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CCAM Infrastructure Support for 5G Advanced Driving Scenarios

João Almeida[1], Joaquim Ferreira[1,2], João Moutinho[3], Daniel Jáuregui[4], Estrela Álvarez[4], Marcel van Sambeek[5]

1. Instituto de Telecomunicações, Campus Universitário de Santiago 3810-190 Aveiro, Portugal, {jmpa, jjcf}@ua.pt
2. Escola Superior de Tecnologia e Gestão de Águeda - Universidade de Aveiro, Apartado 473, 3754 – 909 Águeda, Portugal
3. Centro de Computação Gráfica, Guimarães, Portugal, joao.moutinho@ccg.pt
4. Centro Tecnológico de Automoción de Galicia, Porriño, Spain, {daniel.jauregui, estrela.alvarez}@ctag.com
5. TNO, The Hague, The Netherlands, marcel.vansambeek@tno.nl

Abstract

This paper presents a Connected, Cooperative and Automated Mobility (CCAM) architecture to support the operation of advanced driving services based on 5G cellular networks. The proposed architecture will be deployed in the scope of 5G-MOBIX project, specifically in the border between Portugal and Spain. This work focusses on the role played by the roadside infrastructure to help assisting complex manoeuvres performed by autonomous vehicles, e.g. lane merging and automated overtaking. For that purpose, roadside sensors such as traffic radars are employed, in order to detect legacy non-connected vehicles or other (vulnerable) road users (like pedestrians or cyclists) and transmit this information to the 5G connected and autonomous cars, thus extending the field of view derived from their own sensors. By testing the proposed framework in cross-border settings, it will be possible to evaluate the potential of 5G technology to provide ultra-reliable low-latency communications in handover and roaming scenarios.

Keywords: Intelligent Transportation Systems, Advanced Driving, 5G-V2X

Introduction

CCAM applications pose challenging requirements on communication technologies in terms of latency and dependability to the communications network. The low end-to-end delay required to exchange information via mobile networks among vehicles and between vehicles and the roadside infrastructure can only be achieved through the use of new network functionalities, such as 5G New Radio (NR) with Ultra Reliable Low Latency Communication (URLLC), Multi-access Edge Computing (MEC) and network slicing. These features will be provided by the 5G-V2X technology, enabling the operation of real-time services in autonomous driving scenarios. C-V2X technologies to interlink connected vehicles, roadside infrastructure and vulnerable road users, started with LTE-V2X in 3GPP Release 14 with a focus on low-latency communications via direct short-range mode for vehicle-to-vehicle (V2V, via the “sidelink” or “PC5-interface”) and network-based communications (V2N, via the link to the 4G or 5G base station or Uu-interface). 3GPP Release 15 and later introduce the 5G-NR interface to be used for V2V and V2N communications, increasing the data rate and enabling URLLC.

The H2020 5G-MOBIX project [1] aims to evaluate the suitability of this new set of features to support the operation of CCAM use cases, by deploying a 5G connectivity infrastructure in cross-border conditions. The real-world 5G network roll-out will enable roaming among European countries, providing a testbed for the evaluation of inter-Public Land Mobile Network (inter-PLMN) and MEC interconnection solutions. Furthermore, additional roadside infrastructure will be installed in order to include the operation of legacy vehicles and other non-connected road users in the system, by detecting them and sharing their state and position to the 5G network. This will provide the basis for the future deployment roadmap of European transnational corridors, qualifying 5G mobility services that have already been successfully tested in urban and highway conditions, but usually taking place in controlled environments and without roaming and inter-PLMN capabilities.

This paper provides an overview of the CCAM architecture for the Spain-Portugal (ES-PT) trial site of 5G-MOBIX project, focusing on the advanced driving scenarios, namely lane merging and automated overtaking. After this introductory section, a description on C-ITS services and message sets related to these use cases is provided. Then a CCAM scenario description of the ES-PT trial site is presented, as well as the deployment architecture for these complex manoeuvres in cross-border settings. Finally, some details about the roadside infrastructure installation are provided, together with the conclusions and future work.

C-ITS Services and Message Sets

The ETSI ITS task group on Cooperative Intelligent Transportation Systems (C-ITS) has defined a set of messages and protocols to exchange information among nodes of a vehicular network. Despite being originally designed for the ETSI ITS-G5 Dedicated Short Range Communications (DSRC) technology, based on the IEEE 802.11p medium access control and physical layers, many protocols and messages specifications from this C-ITS stack remain valid and useful for the operation in the C-V2X context. For instance, the periodic Cooperative Awareness Messages (CAMs) transmitted every 100 ms to 1 s with information regarding the vehicle’s status and attributes, as well as the event-driven Decentralized Environmental Notification Messages (DENMs) that are generated in case of an accident or another hazardous road event, can be easily integrated in the 5G-V2X framework, allowing the operation of the C-ITS use cases initially devised.

The initial C-ITS services for CCAM, as specified by ETSI ITS and C2C-CC, had their focus on road safety via ‘awareness driving’ by the exchange of these CAM and DENM messages for cooperative awareness. Currently, there are more C-ITS services being standardized at ETSI ITS with the main goal to enhance CCAM from ‘awareness driving’ to real ‘cooperative driving’ by adding i) the exchange of sensor information from other vehicles or roadside systems on detected non-equipped vehicles or (vulnerable) road users (extended sensors) via the Collective Perception Service (CPS) and ii) informing on intentions of manoeuvres and the coordination of these manoeuvres between vehicles via the Manoeuvre Coordination Service (MCS).

The MCS is intended to reduce prediction errors by exchanging detailed information between vehicles about intended manoeuvres. Furthermore, the MCS provides possibilities to coordinate a joint manoeuvre if several vehicles intent to use the same space at the same time e.g. during lane change/merge or left/right turn on intersections. Within ETSI ITS work has started to specify the MCS which defines an interaction protocol and the corresponding Manoeuvre Coordination Messages (MCMs) [2,3]. The MSC is intended to support automated vehicles as well as manual driven vehicles. The MCS is at early stage of standardization. 5G-MOBIX partners (e.g. VEDECOM through PACV2X project) are actively contributing to the standardization process by presenting the proposals for the MCS. Pre-standardized versions of MCS will be used in 5G-MOBIX.

The aim of extended sensors is to share additional information about the current driving environment with another ITS stations. For this purpose, the Collective Perception Service (CPS) as defined in ETSI specifications [4,5] provides data about ‘detected objects’ (i.e. other road participants, obstacles and alike) in abstract descriptions. This includes the definition of the syntax and semantics of the CPS and detailed specification of the data, the messages and the message handling to increase the awareness of the environment in a cooperative manner. Also roadside detection systems based on radar or video detection technology can be used to share information on detected road users via CPS or create warnings for potential dangerous situations.

The need for Collective Perception Messages (CPMs) results from the fact that during an initial penetration phase, only a few number of vehicles will be equipped with on-board communications devices, hindering the deployment of C-ITS services, especially the ones focused on collaborative manoeuvres. With this problem in mind, Vlastaras *et al.* [6] proposed the implementation of a roadside unit (RSU) that scans for vehicles with the aid of a universal medium-range radar (UMRR) and emulates the CAM that they would transmit if equipped with their own communications unit. This additional information about non-connected vehicles, other road participants or even obstacles can be also transmitted by Connected Autonomous Vehicles (CAVs) or Connected Vehicles (CVs) based on data from on-board sensors, thereby increasing the perception range of connected users [7].

Typically, the CPMs have a higher transmission latency than CAMs and may also consume more bandwidth. In order to mitigate this issue, CPM generation rules are being investigated and are currently under standardization. Some proposals include optimizing efficiency by avoiding redundant detection and transmission of the same data objects [8]. These optimizations can be based on factors such as novelty, distance, speed or age of the detected road objects [9]. The additional information collected by the roadside infrastructure can broaden even more the perception boundaries of connected vehicles through the use of high-speed backhauling networks and MEC solutions [10]. Nevertheless, there are some drawbacks on the utilization of indirect data about the perceived environment, namely with respect to the quality of received information and the trustworthiness of entities involved in the Collective Perception Service (CPS) [11].

CCAM Scenario and Use Cases Description

In the scope of 5G-MOBIX project, several European and Asian sites will host trial tests for the evaluation of 5G technology as an enabler of CCAM use cases. Besides the six trial sites located inland in France, Germany, The Netherlands, Finland, China and South Korea, there will be two cross-border corridors. The Spain-Portugal (ES-PT) corridor connecting Vigo and Porto (with a distance of approximately 150 km), and the Greece-Turkey (GR-TR) corridor located in the South-Eastern borders of Europe are the two cross-border corridors of 5G-MOBIX. The ES-PT cross-border corridor is at the border of the north of Portugal with Spain. This border is established by the Minho/Miño river, disposing of several bridges to connect both countries. Both trucks, cars, bicycles and pedestrians make use of the road infrastructure at this border for international trade as well as passenger commuting.

Figure 1 depicts the ES-PT cross-border corridor and the three different user stories that will be deployed in this trial site: complex manoeuvres in cross-border settings (Advanced Driving UC category), automated shuttle remote driving across borders (Remote Driving UC category) and public transport with HD media services and video surveillance (Vehicle Quality of Service Support UC category) [12].

This paper focusses on the Advanced Driving UCs, i.e. the complex manoeuvres in cross-border settings, involving two different scenarios: lane merging and automated overtaking. The connectivity and road sensing technologies will provide an extra perception layer to automated vehicles, in order to guarantee the safety and provide a more comfortable solution to the driver. As a result, this user story consists of two different scenarios where connectivity will support complex manoeuvres in cross-border settings (Figure 2):

Figure 1 – Spain-Portugal cross-border corridor of 5G-MOBIX project.

- Lane merge for automated vehicles: this UC manages the situation where automated vehicles are in a lane merge scenario, analysing the traffic flow of the target lane. In this way, the system is able to detect existing vehicles including their lane position, acceleration, speed, size, etc. providing an extended perception layer which is taken into account by the automated vehicle to determine the best merge manoeuvre according to the current situation. Vehicles in the lane to be merged are connected vehicles that share their vehicle data with the use of a communication unit with 5G capabilities and through a MEC node. Road sensing technologies, such as traffic radars, are also used to detect the presence of vehicles in the target lane and to transmit their position and speed to the automated vehicle. The automated vehicle uses the communication unit as well in order to receive the information sent by surrounded vehicles and the road-side infrastructure, to derive the presence of other road users and the best way to adapt speed for a safe and comfortable lane merge.
- Automated Overtaking: when an automated vehicle needs to overtake a vehicle that precedes it, additional information provided by communication technologies will drastically improve and complement the information provided by its sensor constellation. There are many situations where the dimensions of other vehicles can cover the field of view of the autonomous vehicle sensors (for example, a truck can reduce the vision of a camera, a laser or a radar sensor).

Moreover, according to the route followed by the vehicle, it can happen that a highway exit or a toll station is near to the point where the overtaking takes place, and a queue of vehicles can complicate the scenario reducing free space and therefore producing a less appropriate manoeuvre. Other complex scenario can appear when there are vehicles behind the automated vehicles that occludes the vision of rear sensors. Considering that we are driving on a two-lane road with a right-hand traffic regulation, this occlusion can result in situations where the automated vehicle is not able to perceive a vehicle driving fast in the left lane. The purpose of this use case is to extend the 360º perception layer of the automated vehicle by integrating communication capabilities in the different vehicles of the scenario and additional road sensors (e.g. traffic radars) in the infrastructure. In this way, vehicles will be able to share their positions, speeds, sizes, etc., as well as the road-side infrastructure, helping automated vehicle to understand current situation and thus take the best decision of how to proceed with the automated overtaking.

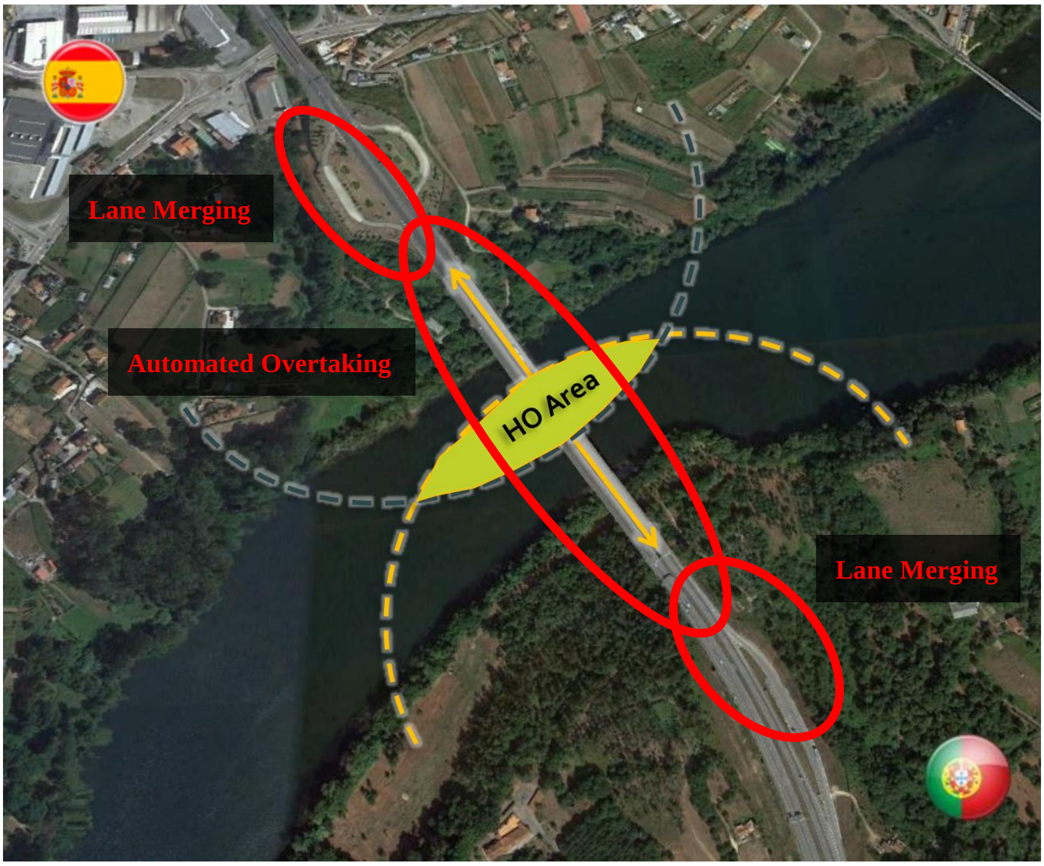

Figure 2 – Complex manoeuvres in cross-border settings (ES-PT trial site).

Deployment Architecture for Advanced Driving Scenarios

Description

This user story (US) consists of lane merging and overtaking scenarios, in which the CCAM architecture helps supporting automated manoeuvres [13]. As a result, the role of the roadside and cloud infrastructure in this case is to assist the 5G CAVs and CVs in their environmental perception, planning and decision making, see Figure 3.

To achieve these goals, the road infrastructure is equipped with sensors that provide additional information to the autonomous and other 5G-enabled vehicles. The CCAM infrastructure can independently detect vehicles and their attributes (position, speed, heading, …) and forward this information in real-time (via MEC node) to all relevant vehicles in the neighbouring area.

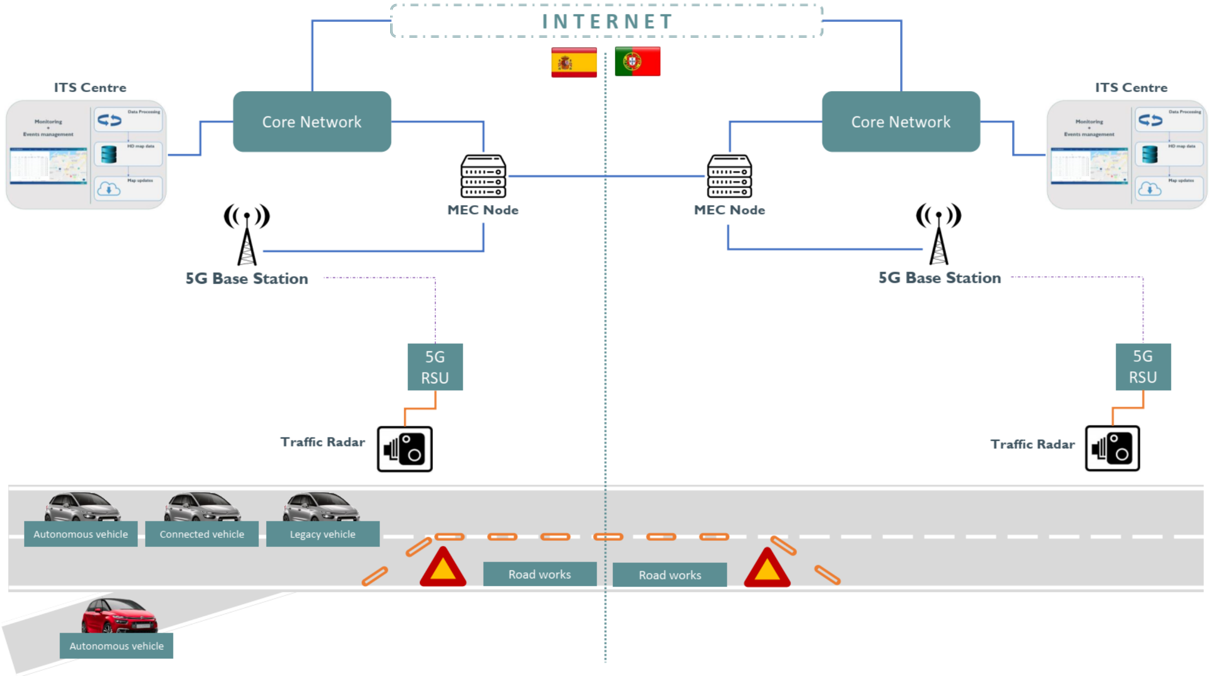

Figure 3 – CCAM infrastructure to support US complex manoeuvres in cross-border settings.

The roadside sensors will capture a big amount of data. This data must be compiled and managed by a 5G roadside unit (RSU), to be capable of delivering a detailed image of the surroundings and hence the requirements for the CCAM operation. The goal behind these sensors is thus to detect, localize, and classify road objects such as vehicles or environment related aspects. The collected information can be transmitted to the vehicles in the area via a MEC node.

This additional source of data can be used for three different purposes:

- Cross-validate the information received directly from the vehicles in the vicinity, to independently check the veracity of the data transmitted by the other cars;
- Extend the vision of 5G CAVs and CVs, by detecting legacy vehicles or road events outside the range of vehicles' sensors, thus increasing the field of view of automated cars;
- Collect auxiliary data related to the pilot execution, so the evaluation is enriched with additional information that will increase the quality of the conclusions derived.

High-level Architecture of the Roadside & Cloud Infrastructure

The high-level architecture of the CCAM infrastructure for this US is shown in Figure 4. The functional elements in the physical layers are shown in blue, the network / communication elements are shown in green, the information exchange is shown in brown. The architecture does not cover the cross-order aspects. It should be also noticed that for all the three complex scenarios, the "Edge CCAM info collection & distribution" element, i.e. the MEC node, is only responsible for forwarding all the shared/exchanged messages between vehicles, the roadside infrastructure and the ITS-Centre, acting as a relay node or a broker among the different CCAM building blocks.

The ITS-Centres are cloud applications running on each side of the corridor. Each ITS-Centre is connected to the MEC node of the same country and consumes the data passing through this node in order to monitor vehicles connected to the regional network. Furthermore, both ITS-Centres share data from vehicles of both sides, when they are in cross-border areas.

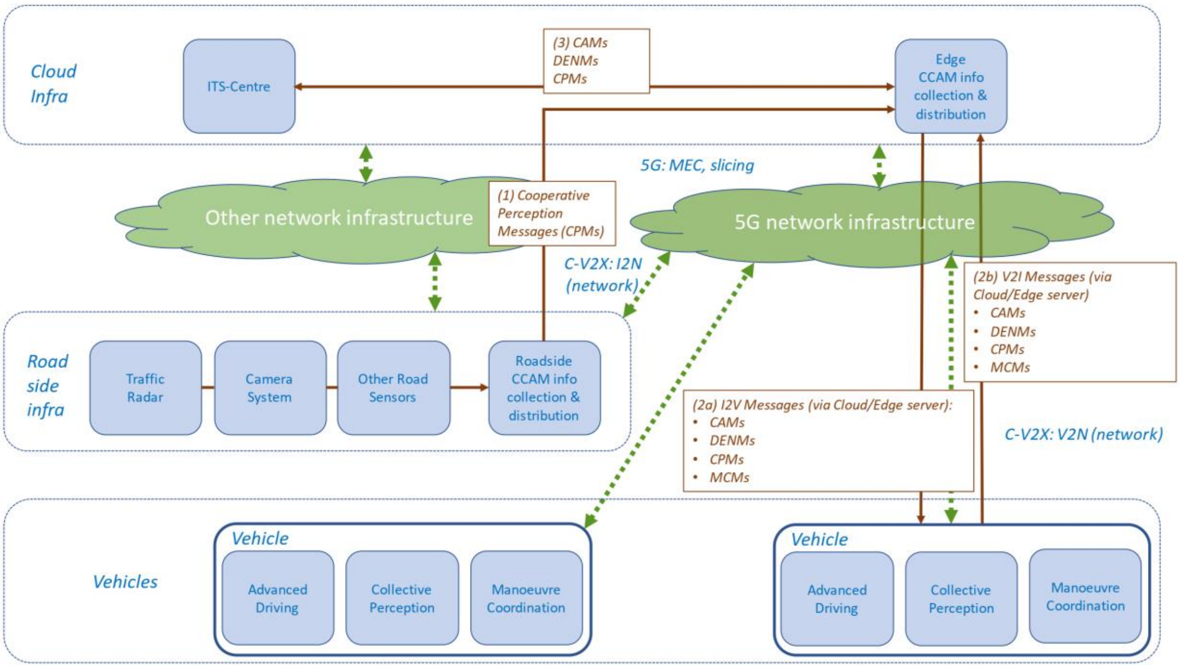

Figure 4 – CCAM architecture for the ES-PT US complex manoeuvres in cross-border settings.

The interfaces depicted in Figure 4 have the following specifications:

1. Roadside-to-Cloud messages (Infrastructure-to-Network or I2N messages): Cooperative Perception Messages (CPMs) from traffic radars and other roadside sensors with information regarding vehicles' detection and attributes and exchanged via 5G communications modules.
2. Cloud-to-Vehicle and Vehicle-to-Cloud messages: network-based communication supported by central or edge CCAM server, with 5G eMBB, 5G URLLC, edge computing and network slicing capabilities:
    a. Network-to Vehicle or N2V messages: CAMs, DENMs, CPMs, MCMs
    b. Vehicle-to-Network or V2N messages: CAMs, DENMs, CPMs, MCMs
3. Internal Cloud messages: ETSI ITS message sets or other, web-based (publisher-subscriber model + geographical scope), exchanged via IP network (Internet): CAMs, DENMs, CPMs

Sequence Diagram and Detailed Specifications

As an example, figure 5 depicts the sequence diagram of the lane merging scenario and how the block components and interconnections are mapped into the CCAM architecture presented in Figure 4.

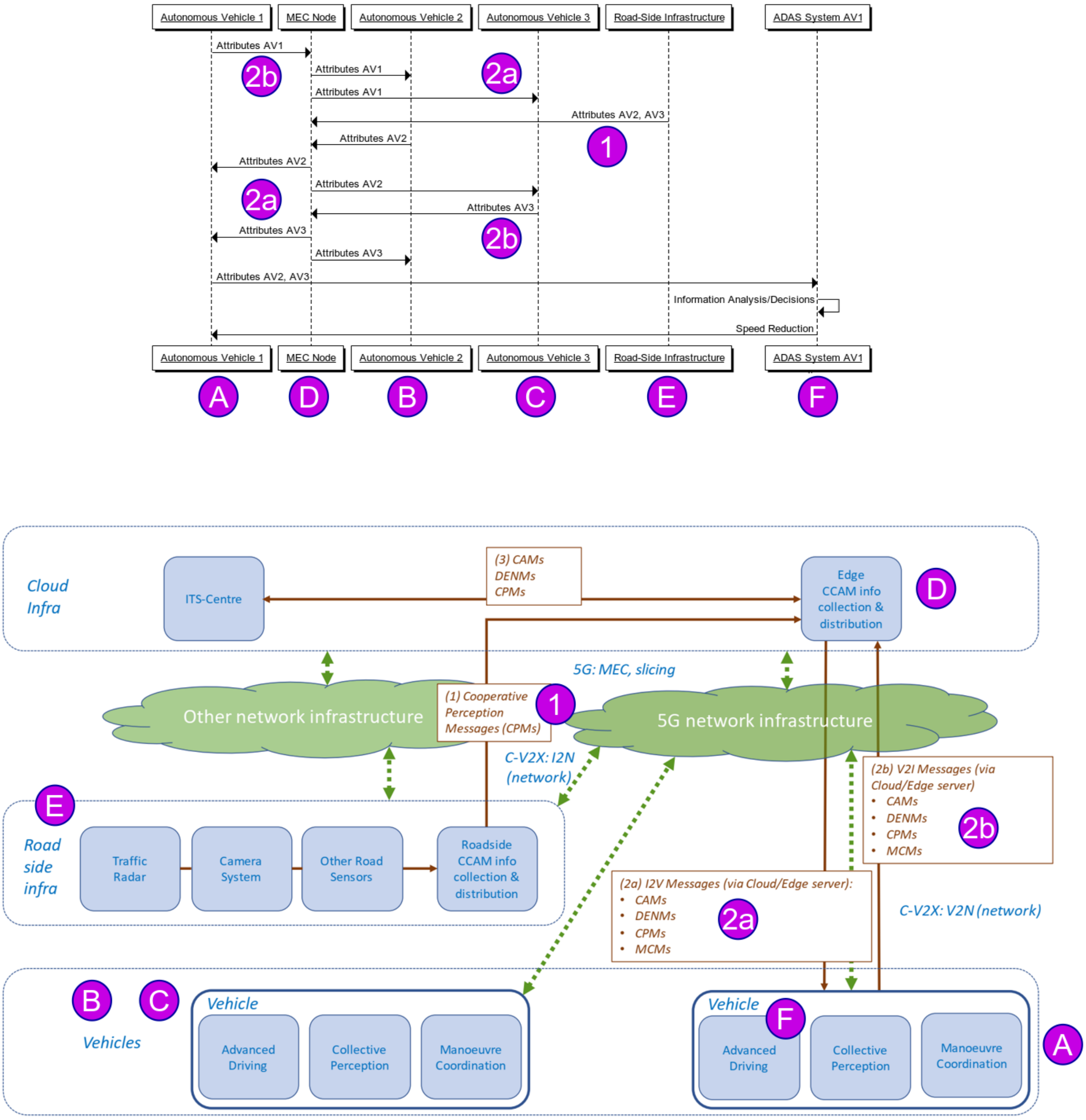

Figure 5 – Sequence diagram of the lane merging scenario mapped into the CCAM architecture.

Based on the above architecture, the CCAM infrastructure is capable to include the messages that would be transmitted by all vehicles in the traffic system, even the ones with no wireless connectivity, and make this information available to the 5G-enabled connected vehicles. The connected cooperative vehicles may create some message redundancy (coming from the vehicle and from the Infrastructure sensors) but this will be processed in order to fuse those two sources of information into a single message.

For this purpose, the road infrastructure includes UMRR traffic radars and 5G RSUs. The traffic radar can detect 7 different classes of objects (pedestrian, bicycle, motorbike, passenger car, transporter, truck/bus and long truck) with good accuracy [14].

Figure 6 presents the traffic radar configuration for the lane merging scenario in the ES-PT border, close to the river bridge on the Portuguese side. The radar will be installed in the same site as the 5G-NR base station (gNodeB) from NOS, the Portuguese Mobile Network Operator (MNO) involved in the 5G-MOBIX project. Placed at a height of 6 m and with a maximum range of approximately 250 m, the radar will be directly connected to a 5G RSU that will translate the raw sensor data into CPMs and forward this information both to the gNodeB and to the fiber backhauling network. By sending the data to the MEC node via both interfaces, it will be then possible to compare the timings of both message paths.

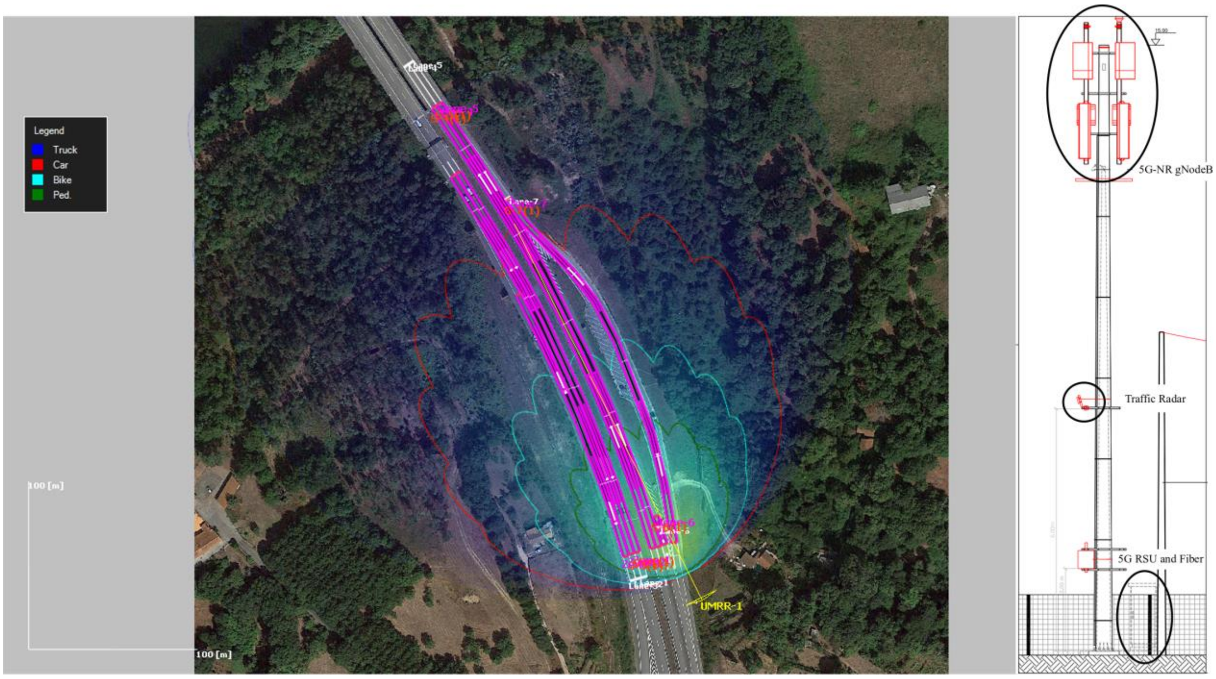

Figure 6 – Traffic radar configuration and site drawing in the ES-PT border.

Conclusions and Future Work

This paper describes the CCAM architecture developed in the scope of 5G-MOBIX project, with the main goal of supporting advanced driving scenarios, such as lane merging and automated overtaking, in the ES-PT cross-border corridor. The roadside infrastructure plays a crucial role in this framework, due to its ability to extend the field of view of all connected vehicles, either autonomous or not, contributing to an enhanced perception in mixed traffic scenarios, where CVs and CAVs coexist with legacy vehicles. The 5G-enabled vehicles are able to receive information, such as position and speed, of the non-connected vehicles through indirect measurements of roadside sensors (traffic radars) and the transmission of CPMs. At the end of 2020, this infrastructure will be installed in the field and it will be possible to obtain trial results regarding detection time and end-to-end latency, among other parameters, enabling the evaluation of 5G as the communications technology for the CCAM environment and the importance of additional roadside information in the system.

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