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Cloud Based HD Maps Scenario in the 5G-MOBIX Project

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Abstract

This paper focuses on A-to-Be's contributions to the 5G-MOBIX Project. The 5G-MOBIX project aims to provide a proving ground for the application of 5G technology to the most demanding ITS and CAV/CCAM applications that cannot be supported by previous communication technologies. A-to-Be is contributing with sensor data processing and HD Map updates to a trial in the Spanish-Portuguese border. That will test connected and automated vehicles using a cloud produced HD Map. The paper presents the 5G-MOBIX project, the HD Map portion of the trial in the Spanish-Portuguese border, the 5G Portuguese connected vehicle and explores the ongoing sensor data processing development that will produce updates to the HD Map.

Keywords:

HD Maps, Cooperative Connect Automated Mobility (CCAM)

The 5G-MOBIX Project

The 5G-MOBIX project aims to provide 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 and highways but not only there. 5G-MOBIX is developing two 5G-enabled cross-country corridors between the borders of Spain-Portugal and Greece-Turkey and includes national trials in France, Netherlands, Germany, Finland, China and Korea [1]. The national trial sites have developed, tested and demonstrated 5G CCAM solutions like remote driving [2] and Service Discovery [3]. A wider set of 5G CCAM solutions are then trialled together at the cross-border sites, including knowledge, results and even the actual solutions from the trials sites, allowing for comparisons and benchmarking.

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

HD Maps in the ES-PT Cross-Border Trial

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.

Figure 1 – ES-PT cross-border corridor (trial locations – green lines) Credit: 5G-MOBIX [4]

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 (see **Figure 2**) 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 (the case in this 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.

HD Maps

The existing web map services technologies were born from the emergence of GPS technology and the widespread adoption of GPS Navigation devices. The main purpose of the map services behind GPS navigation is to provide routing information from point A to point B and add contextual graphical information to aid the user interpretation of the guidance service. For these services, it is irrelevant the exact lane the driver is travelling on or the detailed topology and road-marks of the roads. It is enough to know how the roads connect and their traffic direction.

However, autonomous vehicles need to maintain the lane, avoid hitting something and change lane when required. For that, a centimetric level localization system is mandatory and current GPS systems and associated map services are not enough. Usually, autonomous vehicles use a map that is built a priori. These a priori maps include a detailed description of road topology, precise vertical signs and road-marks locations or even a detailed point-cloud of the road surroundings. These elements are used to increase the accuracy of their navigation overcoming GPS limitations. For instance, if the GPS position has a 3 to 4-meter precision, if the vehicle determines its' X, Y and Z centimetres (±10cm) away from at least 3 specific road-signs it knows the precise location of, then it can enhance its' 3 to 4-meter precision down to cm level precision.

This is where HD Maps come in. In [5] HD Maps are made up of 5 different layers:

1. Base Map – the equivalent to the current web mapping services maps;
2. Geometric Map – a 3D volumetric map of the real world;
3. Semantic Map – Adds meanings to the 2D and 3D map elements from the 2 previous layers (e.g. this is road M2011, this is a fixed-line road-mark, this is a light pole, etc.), also adds additional data and rules (e.g. the maximum speed for a road stretch);
4. Map Priors – recurring dynamic information (e.g. estimated wait time at a traffic sign, prediction on travel times for a road stretch, sequence of lights for a specific traffic light);
5. Real-time – real-time data exchanged between vehicles, infrastructure and control centres (e.g. detailed location of vehicles, events with a 3D geometric representation of obstructions caused, real-time information on travel times, etc.).

If the first two layers are about gaining precision through detail, it is from layer 3 on that things get more interesting with semantic rules and dynamic information that will help optimize CAV / CCAM.

HD Maps are usually produced from existing conventional map data allied with data extracted and processed from vehicle sensors like cameras, LIDAR, etc. that is captured while vehicles are driving. Thus, HD Maps are typically produced inside each vehicle, or offline, and later uploaded to the autonomous vehicles. In either case, the HD Maps are stored locally but can also be exchanged with other parties. HD Maps can contain large blocks of data, especially for Layer 2, the Geometric Map. Although sensor data processing at the vehicle level is the typical approach, HD Maps can also be produced in the cloud, with more diverse sensor data and other kinds of data sources and an unlimited evolving computing power, unavailable inside each vehicle. The cloud approach is what will be used for the HD Maps solution in the ES-PT Cross-Border trial.

Technical Solution for HD Maps in the ES-PT Cross-Border Trial

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-S where it is translated. This message is then encoded using the DENM [6] standard 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). After passing the event the vehicle synchronizes and packs the distinct sensor data streams using the ADTF format [7] and uploads it, using 5G, to the ITS Centre where it will be processed (Step 3 – Processing).

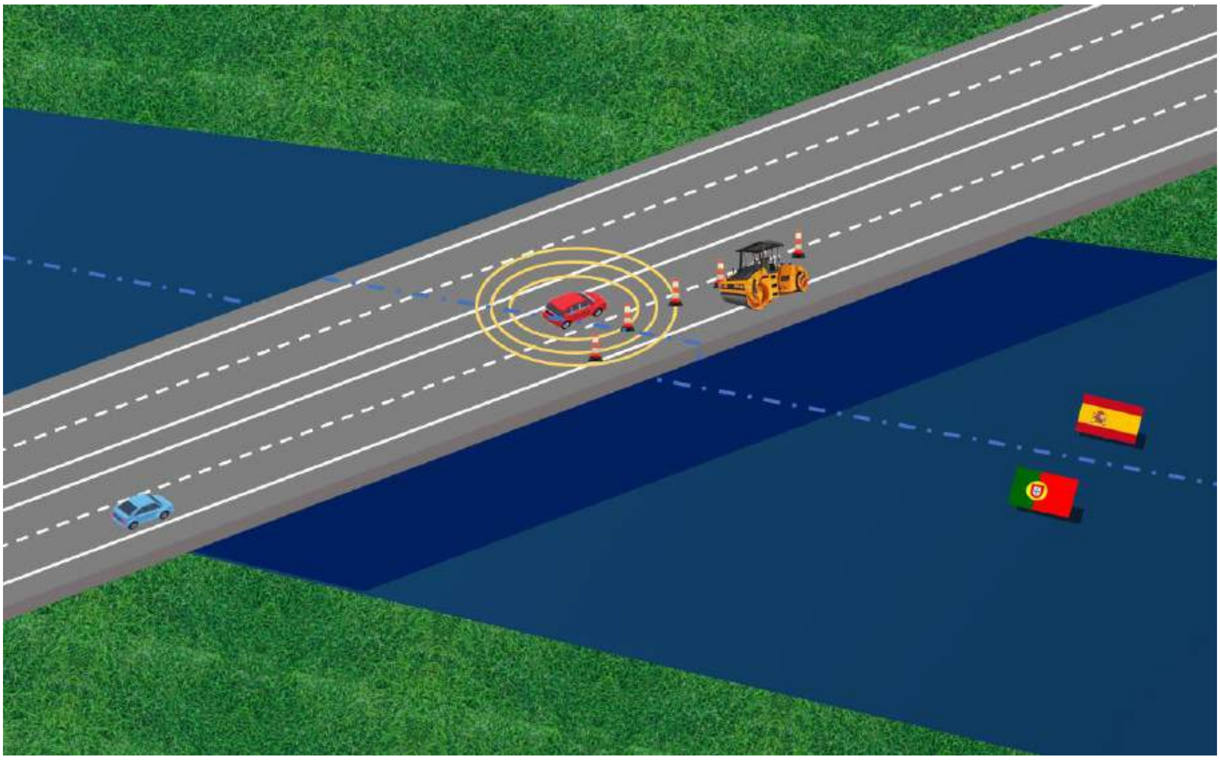

Figure 2- Representation of the HD Maps scenario in the ES-PT border during sensor data collection (during Step 2)

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 in an effective time due to the longer time to transfer sensor data 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).

The 5G Connected Vehicle

Although this scenario was developed around the needs of autonomous vehicles, we considered that the resulting HD Map updates had 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 and other 5G-MOBIX scenarios (lane merge and overtaking), 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.

Visualization of HD Map updates

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. 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.

Figure 3- A-to-Be V2X App displaying an HD Map update for an obstacle on a track

Sensor Data Processing and HD Map Updates Production

Sensor Data Processing consists of two main steps: first, the received sensor data (ADTF package) is unpacked and the information contained 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.

HD Map production step by step

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 of 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 data streams, one for each sensor, by identifying the stream each chunk belongs to and mixing chunks from all streams together in the data section. A specific file extension is then used to index each distinct data stream in the file, providing information like the stream name, data size and associating it with the stream identifier that is used for each chunk of data.

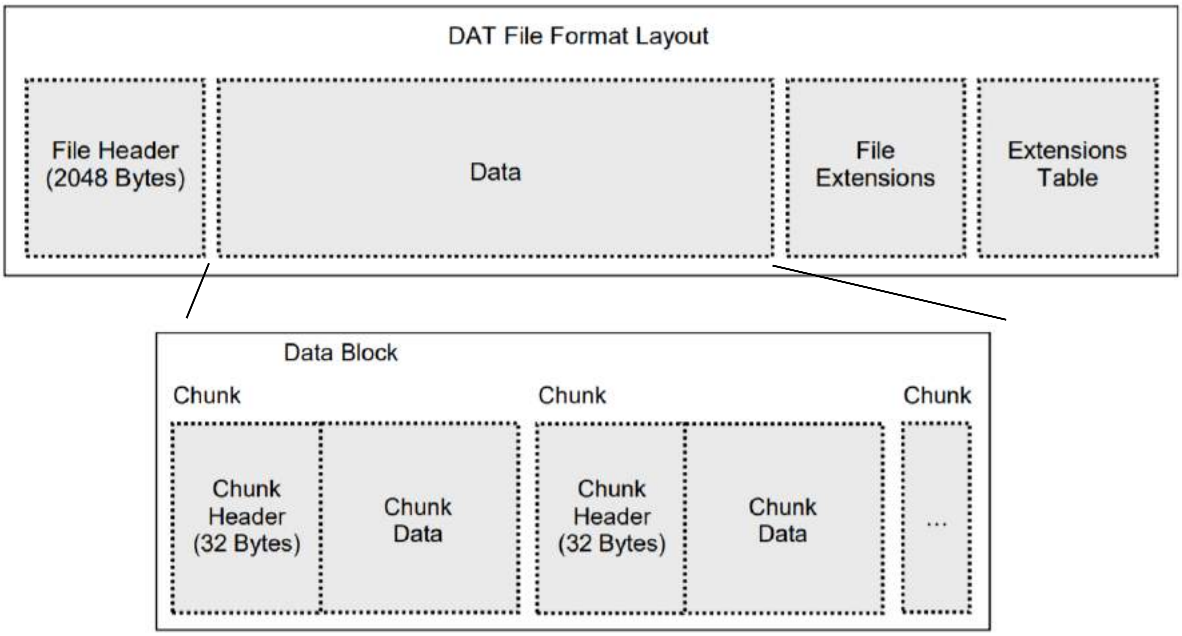

Figure 4- Layout of the ADTF DAT file format (Adapted from [7])

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 below in **Figure 5** along with a visualization of the produced HD Map update (which actually is only produced later on).

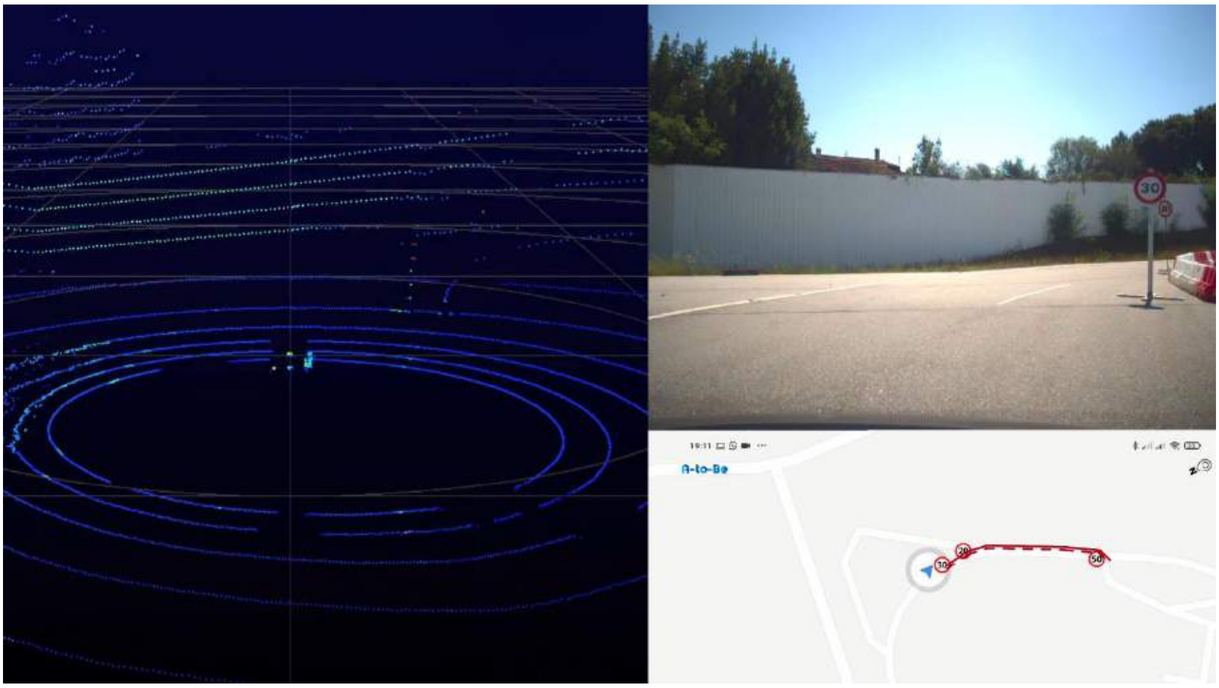

Figure 5- Synchronized visualization of LIDAR (left) and video (top right) with the resulting HD Map update visualization (bottom right) (Sensor data provided by CTAG)

Processing sensor data can be a very complex task which requires several combinations of different approaches from the fields of AI, image processing and others. But the focus of the 5G-MOBIX project 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.

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 [8]. As a result, we will get a list of signs detected, associated probability and coordinates for a rectangle bounding each sign. From here 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 along with data from 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, inertial measurement unit and information regarding the assembled position and orientation of the LIDAR sensor. We will produce a 2D occupancy map [9] at a specific band (out of the 16 vertical bands collected by the VPL-16 LIDAR sensor) relative to a specific observation height. The production of the 2D occupancy map 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 as already described.

Conclusions

This article explored an HD Maps updating scenario centred around a roadworks event and autonomous vehicles in the 5G-MOBIX ES-PT Cross-border corridor. It showed how the scenario will be developed and implemented and how a 5G Portuguese connected vehicle will add a visualization element that will 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-Centres 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.

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