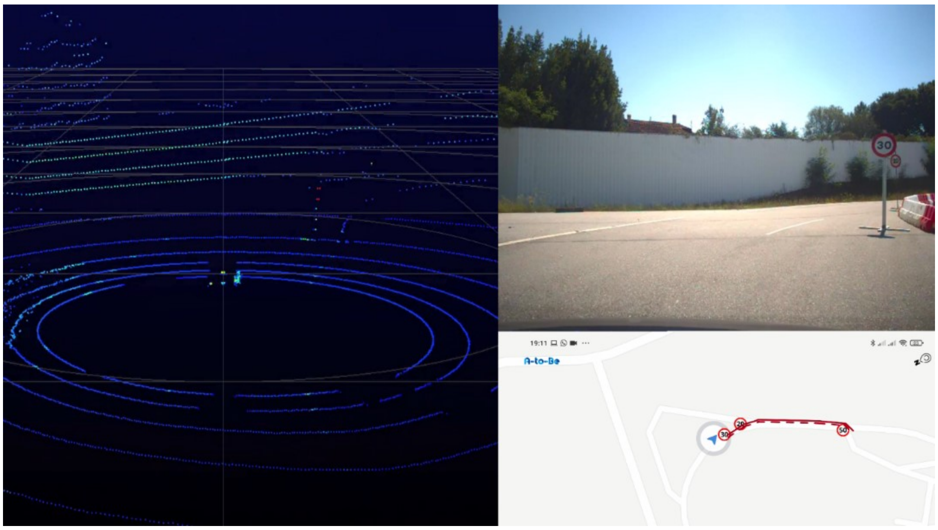

Fig. 7 - Synchronized visualization of LIDAR (left), video (top right) and the resulting HD Map update (bottom right) (sensor data by CTAG).

4. Conclusions and Future Work

This article explored an HD Maps updating scenario centered around a roadworks event and autonomous vehicles in the 5G-MOBIX ES-PT Cross-border corridor. It showed how the scenario was developed and implemented and how a 5G Portuguese connected vehicle added a visualization element that make the HD Map updates also useful for human drivers.

Furthermore, transferring the high volume of sensor data for HD Map processing is an adequate challenge for 5G evaluation, in the context of advanced CCAM applications. The ES-PT HD Map scenario goes one step further in the challenge by achieving this at a cross-border location, adding handover and two different ITS-Centers to the equation.

The keys for success in this scenario are the implementation of an adequate 5G network, testing it with realistic workloads, the adequate packing of sensor data, the HD Map distribution at the edge and, finally, the implementation of a simplified and efficient sensor data processing solution based on proven technologies.

Initial trials started in September 2021 in the A55, on the Spanish side of the border, followed by cross-border trials on the Valença-Tui new bridge in April 2022. It was possible to detect issues with wrong road sign classifications which are now being addressed. Road sign identification and tracking worked correctly and obstruction identification, after some optimization, was also producing promising results. As such, our current focus is on tuning the CNN used for road sign classification and perform systematic testing of the whole solution.

The entire process duration is below 2 minutes only using CPU processing. The upload of sensor data (200-300 Mbyte) has taken up to 30 seconds in initial 5G testing conditions, but it is expected that with enhancements currently underway, to achieve a full upload well under 10 seconds. This will increase pressure to lower the processing time on the cloud. As such we will also consider testing and optimizing our solution for GPU processing.

Future work will be divided between two main tracks: exploring strategies and technology for the road infrastructure to enhance safety and quality of Connected and Autonomous Vehicles and additionally, explore usages for HD Maps technology for road operators, namely on road monitoring and real-time infrastructure quality assessment.

Acknowledgements

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

Laviv, R., Azaria, M., Menon, V., 2021. Which trends are driving the autonomous vehicles industry?, World Economic Forum, 8 Nov 2021, Online at https://www.weforum.org/agenda/2021/11/trends-driving-the-autonomous-vehicles-industry.

Martin, Á., Vélez, G., 2019. D2.1 5G-enabled CCAM use cases specifications, 5G-MOBIX Consortium, Online at https://www.5g-mobix.com/assets/files/5G-MOBIX-D2.1-5G-enabled-CCAM-use-cases-specifications-V2.0.pdf.

KPN, 2020. 5G-MOBIX demo: Remote driving, 5G-MOBIX Consortium. Available online at https://www.5g-mobix.com/resources/videos/5g-mobix-demo-remote-driving.

Dang, X., Sivrikaya, F., Peters, S., 2021, Integrated Service Discovery and Placement in Information-Centric Vehicular Network Slices, 2021 IEEE 93rd Vehicular Technology Conference, VTC2021-Spring.

5G PPP Consortium: Trials and Pilots for connected and automated mobility, brochure. Available online at https://5g-ppp.eu/trials-and-pilots-for-connected-and-automated-mobility.

Kousaridas et al., 2020. 5G Cross-Border Operation for Connected and Automated Mobility: Challenges and Solutions. Future Internet 2020, 20, 5.

Hetzler, D. et al., 2021. 5G connected and automated driving: use cases, technologies and trials in cross-border environments, EURASIP Journal on Wireless Communications and Networking, 2021:97.

Muehleisen et al., 2021. Performance and Service Continuity of HD Map Downloads in MEC-Enabled Cross-Border Mobile Radio Networks, 2021 Joint European Conference on Networks and Communications & 6G Summit 2021 (EuCNC/6G Summit).

Sultanoiu et al., 2121. Advanced 5G Architectures for Future NetApps and Verticals, 2021 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom).

VITAL-5G Project: Vertical Innovations in Transport and Logistics over 5G experimentations facilities, H2020-ICT-2020. 2022 Project Description. Available online at: https://www.vital5g.eu/.

ETSI, 2014, ETSI EN 302 637-3 V1.2.1: Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service, ETSI. Available online at https://www.etsi.org/deliver/etsi_en/302600_302699/30263703/01.02.01_30/en_30263703v010201v.pdf.

Elektrobit Automotive GmbH, 2010, ADTF DAT File Format 2.1.1, EB Assist ADTF.

Karovalia, A., 2021, Traffic Signs Detection using Tensorflow and YOLOv3/ YOLOv4, Medium. Available online at https://bit.ly/3MfKw71.

Koide, K., Miura, J., Menegatti, E., 2019, A Portable 3D LIDAR-based System for Long-term and Wide-area People Behavior Measurement, Advanced Robotic Systems, 2019. Available online at https://bit.ly/3L9IwvK.