A Toolkit for Visualizing V2X Messages on the Smart Highway Testbed

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***Abstract*—Vehicle to Everything (V2X) systems are starting to be used in some regions worldwide; consequently, this leads to the consolidation of its major components, putting into practice all the potential of V2X. The Smart Highway testbed located in Antwerp, Belgium, makes available V2X systems for experimentation and evaluation, providing flexible support to different V2X access technologies simultaneously. Namely, ITS-G5 for short-range communication and Cellular Vehicle to Everything (C-V2X) for short- and long-range communication. Smart Highway testbed applications are needed to explore, support, and disseminate research opportunities. It motivates us to make available examples of testbed applications as monitoring tools for researchers and industry. Our solution makes available a toolkit using a graphical interface to monitor C-ITS Cooperative Awareness Messages (CAMs) and Decentralized Environmental Notification Messages (DENMs) in a user-friendly way. An additional application plots the current location of C-ITS entities in our Local Dynamic Map (LDM).**

***Index Terms*—autonomous driving, C-ITS, CAM, DENM, LDM, hybrid communication, ITS, RSU, testbed, V2X, vehicular communications.**

I. Introduction

The potential of technologies and systems for Vehicle to Everything (V2X) are available to use in real life from now on. Semi-autonomous and autonomous driving is a reality in some regions worldwide. One of the world players in electric and autonomous vehicles, TESLA sold 500 thousand vehicles in 2020, a 40% increase of its cars sold in 2019 [1]. It indicates that the adoption of autonomous vehicles increases at a fast rate. V2X impacts our way of living in situations still to be discovered as human drivers are an element of the past.

Cooperative Intelligent Systems (C-ITS) [2] provide smooth, safer, comfortable, greener, and efficient traffic. C-ITS aggregated with sensors from vehicles and road infrastructure nodes contribute to consolidating the potential of V2X into practice, e.g., deploying onboard cameras for traffic sign recognition [3]. The road infrastructure nodes are called roadside units (RSUs). The European Community launched the Cooperative, Connected and automated mobility [4] to assist the implementation of V2X for the countries and related industries in the European Union. Cooperative driving from C-ITS expands the awareness area that a vehicle or a driver has of the road. As vehicles and the road infrastructure exchange information about traffic, other vehicles, road conditions, road events, and sensors, these features leverage autonomous vehicles capabilities [5] adding more efficiency and safety instead of being standalone vehicles. However, there is a problem with integrating different standards for short- and long-range C-ITS communication. There is only one standard for long-range communication in Europe: the Cellular Vehicle to Everything (C-V2X), which uses 4G/5G cellular networks, but there are two different standards for short-range communication. These standards, the ITS-G5 and C-V2X PC 5 interface, use different communication technologies. Some automakers adopt ITS-G5 while other automakers adopt C-V2X PC5, which raises questions on how to integrate these three different technologies. Indeed, these standards have to be incorporated in C-ITS vehicles to guarantee the availability and the best usability of V2X.

The Smart Highway testbed [6] offers a communication management framework with flexible support for the three different communication technologies aforementioned. It makes available a hybrid communication environment for research and evaluation where C-ITS entities, e.g., vehicles, can exchange messages using these different communication technologies simultaneously. To the best of our knowledge, only Continental AG announced in 2019 that it would provide a hybrid communication platform called 5G-Hybrid V2X to automakers in 2023 [7].

Smart Highway testbed applications are needed to explore, support, and disseminate research opportunities. It motivates us to make available examples of testbed applications as monitoring tools for researchers and industry. The main contribution of our work is offering a toolkit using a graphical interface to monitor C-ITS Cooperative Awareness Messages (CAMs) [8], and Decentralized Environmental Notification Messages (DENMs) [9] in a user-friendly way. An additional application plots the current location of C-ITS entities, e.g., vehicles, in our Local Dynamic Map (LDM) [10]. Responsible web services applications create the graphical interface resulting in better readability independent of screen size and device types, whether PCs, smartphones, or tablets. The user only needs an Internet browser connected to our web services. We make our source code available in Gitlab repositories. Moreover, we provide manuals to install and configure the toolkit applications.

II. Toolkit Overview

Our toolkit is a set of software applications developed in the Smart Highway testbed using lxc containers. The Smart Highway testbed comprises seven Roadside Units (RSUs) and one BMW car model X5 for experimentation. Every RSU has an NVIDIA® Jetson™[1] computing station and the three communication technologies available with its devices and antennas and a Global Positioning System (GPS) device. The BMW has the same devices in an internal unit called Onboard Unit (OBU).

Following sections present the deployed CAMINO [11] and DUST [12] frameworks, then we present the three applications of our toolkit: (1) CAM Server, (2) DENM Visualizer, and (3) LDM Display.

A. CAMINO

CAMINO [11] is a vehicular communication management framework that allows the hybrid use of the three different technologies standardized for V2X in Europe and the services running on top of them. These technologies are the C-V2X PC5 and ITS-G5 for short-range communication and the C-V2X (4G/5G) Uu for long-range communication. It also permits merging separated actuators, sensors from vehicles and road infrastructure, Human-Machine Interfaces (HMIs), and internal/external service providers. CAMINO can be deployed on top of any Vehicular Network entity. Moreover, it allows monitoring and logging information such as the transmitted and received messages, station ids, timestamps, and data from GNSS.

Figure 1 shows a generic flow of the C-ITS message data in all our toolkit applications. The messages are created in an RSU or OBU on the Smart Highway testbed. Then they are delivered by CAMINO using MQTT to a message decoder in a vehicle that sends the message data to a web application. A researcher connects to the web application to access the graphical interface via a browser. Although we used only MQTT, ITS-G5 or C-V2X can be used by CAMINO to transport the C-ITS messages.

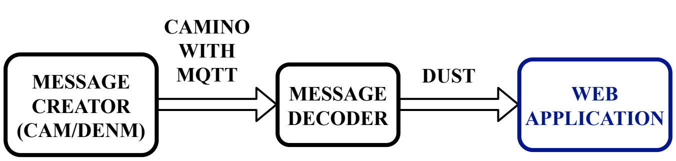

Fig. 1. Flow of message data

[1] https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/

B. DUST

The Distributed Uniform Streaming (DUST) [12] is an open-source framework [13] that enables transport-agnostic applications to communicate using a publisher/subscriber architecture. It enables CAMINO to interconnect between different applications over heterogeneous networks from cloud to edge devices.

C. CAM Server

The CAM server provides a CAM [8] information dashboard. It deploys the Spring Boot project [14] to run the web application, which monitors CAM messages from the surroundings C-ITS stations on the road. It comprises three different applications:

- CAM generator
- CAM decoder
- CAM Web server

1) CAM Generator: The CAM generator creates and sends custom messages. We use an RSU along the Smart Highway to transmit the same custom CAM messages as if they were coming from a vehicle. The custom CAM messages are encoded in the ASN.1 standard [15] and sent over a DUST channel to the CAMINO framework using MQTT. CAMINO sends CAM messages to a vehicle that runs our CAM decoder and CAM Web server applications.

2) CAM Decoder: The CAM decoder receives the custom CAM messages sent by our CAM generator over a DUST channel to CAMINO and saves each decoded CAM message in a JSON file. Furthermore, after filtered by configurable conditions, the decoded message is sent to the CAM web server over a DUST channel using ZMQ.

3) CAM Web Server: The CAM web server runs in the same vehicle where the CAM decoder runs. The server uses the Spring Boot project [14] to run the web application, and it monitors all CAM coming from the CAM decoder. According to a defined priority based on the distance between the sender and the receiver, the dashboard can switch its background color from green (Figure 2) to other ascending colors until red (Figure 3). The color is associated with the severity of the received CAM. Moreover, depending on the CAM information, it displays icons on the dashboard to show the speed limit, an emergency vehicle approaching, or mandatory lane merge to the left or right.

D. DENM Visualizer

The DENM visualizer provides an DENM [9] information dashboard. It also monitors DENM messages from the surroundings C-ITS stations on the road. It comprises three different applications:

- DENM creator
- DENM decoder
- DENM visualizer

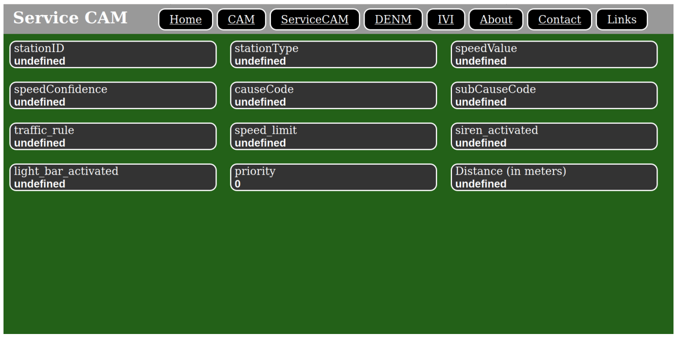

Fig. 2. CAM dashboard zero severity = green

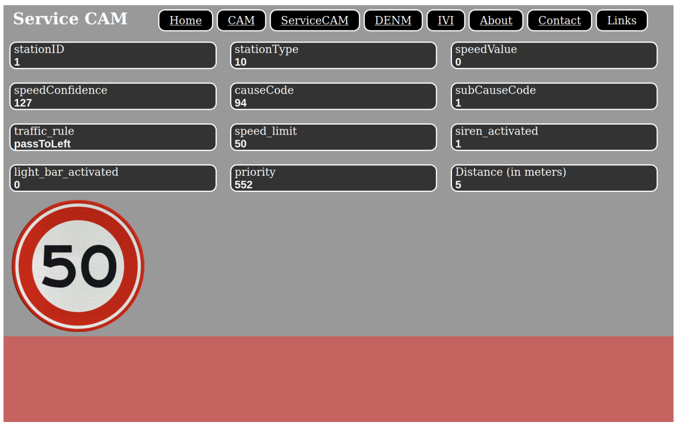

Fig. 3. CAM dashboard high severity = red - current speed limit

1) DENM Creator: The DENM creator sends the same custom DENM message from an RSU similar to our CAM generator to simulate an event disseminated by the RSU. It encodes DENM messages in the ASN.1 standard [15] and sends over a DUST channel to the CAMINO framework using MQTT. CAMINO sends DENM messages to a vehicle that runs our DENM decoder and DENM visualizer.

2) DENM Decoder: The DENM decoder receives the custom DENM messages sent by our DENM creator over a DUST channel to the CAMINO and saves each decoded DENM message in a JSON file.

3) DENM Visualizer: The DENM visualizer runs in the same vehicle where the DENM decoder runs. The visualizer uses the Spring Boot project [14] to run the web application, and it also monitors DENM messages coming from the DENM decoder.

E. LDM Display

The LDM Display uses the idea of the Local Dynamic Map (LDM) guidance for standardization [10] to plot a real-time map showing the location of the vehicle and its surroundings. The application also plots CAM and DENM messages sent from other vehicles or RSUs. As shown in Figure 4, at the right side of the map is a panel showing the received messages where the user can select to track the source of the message

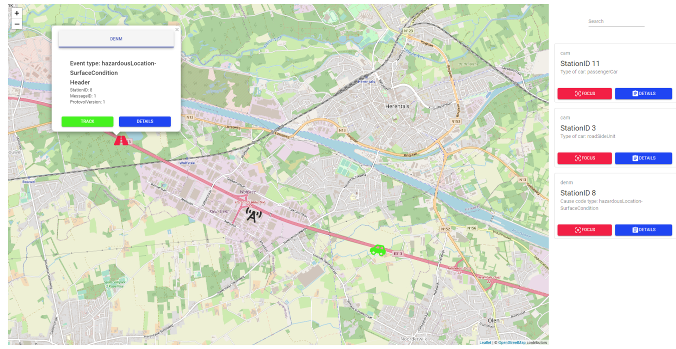

Fig. 4. LDM showing a selected RSU

on the map or to open a box with details of the message. It comprises four different applications:

- LDM sender
- LDM listener
- LDM back end
- LDM front end

1) LDM Sender: The LDM sender disseminates CAM and DENM customized messages from an RSU as in the sender applications above. It encodes CAM, and DENM messages in the ASN.1 standard [15] and sends over a DUST channel to the CAMINO framework using MQTT. CAMINO sends these CAM and DENM messages to a vehicle that runs our LDM listener, LDM back end, and LDM front end.

2) LDM Listener: The LDM listener receives and decodes the CAM and DENM messages sent by our DUST sender over a DUST channel from CAMINO. After decoding, the message is saved in a JSON file sent via DUST to the LDM back end. It can also be modified to receive IVI [16] messages.

3) LDM Back End: The LDM back end validates the received message from the LDM listener. It uses the Spring Boot project [14] to run the web application serving the LDM front end after the validation.

4) LDM Front End: The LDM front end is a responsive React application [17] that fetches the information from our back end on regular periods. To display the map, we use the Openstreetmap project [18]. Our application uses configuration files to display the messages for each type of message and protocol version. Material UI [19] is used for prototyping the application without having to deal with the CSS design aspect.

III. Future Work

We intend to add to our toolkit applications to visualize IVI messages [16], show KPIs such as the message delivery rate and lost messages. Next, we also intend to integrate the toolkit applications into a common graphical application.

Optionally, we could run performance evaluation experiments on each tool, platform, or framework to compare its resource usage and speed in our applications. With the results of the performance evaluation, all the applications could be refactored and implemented using the same elements, e.g., React [17], or Spring boot [14] to implement the web applications. We believe that more applications will be added to our toolkit triggered by:

1) Management of Smart Highway testbed as a road authority using hybrid communications
2) Addition of sensors to the Smart Highway infrastructure, e.g., detectors of the flow of vehicles and speed
3) Addition of more and different types of vehicles, e.g., trucks and motorcycles
4) Research with Vulnerable Road Users (VRUs) [20], e.g., pedestrians and cyclists
5) Integration of short- and long-range applications in the same entity, e.g., a vehicle using C-V2X PC5 and C-V2X Uu (4G/5G)

IV. Conclusion

This paper presents an toolkit Smart Highway testbed applications for researchers and industry available source code to the users. Usually, research applications start with data acquisition for posterior statistical analysis and plotting; we provide a graphical interface with real-time characteristics in our applications. The graphical interface presents dynamic data and information more user-friendly than lines of numbers sometimes separated with commas. After our successful experimentation, we consider the toolkit an attractive way to get the attention of researchers and industry and to support new research.

Users can also deploy the toolkit to assess prototypes checking the behavior of messages in our Local Dynamic Map using hybrid communications. This way, researchers and the industry can analyze hardware and software changes related to C-ITS messages as soon they are implemented. The toolkit is for passive monitoring only, which is commanding no action to change the state or dynamics of the C-ITS entities.

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