Demo: Interoperability between Cellular and V2X Networks (802.11p / LTE-PC5) under a Cloud Native Edge Scenario

Jordi Marias-i-Parella*, Adrián Pino*, Bruno Cordero*, Jordi Casademont†*, Estela Carmona-Cejudo*, and Francisco Vázquez-Gallego*
*i2CAT Foundation, Barcelona, Spain; Email: {jordi.marias, adrian.pino, bruno.cordero, estela.carmona, francisco.vazquez}@i2cat.net
†Universitat Politècnica de Catalunya (UPC), Barcelona, Spain; Email: jordi.casademont@upc.edu

***Abstract*—By leveraging the use of wireless communication technologies and edge computing capabilities, Cooperative Intelligent Transport Systems (C-ITS) aim to improve safety and traffic management in mobility use cases. However, the deployment of C-ITS poses some critical challenges. Specifically, in heterogeneous systems, it is necessary to guarantee interoperability among the various available wireless technologies. This paper presents a cloud native infrastructure architecture for vehicular communications that guarantees the interoperability between cellular technologies (4G/5G), and specific Vehicle-to-Everything (V2X) communication technologies, such as LTE-PC5 and IEEE 802.11p wireless communications standards. Such interoperability is demonstrated through the implementation of an Edge Infrastructure where a vehicle equipped with one of the aforementioned radio access technologies, sends cooperative awareness messages, and such messages are received in vehicles provisioned with different wireless technologies.**

***Index Terms*—V2X, C-V2X, IEEE 802.11p, Cloud Native, C-ITS, Edge Computing, Kubernetes, 5G NR**

I. Introduction

During the past decade, significant growth was expected for the Vehicle-to-Everything (V2X) applications market on a global scale. Most car manufacturers have prototyped solutions for this technology, but it has yet to be widely adopted. One major setback has been the availability of multiple wireless standards, each requiring specific fit-for-purpose equipment in all vehicles. Since the release of the standards IEEE 802.11p and IEEE 802.11bd (still in draft stage), the emergence of the standard based on 4G Long Term Evolution (LTE), the LTE-PC5, and the subsequent appearance of the 5G New Radio V2X (NR-V2X), V2X radio technologies have failed to reach the market widely. Thus, manufacturers have grown wary of adding V2X communication capabilities to their vehicles [1]. It is then key to enable vehicles that use various access technologies, e.g., 802.11p, LTE-PC5, and cellular connections, to seamlessly exchange V2X messages and enable Cooperative Intelligent Transport Systems (C-ITS) applications.

Interoperability among multiple radio access technologies in vehicular communications can be provided by equipment deployed in the road infrastructure. In this work, we propose an edge computing software framework deployed on a smart edge infrastructure which plays a vital role in orchestrating and managing C-ITS applications. By moving C-ITS applications closer to where the data is produced (i.e., vehicles), and avoiding transporting the data far from its source, the stringent latency requirements of these type of applications can be met, whilst reducing the load on the transport network. These capabilities contribute to improving efficiency of the system, as well as the safety and the experience of road users [2].

This demo presents a roadside infrastructure architecture, based on vehicle-to-infrastructure-to-vehicle communication, that enables interoperability among vehicles and road users using three different radio access technologies: IEEE 802.11p, LTE-PC5, and conventional cellular 5G network. Thus, vehicles not specifically equipped for V2X communication can still participate in V2X communication through a cellular connection. The proposed system uses a module on the edge that forwards V2X messages generated by one vehicle to other ones that may have missed the message due to radio heterogeneity. This forwarding intelligence is deployed within a cloud native multi-access edge computing (MEC) architecture.

II. V2X Radio Interoperability System

The architecture for the system that enables the interoperability of multiple V2X radio access technologies is represented in Fig. 1. The physical road infrastructure includes a MEC server that runs all necessary software, as well as two types of road side units (RSU), one for IEEE 802.11p and another for LTE-PC5, to transmit and receive V2X messages. In addition, a public 5G cellular network is used. All software components are containerized and orchestrated using Kubernetes on the MEC. The road side units are connected to the MEC server's software modules through virtual local area networks. Vehicle on-board units (OBUs) run client-side software modules on specialized boards equipped with the appropriate chipset according to the assigned radio access technology. To connect to the 5G network, the OBUs use commercial 5G modems that provide standard IP interfaces. In this setup, V2X messages are transmitted as any other IP datagram. The proposed architecture has been implemented in a laboratory-based testbed, and has been validated with 802.11p and LTE-PC5, but it could be used with any other

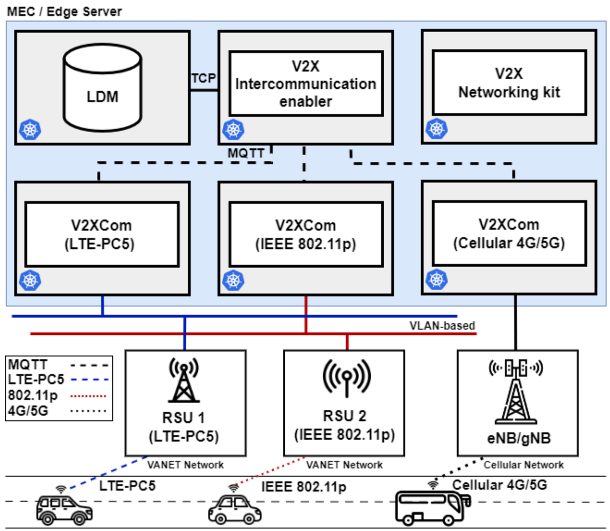

Fig. 1. V2X interoperability system architecture

technology such as NR-V2X or 802.11bd. The first version of this setup was tested during CARAMEL project [3], and are currently being updated and used in PODIUM project [4], both involving road traffic efficiency and safety applications.

Four software components run in the MEC, as listed below:

1) V2X Communication module (V2XCom): It handles the network, transport, management, security, and facilities layers of the European Telecommunications Standards Institute's ITS-G5 protocol stack, using release 2 of the security layer that implements IEEE 1602.2 formats. This module is responsible for fully signing and authenticating all incoming messages. The messages are decoded and then published to message queuing telemetry transport (MQTT) queues, where the intercommunication module can forward them to other radio access technologies. IEEE 802.11p and LTE-PC5 support broadcast addressing, allowing a single message transmitted from a road side unit to reach all OBUs within its coverage area. In contrast, current public 5G cellular networks do not provide support for multicast or broadcast addressing. As a result, every message received by the MEC server must be retransmitted using unicast addressing to each OBU connected through the cellular network. This communication is achieved through the use of TCP or UDP sockets, depending on the presence of a network address translator (NAT).

2) Local dynamic map (LDM): It serves as a system database, storing information such as location and radio technology of the OBUs, in order to maintain a rich and updated view of the system. It can be easily integrated into a dashboard or alert system to extract values from it.

3) V2X Intercommunication enabler: It receives all the incoming messages from the OBUs, processes them, and updates the LDM accordingly. Its main role is to ensure that all OBUs receive the V2X messages they may be interested in. Thus, in the event of receiving a new incoming message, it adds the necessary logic to detect which OBUs have not received this message (either because they use another radio technology, or because they are outside the coverage radius of the sender), and transmits such message via MQTT to the associated V2XCom module, which in turn sends the V2X message to the radio equipment. This module also has the intelligence to apply forwarding policies, e.g. it may forward messages to specific regions of interest or types of vehicles.

4) V2X Networking kit: It addresses the various network requirements and configurations needed to establish connectivity between the V2X interoperability system components running on the MEC server and the radio equipment, in an automated manner and following a cloud-native approach.

III. Demonstration

Our testbed consists of three OBUs that independently run a cooperative awareness service and communicate through a different radio access technology, as depicted in Fig. 1. The demo infrastructure includes a MEC server connected to two road side units (RSUs), one communicating through IEEE 802.11p and another with LTE-PC5; and to a public cellular 5G network. The V2X interoperability architecture includes a set of containerized software modules. OBUs communicate with those radio units equipped with the given radio access technology. OBUs are implemented on custom boards with an appropriate radio connectivity chipset. The SUMO traffic simulator is utilized to provide positions to each vehicle, enabling them to be identified when running the demonstration.

Throughout this demo, we showcase our hardware and software architecture. The transmission, reception and processing of cooperative awareness messages is demonstrated. In addition, an interactive front-end is provided, which demo attendees can interact with. The use of SUMO is demonstrated for the simulated OBU positions, with a map showing the vehicles in movement. Attendees connected to the front-end will see the three vehicles moving in their displays, with each OBU transmitting through a different radio access technology.

Acknowledgment

This work was supported by the grants ONOFRE-3 PID2020-112675RB-C43 and PID2019-106808RA-I00 funded by MCIN/AEI/10.13039/501100011033, INTEGRA CER-20211031 funded by CDTI Cervera, the PODIUM project (101069547) funded by the European Commission, and the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 951947 (5GMED). The authors would also like to acknowledge CERCA Programme Generalitat de Catalunya for sponsoring part of this work.

References

[1] Renner, M., et al., "Challenges of Vehicle-to-Everything Communication". *Interviews among Industry Experts. 2020.*

[2] 5G Americas. "5G Edge Automation and Intelligence".*5G Americas White Paper. Oct 2021.*

[3] Vitale, C., et al. "CARAMEL: results on a secure architecture for connected and autonomous vehicles detecting GPS spoofing attacks". *J Wireless Com Network 115 (2021).*

[4] "PODIUM project: PDI connectivity and cooperation enablers building trust and sustainability for CCAM". EU HORIZON Program. *https://podium-project.eu (accessed Feb. 2023).*