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Cloud Based HD Maps in the 5G-MOBIX Project

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Abstract

This paper is centred around A-to-Be's contribution to the 5G-MOBIX Project. The 5G-MOBIX project aims to provide strong 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 production to a trial in the Spanish-Portuguese border that will test CAV/CCAM vehicles using a cloud produced and updated HD Map. The paper presents the 5G-MOBIX project, the HD Map portion of the trial in the Spanish-Portuguese border and explores the approach of centrally producing and updating the HD Maps as opposed to the more frequent approach of producing and updating them nearer to the Roadside.

Keywords:

HD Maps, Connected Automated Vehicles, Cooperative Connect Automated Mobility

The 5G-MOBIX Project

The 5G-MOBIX project aims to provide strong 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 way, 5G-MOBIX will validate if 5G technology can be the enabler of more advanced levels of vehicle autonomation, namely SAE Level 4 and above. This will be done in real European roads and highways but not only there. 5G-MOBIX will develop two 5G-enabled cross-country corridors between the borders of Spain-Portugal and Greece-Turkey. 5G-MOBIX also includes trials in China and Korea.

5G-MOBIX will first analyse the general telecom, application, security, data privacy and regulatory issues present at the cross-border corridors. From there, 5G-MOBIX will implement a set of CCAM use cases that require the advanced connectivity provided by 5G.

5G-MOBIX also aims to produce sustainable business models for the deployments, namely for the cross-border corridors. 5G-MOBIX will identify new business opportunities for the 5G enabled CCAM and propose recommendations and options for its deployment [2].

Through its findings on technical requirements and operational conditions 5G-MOBIX is also expected to actively contribute to standardisation and spectrum allocation activities.

HD Maps

To understand the importance of High Definition Maps (HD Maps) and their usage in CAV / CCAM it is first necessary to understand what they are, and why current web map services are not adequate for CAV / CCAM.

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 not relevant the exact lane you're traveling on or the detailed topology and road-marks of the roads. It's enough to know how the roads connect and if they allow traffic in both directions or only one direction.

However, autonomous vehicles need to maintain on the same lane, avoid hitting something and just change lane when required. For that a centimetric level localization system is mandatory and current GPS systems are not enough. Usually autonomous vehicles use a map that's built *à priori*. These *à 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 own 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 it's 3 to 4-meter precision down to cm level precision.

This is where HD Maps come in. In [1] 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 an accident with a 3D geometric representation of the obstruction caused, real-time information on travel times, etc.).

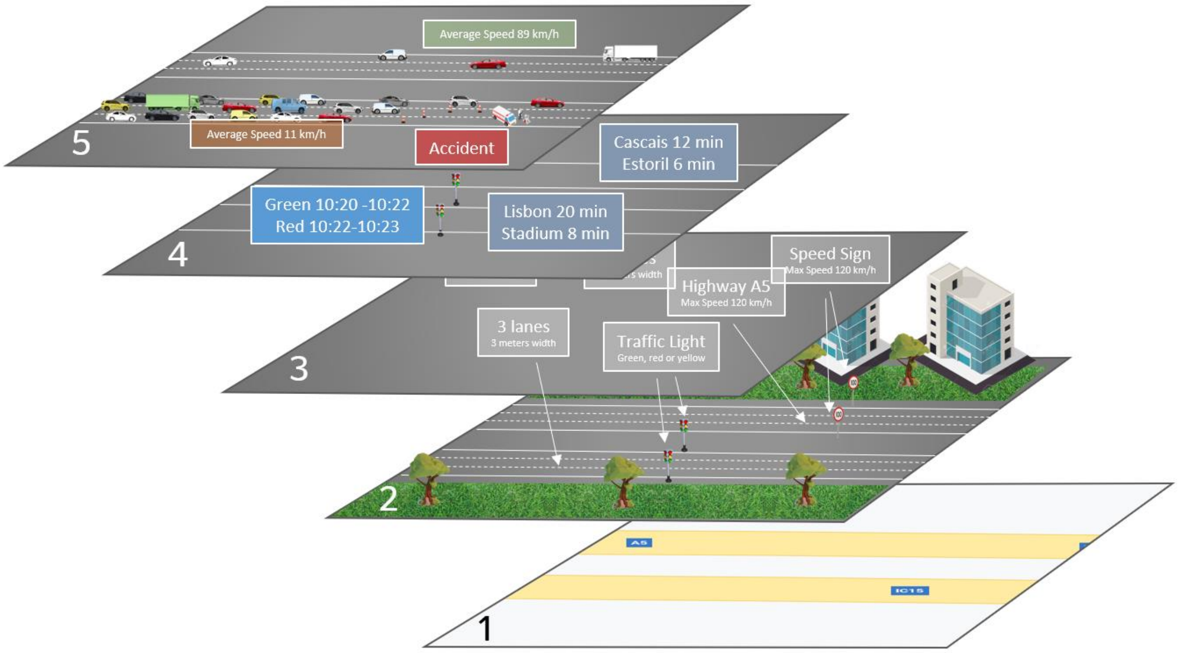

Figure 1- The 5 HD Map layers used in [1]

If the first two layers are about gaining precision through detail, it's from layer 3 on that things get more interesting with semantic rules and dynamic information that will help optimize CAV / CCAM. Therefore, HD Maps can power use cases like:

- Automated driving by hazard locations: while today CAV need to engage manual driving to pass unmapped hazard locations, a CAV vehicle using an HD Map can continue autonomous driving through an accident location thanks to detailed obstruction geometry information collected by other vehicles – this is the use case explored further in this paper;
- Ability to infer information not always visible on the road – e.g. to my right is a bike lane I need to cross to turn right, I can turn right here but I can't turn left;
- Help the CAV vehicles identify objects: CAV vehicles will be able to infer that a moving object is in fact a pedestrian crossing a cross-walk by using HD Map information on the road geometry and elements like cross walks;
- Parking in a vacant parking spot using parking availability information collected by several vehicles passing by the parking spots while driving;
- Creating and maintaining a road infrastructure database with road-marks, road-signs, light poles, trees and all other elements that make up the road infrastructure;
- Automatically reporting and classifying hazards like pot holes, fallen trees, etc.

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. To avoid exchanging the HD Map fully each time it changes, HD Map protocols have been adopting strategies to implement HD Map streaming technologies where, after a first load of the full HD Map, incremental data can be exchanged and updates the HD Map in the different parties receiving it.

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 is explored in this article.

Finally, to understand that this is only the beginning with HD Maps, it’s easy to think of ways they can help us even further, for instance, HD Maps could incorporate driving rules for each country / region allowing CAV / CCAM vehicles to cross borders and adopt the rules of the country they are entering automatically.

HD Maps in the ES-PT Cross-Border Trial

The ES-PT corridor is mostly centred around the north border of Portugal with Spain, near the cities of Valença and Tui. This corridor connects the cities of Vigo and Porto, 250 Km apart, and is comprised of roads and highways in Spain and Portugal.

Figure 2 – ES-PT cross-border corridor (trial locations in green) Credit: 5G-MOBIX [3]

The HD Maps scenario in the ES-PT cross-border trial is focused on the dissemination of 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 vehicle doesn’t have detailed information on the obstacle geometry and how it obstructs the road. In many cases it’s not even known where the obstacle starts and ends.

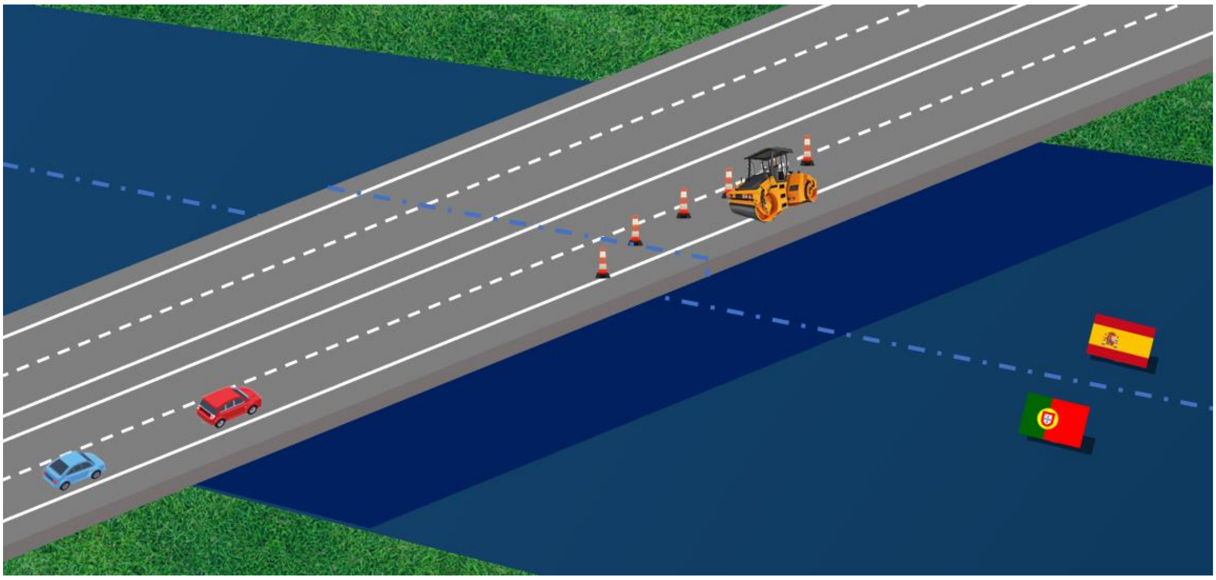

Figure 3 – Representation of the HD Maps scenario in the ES-PT border – initial conditions

This is where our HD Map solution comes into play. The first vehicle to cross the obstruction sends the sensor data to our servers and an HD Map is extracted. With an updated map delivered to the autonomous vehicle on time, autonomous vehicles may remain autonomous while driving through temporary obstacles such as road-works (the case in this scenario), accidents and other hazards, minimizing human intervention. This is because the detailed 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 and maintain or even increase safety.

This scenario focuses on the capability of the cloud infrastructure to detect changes in the road, like obstructions, and update the HD-Map used for driving. This is achieved by having vehicles send the road data, obtained from sensors, at the hazard location, to the cloud to be processed. In the cloud processing component, sensor data like Lidar, camera and GPS information is fused and processed in order 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. It was considered to be an ITS-Centre functionality as it typically monitors and actuates to solve hazards on the road but also has information dissemination functionalities (Variable Message Signs, Web and User Apps, TMC, Datex II to other operators, etc.).

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

A-to-Be has a range of products for Mobility and Traffic Management, supporting a wide range of complex Tolling Operations and large Traffic Control Centres in Europe and the US. This positioning placed A-to-Be as a perfect partner to implement the centralized component of 5G-MOBIX that is responsible for processing the stream of sensor data coming from CAV/CCAM vehicles on the Portuguese side, updating an HD Map and distributing it to connected vehicles. This way future versions of A-to-Be’s Atlas Traffic Management System may be able to become more independent from operators and be used to directly help and support automated vehicles.

The scenario starts with a dissemination from the ITS-Centre of information about a road-work. The information is disseminated to several vehicles driving towards the road-work situation (Step 1 - Alert). The alert consists of an ITS message notifying the basic information about the event (type of event, start location of the event, end location of the event). This message will be encoded using the DENM [4] standard but its’ content will be transmitted over 5G instead of ITS-G5, like it was originally designed for.

With this information, the leading autonomous vehicle checks if the notified event is already registered in its internal HD map. In case it is not registered, the vehicle assumes the map is outdated, so it asks the driver to take control so the driver can deal with the road works situation on his own. While passing the obstruction, the leading autonomous vehicle collects sensor data for the duration of the event. It keeps the sensor data locally.

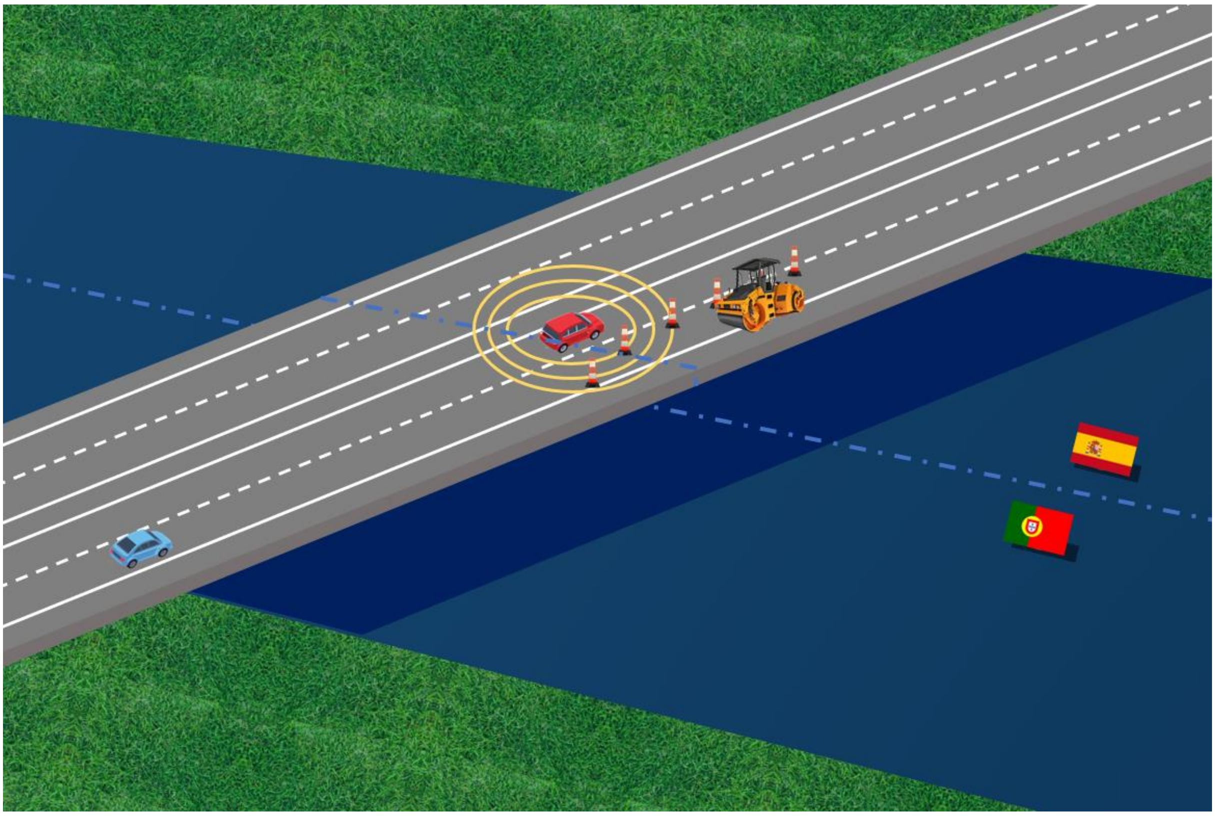

Figure 4- Representation of the HD Maps scenario in the ES-PT border before Step 2

Once the vehicle determines the event / obstruction has passed, a sensor data package with all the collected data is sent to the ITS Centre (Step 2 – Sensor Data) where it is processed (Step 3 – Processing).

The sensor data needs to flow from vehicles to the ITS Centres where the data is processed and eventually updates the HD Map. Sensor data will include data from the following sensors: GPS; Lidar and Camera, it’s time-synchronized and packaged using the ADTF format.

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 won't be able to cope with this scenario in effective time due to the longer time to transfer sensor data to the cloud.

It's also important to note that only the local ITS-Centre receives the Sensor Data, so it is processed only by a single ITS-Centre.

The processing phase consists of the following steps: first, the sensor data package previously received in the ITS-Centre is unpacked in order to fuse and process the contained sensor data. Then, the fused data is analysed and processed. The results from this step are the relevant features of the road like road-signs but also the geometry of temporary obstructions. Afterwards, these features are used for updating the HD map contents.

Once the HD map is updated in one of the ITS-Centres, it is distributed to the other ITS-Centre and to other vehicles, namely those that drive towards the road work (Step 4 – HD Map provision).

Vehicles driving towards the road-works will receive the updated HD map and will integrate it internally. 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).

Centralized vs. Distributed Approaches for HD Maps

The first HD Maps were most likely born inside autonomous vehicles as they collected and processed sensor data to interpret their vicinity. Autonomous Vehicles need this processing to plan their interaction with the real-world. But these views are limited to the vehicle's vicinity and to eventual mistakes the processing algorithms can make. It might also not be possible to store all HD Map data for all the locations travelled by a specific vehicle locally.

This way, exchanging HD Map data between vehicles was a natural evolution, namely with Local Dynamic Maps [5]. Vehicles can get information from other vehicles traveling ahead and execute a less reactive but a more strategic planning. Nevertheless, fusing HD Map data from all the different vehicles might not be an easy endeavour for a single vehicle. Meanwhile, each vehicle would be fusing very similar information, repeating many equivalent parts of the fusing process across a wide set of different vehicles.

A natural optimization is to have intelligent nodes, namely roadside equipment, near the vehicles, process the different HD Map data and fuse it into a single unified local view that can be shared among the different vehicles traveling near the nodes. This is clearly an optimization of resources, leaving the vehicle resources free for other computer intensive tasks other than fusing sets of different HD Maps.

It's important to notice how up to this point sensor data is always processed locally by each vehicle and the HD Map is produced by the vehicle.

The centralized HD Maps approach takes it not one but two steps further, instead of using local intelligent nodes it uses the cloud, but also it doesn't receive HD Map from vehicles, but receives the actual sensor data. Centralized HD Maps thus require a very large data exchange from the vehicle to the cloud. An optimization is to only send this data when something is not according to the “normal” situation, for example, when there is a hazard on the road. But still the amount of data can be very high especially for a large network with hundreds of hazards taking place at once. But, in return for the higher data transfers from vehicles, a centralized HD Map will provide the following benefits:

- Complete elasticity of the computing power used to process sensor data. The computing power available is not limited by the vehicle’s capabilities;
- This allows for different processing algorithms and strategies to co-exist, enabling much quicker benchmarking so essential for trialling stages;
- Accuracy can be greatly enhanced by fusing data from different sources and taking it into account in the processing stages;
- HD Maps can be built from vehicle sensor data but also from a myriad of other sources like road cameras and radars, providing a much more complete picture;
- Sensor data can easily be processed for other ends like infrastructure inventory or damage assessment. New processing functions can more easily be added as necessary.

Conclusions

Transferring the high volume of sensor data for HD Map processing is clearly a challenge adequate 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. But, given a sound architecture for the scenario, adequate processing algorithms and if the 5G network is able to respond to the high demand, the challenge will most likely by successfully overcome.

Currently, the major technical challenges to be tackled or at least considered in this scenario are:

- **Distribution** – how can the DENM alert and HD Map updates be distributed to the appropriate vehicles using the 5G network?
- **Performance** – is the process (collection, delivery and processing of sensor data and updated HD Map distribution) fast enough to let the HD Map arrive to the vehicles behind the leading vehicle before they pass the obstruction?
- **Network capabilities** – will the 5G network be able to transmit the large packages of sensor data in a short time period?
- **Handover between ITS Centres** – will the approach of exchanging updated HD Maps between ITS Centres work even if there are concurrent updates on both sides?
- **Dynamics of the obstruction** – Obstructions like road works and accidents can be highly dynamic, in an accident the vehicles involved can start by occupying central and left lanes and after a while can be waiting for a tow in the shoulder of the road. It is important to study the risks for the first autonomous vehicle that is using outdated HD Map information and how it can detect and address such situations.

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