SEP4CAM – A Simulative / Emulative Platform for C-V2X Application Development in Cross-Border and Cross-Domain Environments

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***Abstract*—The complex interactions in advanced CCAM use cases that utilize C-V2X infrastructure require novel means to develop and test the solutions, especially when it comes to cross-border or cross-domain environments that consist of an overlay of multiple stakeholders. Accordingly this paper proposes a concept for a simulative / emulative platform for C-V2X applications in order to facilitate the development of advanced CCAM use cases. For this purpose we combine different simulation approaches with the in-vehicle C-V2X infrastructure, which allows us, based on realistic traffic conditions, to create additional emulated road users and test the integration of multi-operator C-V2X platforms.**

I. Introduction

Communication among vehicles, roadside infrastructure and other road users is envisioned to improve road safety and enable intelligent transportation systems [1]. This vision has become a central aspect of the fifth generation of mobile networks (5G), which has been designed with the requirements of cellular vehicle-to-everything communication (C-V2X) in mind, thereby creating a new vertical market for mobility solutions for all road users [2]. While the standardization of the relevant interfaces for C-V2X in 5G is completed, the incubation of interwoven C-V2X platforms offered by a multitude of stakeholders is still at the beginning [3].

The European Union's strategy to foster Cooperative, connected and automated mobility (CCAM) includes the goal to establish CCAM solutions in cross-border environments in between European countries[1]. The H2020 project 5G-MOBIX[2] focuses on developing and employing 5G technological innovations along multiple cross-border corridors and urban trial sites for realizing and testing CCAM scenarios under different conditions of vehicular traffic, network coverage, service demand, and legislation.

A. Motivation

The evaluation of C-V2X solutions by means of simulation comes to its limits when the complex distributed system architecture and the interplay of the involved components with their disparate characteristics meet advanced CCAM use cases. Especially when it comes to the interaction of different stakeholders that offer C-V2X infrastructure, a realistic assessment of the C-V2X applications is only viable when real deployments are used with the end-to-end connections established over the interconnected components. Furthermore, as long as the landscape of C-V2X services and overall ecosystem is still in incubation stage, the challenge for developers lies in the very limited number of users that could engage in real trials of a particular C-V2X use case. Taking the example of the 5G-MOBIX project, trialling a C-V2X use case with the partners' vehicles along the C-V2X-enabled digitized road stretch includes lower single digit number of vehicles participating in the experiments. Given the predicted penetration rate of C-V2X-capable vehicles will only start to grow slowly, this situation will remain roughly the same in the years to come. This makes it difficult to test and experiment with the scalability of the developed CCAM use cases, and also makes it harder to debug advanced features that are supposed to interconnect the services across C-V2X platforms of different providers. To give an example, complex relationships of C-V2X application providers are to be expected in cross-border areas or in geographical areas served by two providers offering the same application on an infrastructure that is physically separated from each other (e.g., an overlay of two mobile networks providing coverage in the area). In such settings the C-V2X application providers should forward relevant information to road users of the other provider, a functionality that is provided by a Geoserver component. Testing the correct behavior of the Geoserver component in the real trial site environment with vehicles can be a daunting task given the need to drive test specific scenarios. This holds true especially in cross-border settings, where the vehicle crosses the national border to drive test the behavior of the Geoserver component when moving from one C-V2X domain to another.

B. Focus and Contribution

With the aim of addressing the aforementioned issues, this paper proposes a simulative / emulative platform for C-V2X applications in order to facilitate the development of advanced CCAM use cases (SEP4CAM). To achieve this, we combine

[1]https://ec.europa.eu/transport/themes/its/c-its_en

[2]https://www.5g-mobix.com/

different simulation approaches with the in-vehicle C-V2X infrastructure, which allows us to create additional "emulated road users" based on the particular *real* traffic conditions prevalent on the 5G-MOBIX trial site or cross-border corridor. As an example, Figure 1 shows the recent traffic pattern along the Berlin trial site, with a peak value of over 400 vehicles passing the trial site infrastructure and a potential interaction with the C-V2X infrastructure - given the legacy vehicles would be equipped like the 5G-MOBIX trialling vehicles to actually take part in the use case. The SEP4CAM concept presented in this paper allows for the creation of a configurable amount of road users to participate in the use case, thus creating an environment to emulate higher penetration rate of vehicles taking part in the C-V2X use cases and testing the behavior of the distributed C-V2X infrastructure according to the emulated interaction with vehicles.

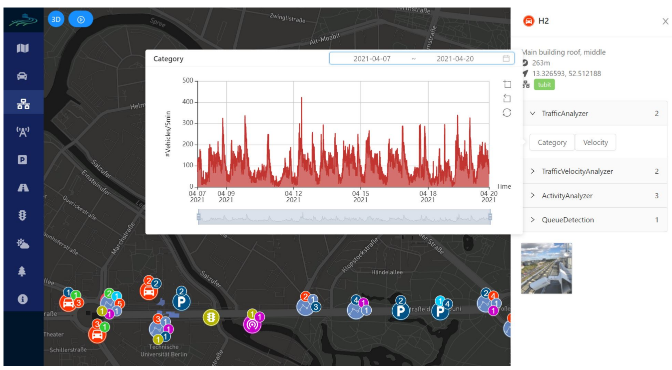

Fig. 1. Traffic pattern of legacy traffic detected by 5G-MOBIX roadside infrastructure at the Berlin trial site, shown within the control center application

II. Background

This section provides a short overview on the relevant C-V2X components by briefly describing the constituent communication and infrastructure elements that facilitate the realization of 5G-MOBIX use cases, and which are important for the SEP4CAM concept.

- CCAM messages: These are either based on a standardized ITS or a custom non-standard protocol that connected elements exchange.
- V2X application server: provides services for one or multiple V2X applications in a specific area. A V2X application server responsible for a certain CCAM application receives the messages from the relevant set of elements (e.g., vehicles, roadside infrastructure, pedestrians) and arranges them in topics, to which elements that participate in this V2X application can subscribe to, in order to learn about events that are of relevance for their own purpose. This communication coordination performed by the V2X application server is known as message brokering, and if deployed in the mobile network operators Multi-access Edge Computing (MEC) infrastructure can be referred to as the MEC Broker.
- Geoserver: An important tool that supports the MEC Broker in serving messages of a particular topic only to geographically relevant areas or communication participants
- ITS center: All the information that reaches the MEC Broker can be displayed in a central monitoring entity that constitutes the ITS center, basically a control center / dashboard that visualizes the current CCAM message events for the geographical area of interest.

Putting all these components together, i.e., the CCAM messages, the communication infrastructure based on 5G Uu or PC5 interfaces, the MEC Broker with Geoserver and the central ITS center, creates the distributed application that realizes the specific purpose of the CCAM application at hand. In 5G-MOBIX a wide range of CCAM applications have been realised with a varying focus on any of the aforementioned components. In the scope of this paper, the SEP4CAM platform should enable to simulate events that originate from the device layer (i.e. the vehicles) and subsequently generate the fitting CCAM messages to trigger the respective handling of this event in the responsible MEC Broker. Another important aspect connected to this is the re-publishing the information from the domain of another MEC Broker, e.g., because of the relevance to the communication participants of the local MEC Broker. The SEP4CAM concept aims to create a platform that uses the real components of the distributed C-V2X system described above, and use simulation and emulation were (additional) road users come into play. In this connection, the SEP4CAM concept should enable the testing of the MEC-related aspects based on realistic loads, and support testing the inter-working and coordination of different MEC platforms e.g., operated by different mobile network operators.

III. Related Work

The SEP4CAM concept makes use of the popular simulation tools ns-3[3] and SUMO[4]. Inspired by the approach presented by Bisio et al. [4], SEP4CAM uses a combination of ns-3 executed in real-time mode and a virtual emulation environment where the triggers from the simulation space are used to trigger events in the emulation space. We further extend this concept by putting this environment into a connected 5G-capable vehicle which then interacts with the distributed 5G infrastructure to emulate larger numbers of vehicles participating in the CCAM application. Choudhury et al. [5] combine different simulation tools into an integrated simulation environment for the testing of V2X protocols and applications. Similar to the approach presented in this paper, the authors provide the mobility information of vehicles to ns-3 via an external component. Pre-dating the C-V2X standardization and 5G technologies the authors focus on DSRC characteristics without mobile network support. In [6] Liu et al. propose a simulation concept that combines SUMO and ns-3 using a feedback loop to co-simulate VANETs based on generated vehicle routes. In contrast to this approach the present paper employs real mobility traces that have been

[3]https://www.nsnam.org
[4]https://www.eclipse.org/sumo/

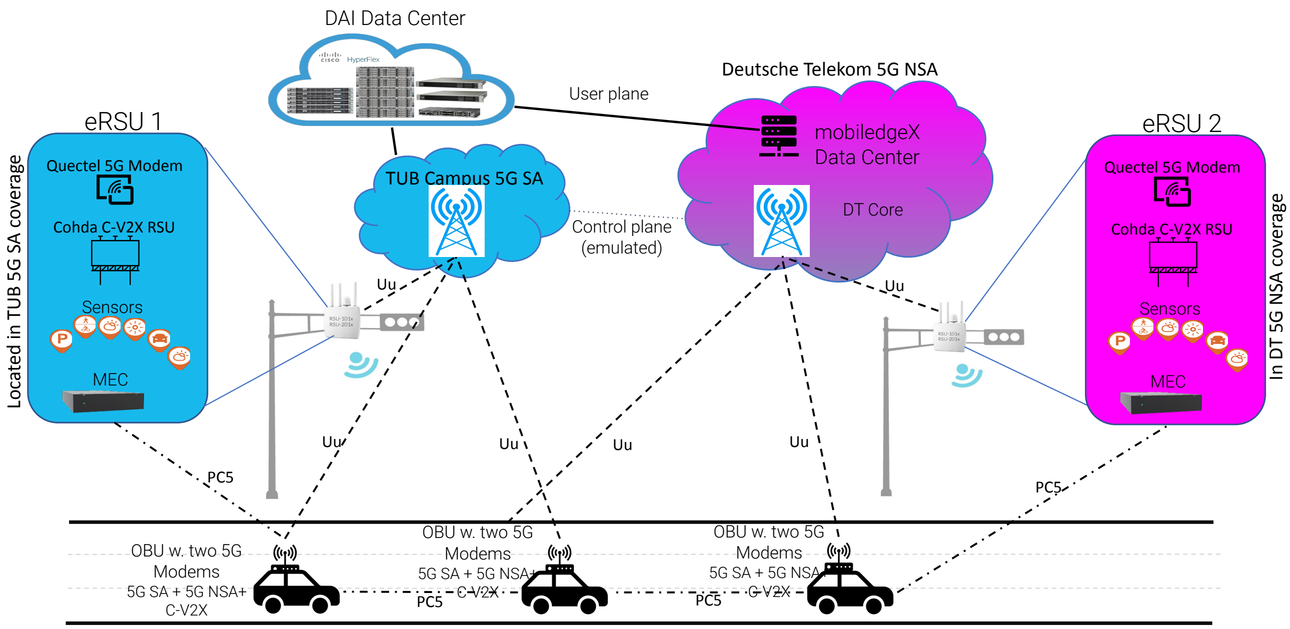

Fig. 2. Overview of the 5G-MOBIX Berlin trial site C-V2X architecture

captured from roadside units along the trial site, and extracted for the purpose of creating ns-3 trace files. Hallerbach et al. [7] use map data for simulations that has been gathered by high-accuracy measurements of the road, in order to couple simulations of cooperative and automated vehicles with other road users. Cooperation simulations that include V2V and V2X are not in the scope of the paper and are stated as potential extension of the concept.

IV. THE SEP4CAM CONCEPT

The SEP4CAM concept presented in this section has been devised to support the C-V2X use case development and validation conducted within the scope of the 5G-MOBIX project. Figure 2 shows the general setup and C-V2X architecture that is deployed in the Berlin trial site, and for which the SEP4CAM platform should facilitate i) the generation of realistic numbers of vehicles arriving on site, that are based on the real traffic patterns and geographical locations prevalent on the local trial site, and ii) generating realistic triggers to the mobile edge computing (MEC) infrastructure and the C-V2X Application Server deployments hosted on this MEC infrastructure.

A. SEP4CAM Components in the Trial Vehicle

In this section we provide an overview on the SEP4CAM components, as depicted in Figure 3. They are deployed in the On-Board Unit (OBU) of the TU Berlin (TUB) vehicle, with the following functionality:

- *MobilityTracer* – As shown in Figure 1, the 5G-MOBIX trial site infrastructure digitizes the traffic of legacy vehicles and other road users and provides the traffic data in real-time or as mobility traces. The MobilityTracer component translates these recorded traffic patterns to generate trace files for ns-3, similar to the TraceExporter tool [8].
- *ns-3 Simulator* – The ns-3 simulator component is fed with the trace file generated by the mobility traces component. Similar to the approach in [4], we operate the ns-3 simulator in real-time mode and use the events generated from the simulation domain as a trigger to the next component.
- *C-V2X Emulation function* – The C-V2X emulation function corresponds to a set of vehicle-initiated interactions that fit to the CCAM use case to be tested. As an example, the trigger from the simulation domain causes the C-V2X emulation function to generate a registration message, which is sent out via the 5G connection to the application server hosted within the MEC infrastructure of the mobile network operator. It should be noted that the traces allow for the differentiation of the specific GPS location and vehicle direction and speed, which constitute important data to be included into the generated messages in order to test the Geoserver interworking with different MEC Brokers.

Based on the above components the SEP4CAM can generate the C-V2X messages following realistic traffic patterns by replaying captured mobility traces and generating events for starting and stopping the use of a specific C-V2X service. The C-V2X messages can be sent out via the 5G modem or via the PC5 sidelink, thus allowing for testing specific hybrid networking scenarios that combine PC5 communication with messages received from Uu interface.

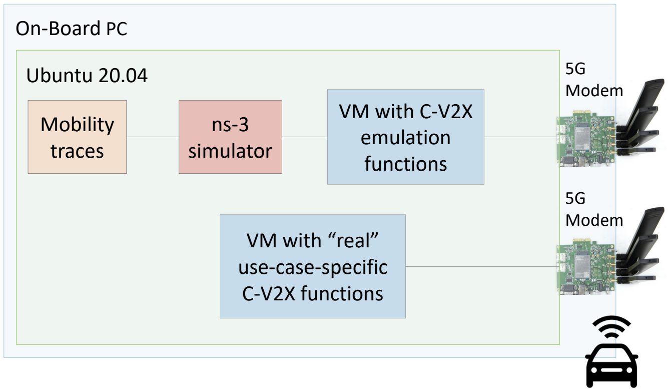

Fig. 3. SEP4CAM concept overview

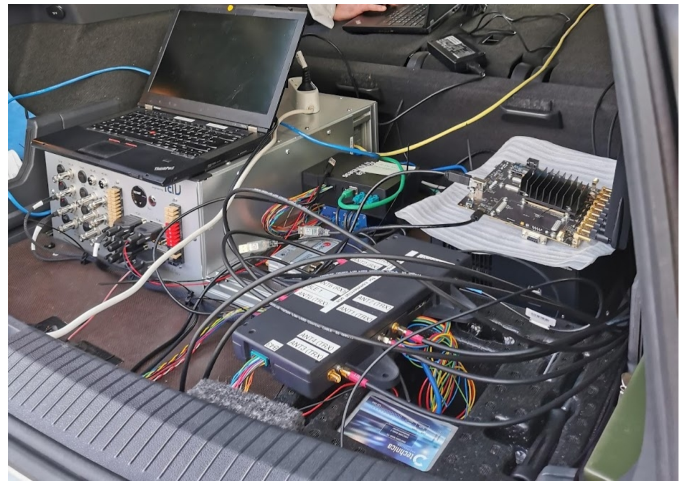

Fig. 4. Hardware setup for SEP4CAM deployment in a vehicle

B. SEP4CAM Operation

When a trial run along the Berlin trial site should be amended with SEP4CAM-originated messages, the first step is to select the preferred mobility traces and generate trace files for ns-3 with the MobilityTracer component. Subsequently, the ns-3 simulator is executed and starts the simulation in real-time mode with the information on each vehicle node being based on the MobilityTracer data. Each time an event is triggered, the corresponding C-V2X function is executed. While this simulation / emulation procedure is on-going and creating load on the C-V2X application server hosted in the MEC of the mobile network operator, the normal 5G-MOBIX use case is executed in parallel and ready to interact with the 5G-MOBIX trial site infrastructure as the vehicle drives along the test track.

C. Equipment for SEP4CAM

Figure 4 shows the hardware setup to be used with SEP4CAM. We are employing Quectel RG-500Q evaluation boards for 5G Uu connection over Deutsche Telekom 5G NSA network and MobiledgeX MEC infrastructure[5] in Berlin node, an On-board PC with Ubuntu 20.04, Cohda Wireless MK6c for PC5 communication with roadside infrastructure. We are using a distinct 5G modem for the emulated and the real C-V2X traffic in order to not impair the data rate of the use case that is being measured while driving along the test track.

V. Conclusion and Future Work

In this paper we have presented the general concept of a novel approach to realize a simulative / emulative platform for C-V2X applications. The described SEP4CAM concept focuses on the ability to generate realistic loads particularly in the V2X application server, hosted on the mobile network operator's MEC infrastructure, and to facilitate the testing of Geoserver-based relaying of information among different V2X service providers. At the time of writing, the SEP4CAM concept is being implemented and is aimed to be employed on two vehicles simultaneously located in different C-V2X domains, thus allowing for the experimentation in cross-domain / cross-border environments.

[5]https://developers.mobiledgex.com/

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