Prototyping V2X Applications in Large-Scale Scenarios using OpenAirInterface

Julio Manco†, Guillermo Gallud Baños‡, Jérôme Härri†, Miguel Sepulcre‡

†EURECOM, Campus SophiaTech, 450 route des Chappes, 06904 Sophia-Antipolis, France
E-mail: {manco,haerri}@eurecom.fr
‡Universidad Miguel Hernandez de Elche (UMH), Avda. Universidad s/n, 03202, Elche (Alicante), Spain.
E-mail: {ggallud,msepulcre}@umh.es

***Abstract*—Prototyping V2X applications in large-scale scenarios is a challenging but demanded task. To address this challenge, this paper presents and evaluates a novel prototyping tool based on OpenAirInterface (OAI). This tool makes use of a new OAI stub interface located at the MAC level that is able to emulate all underlying software and hardware of the LTE V2X technology. The proposed solution delivers packets to the target UEs according to statistical packet loss and delay models. The OAI stub exposes flexible APIs to integrate different models, including different LTE-V2X schedulers, that enable the evaluation of V2X applications under high traffic density scenarios. To showcase the proposed OAI stub interface, this paper also presents two case studies based on two V2X schedulers, the Sensing-based Semi-persistent scheduling (SB-SPS), as well as a Self-organizing TDMA (STDMA) scheduler.**

***Index Terms*—OpenAirInterface, prototype, large-scale, emulation, V2X applications, SB-SPS, STDMA, V2X communications.**

I. Introduction

OpenAirInterface (OAI) is an open source software-based implementation of the LTE system running on Linux operating system along with Off-The-Shelf (COTS) software defined radio (SDR) cards such as the ETTUS universal software radio peripheral (USRP) [1], [2]. Fig. 1 shows as an example an OAI testbed with two UEs (User Equipment), where each UE is composed of a small form factor PC (black box at right side in Fig. 1) connected to a B210 USRP (white box at left side in Fig. 1). OAI provides prototyping capabilities of 4G and 5G radio access network (RAN), for which it has being commonly adopted for the development of real experiments [3]. For that end, OAI is continuously under development to extend the support of 3GPP specifications such as the Release 14 for V2X communications.

In this context, there is an increasing need of prototyping large-scale and challenging scenarios, requested by academies and industrial entities. However, it is often restricted by the high cost of deploying a large number of hardware devices. To address this problem, we present in this paper a prototyping tool that constitutes the first step towards the development of system-level emulations for prototyping V2X applications. To this aim, a MAC-level stub interface has been designed and implemented on OAI. This OAI stub implements a MAC-to-MAC link that performs an abstraction of the physical and

Fig. 1: OAI testbed with two small form factor PCs and two B210 USRP.

MAC layers, as well as radio channel propagation effects. Thanks to this abstraction, the OAI UEs connected to the stub can experience a V2X communications performance that is not limited to the laboratory environment. The proposed software architecture not only provides a full stack for the assessment and evaluation of V2X services and applications, but also provides a framework for experimentation under large scale scenarios. Thanks to this, it avoids overlooking relevant aspects that may affect the obtained results. With this end, an open API is also incorporated into the implemented OAI stub interface to facilitate the assessment of different V2X applications. To show the feasibility of the proposed solution, a case study is presented and evaluated considering two different V2X schedulers [4], [5] under different traffic densities[1].

The rest of the paper is organized as follows. Section II presents the requirements and challenges of prototyping for V2X networks. Section III presents the proposed OAI stub architecture and its operation. Section IV presents the case study and the obtained results. Finally, some guidelines are devised for future works in Section V.

II. Prototyping V2X applications

The process of modelling communications systems often introduces several assumptions and simplifications about its implementations leading to misleading conclusions in the attained performance. As a consequence, prototyping has shown to be an ideal solution to fill the gap between computer-based simulations and real experiments. It

[1]The OAI stub is released under OAI Public License V1.1, as part of the OpenAirInterface (OAI) Software Alliance. More details at https://www.openairinterface.org/.

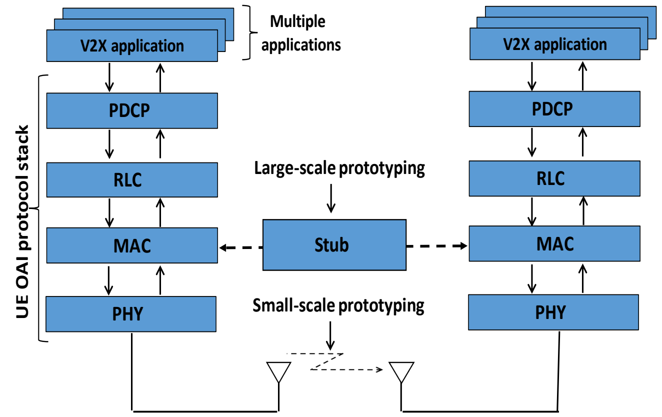

Fig. 2: OAI architecture for V2X application prototyping

constitutes a preliminary stage to implement and debug a system, and thus providing a full-scale and functional realization of a research concept. In the development of V2X technologies, the current progress of standardization in 3GPP has leveraged the industry. Despite the numerous research projects and field tests that have been carried out, it is still essential to provide suitable solutions for LTE-V2X to fulfill the market requirements, while promoting the development of LTE-based V2X industries.

Moreover, there exists an increasing need for more trials and testing supporting a large number of vehicles in real environments for safety applications. Currently simulation tools such as ns-3 and OMNeT++, among others, cannot support the prototyping and testing of V2X applications. Platooning and advanced/remote driving applications, are some of these applications that require stringent reliability, low latencies, high data rates and larger communication ranges. Hence, prototyping plays a key role in the development of V2X applications, in particular it is critical for trustworthy system reliability that moving from small-scale to large-scale can be performed with the same V2X application prototypes.

On the other hand, although there exists commercial products available on the market, they are often specifically designed for a particular application and have a high cost. They are also closed solutions that are not open source, and thus they do not allow further enhancements, as it will be required for Ultra-Reliable Low latency Communications (URLLC) for V2X communications in 5G-NR.

We address these problems with the development of a prototyping tool that not only allow us to evaluate V2X applications in large-scale scenarios, but also it is highly configurable to incorporate different V2X communication protocols and propagation conditions.

III. OAI LINK-LAYER STUB

In this Section, we describe the architecture of the proposed OAI stub, and provide some guidelines for its configuration

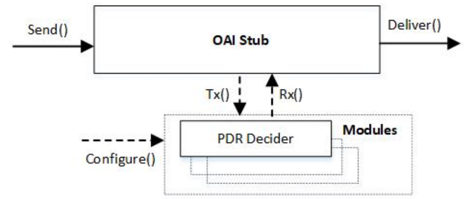

Fig. 3: OAI stub architecture

and operation for the emulation of V2X communications.

A. Stub architecture

The architecture of the proposed solution is depicted in Fig. 2 considering two UEs emulating sidelink (SL) communications tailored for the direct communication between vehicles without passing through the base station. As illustrated in this figure, OAI provides a full implementation of PDCP, RLC, MAC and RRC layers. The MAC layer is the lowest sub-layer of layer 2 in LTE radio protocol stack and constitutes an important part of our stub architecture. This is the case because it connects to the proposed stub entity in order to exchange protocol data units (PDUs) with other UEs, while connecting to the RLC layer using logical channels.

We have introduced into this architecture a link between MAC layers of the UEs, while allowing to run V2X applications. By doing this, we enable their evaluations even when a PHY layer is not available. At the same time, it allows the assessment of upper layer protocols and different aspects of the targeted application. Last but not least, the implemented stub is able to perform this assessment using only two UEs (i.e. two small form factor PCs) while experiencing the V2X communications performance achieved in a large scale scenario with hundreds of vehicles. In doing so, the proposed OAI stub allows the abstraction of scenarios with a large number of UEs by delivering or dropping the packets between two UEs running OAI.

It is worth mentioning that the transmissions of IP, Ethernet, ETSI Geonet, as well as customized packets are allowed in the proposed architecture after V2X SL communications are established over a PC5 interface also known as proximity service (ProSe). Thus providing a flexible and open platform for V2X applications such as security approaches and road safety applications, as well as for the development of future extensions and enhancements.

B. Stub configuration/operation

In an abstract way, the role of the proposed OAI stub is to either drop or deliver packets between two OAI V2X prototypes at MAC layer, considering configurable models. To that end, the OAI stub includes APIs providing the emulation V2X MAC/PHY functions and or V2X channel conditions as depicted on Fig. 3. Without loss of generalities the "PDR setting and decider" module (see stub block in Fig. 2) provides Packet Delivery Ratio (PDR) values under varying conditions.

TABLE I: OAI Stub API description

APIs	Values
send()	packet size, MCS, priority
deliver()	callback(OAI, bool, packet size, priority)
configure()	XML(density, tx rate, tx power, speed,..)
tx()	packet size, MCS, priority
rx()	boolean(rx,dropped)

In this module, the decision for which a packet is delivered or dropped can be configured by the user according to given PDR values. The PDR values embed propagation and interference effects, as well as the physical layer performance in terms of block error rates (BLER). Different PDR values can be used to emulate higher and lower traffic densities. All these aspects are easily configured and changed, while running V2X applications.

To make the aforementioned evaluation easier, we provide flexible APIs to configure the proposed OAI stub module, as described on Table I, where a configure function allows to set the parameters describing the targeted scenario, while tx and rx functions correspond to the input and output of the PDR decider. This module, "PDR decider", is executed each time a packet is received by the OAI Stub.In this way, for instance, a user aiming to evaluate a V2X scheduler could write lookup tables in XML files to configure the required changes into the stub. It is carried out by calling to the configure function, and if required other aspects of Stub are configurable. Therefore, different V2X schedulers can be examined without changes into the OAI prototype, and further knowledge of the OAI architecture, as well as procedures for compilations are not required.

With the proposed OAI stub and modules, different requirements can be solved. For instance, a user may only have analytical models, for which lookup tables may summarize this information by providing PDR values based on a set of input parameters. On the other hand, a stub module may also be written in any language and connected to the OAI stub via socket interfaces. Accordingly, the OAI stub architecture provides means of evaluating V2X applications prototypes, while providing a highly flexible way to replace the underlying V2X models for large-scale emulations.

In the following section, we provide two case studies that illustrate the benefit of the proposed tool in prototyping of V2X applications in large-scale scenarios and two different V2X communication conditions.

IV. Case Study – V2X Awareness Application

With the introduction of SL supported by the PC5 interface to interconnect two or more UEs, new communication modes have been designed for V2V communications. One of the most relevant ones is the LTE-V2X mode 4 defined in Release 14 [6], [7]. LTE-V2X mode 4 is used by vehicles to autonomously select their radio resources without the assistance of the cellular infrastructure. It is based on a Sensing-Based Semi-Persistent Scheduling (SB-SPS) that has been so far well studied and researched [4]. In fact, an analytical performance model has been derived recently under a wide range of parameters and conditions in [8].

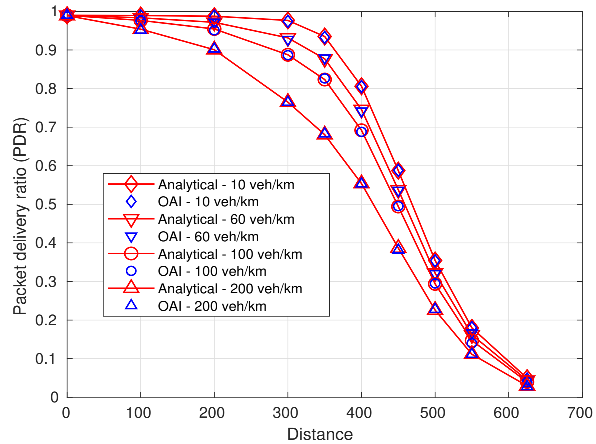

Fig. 4: Packet Delivery Ratio as a function of the distance between transmitter and receiver for the SB-SPS scheduler. Comparison of analytical values and results obtained with the proposed prototyping tool.

In the same way, a distributed protocol STDMA, originally considered as an alternative to CSMA/CA [9], has been adapted for SL communications [5] because of its desirable properties for safety-critical communications. It employs a slot reservation system taken into account the slots reserved by other terminals in proximity, while enabling users to transmit periodical messages.

A. Large-scale V2X evaluations

The SB-SPS is the default C-V2X scheduler available in future commercial C-V2X products. A vehicle reserves selected resources for a random number of consecutive packets, and new resources are selected based on a sensing process that takes into account the previously received and detected packets [2]. Using the proposed prototyping tool, we examine the impact of this scheduler on a V2X awareness application prototype under large-scale conditions.

For that end, we have used the PDR curves of the analytical performance model proposed in [8] considering a highway scenario with different traffic densities, the Winner+ B1 propagation model and the BLER curves defined in R1-160284 (DMRS enhancement of V2V in 3GPP). Both OAI UEs periodically transmit 10 packets per second (size 190 bytes), and we configure the stub for adding additional vehicles, each also periodically transmitting 10 packets per second with a transmission power of 20 dBm, and a packet

[2]For more details, the reader may be referred to [4] and references therein.

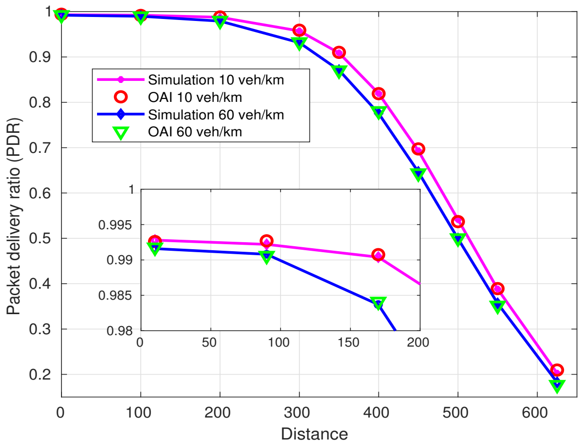

Fig. 5: Packet Delivery Ratio as a function of the distance between transmitter and receiver for the STDMA scheduler. Comparison of simulated values and results obtained with the proposed prototyping tool.

size of 190 bytes. The stub emulates a 10MHz channel in the 5.9GHz band [3].The obtained results are shown in Fig. 4 for four different traffic densities. The solid lines show the analytical PDR, while OAI tests are depicted with markers. Note that both values are close one another with minor differences. It can be explained due to the employed number of packet transmissions that for this example was set to 10^4. Hence, it confirms the feasibility to emulate the impact of an increasing V2X communication density on a OAI-based V2X application prototype.

B. Flexible V2X communication conditions

Due to its modular design, the proposed architecture allows us to easily replace the default C-V2X communication model by another one. For instance, reliability and delay are relevant features for time-critical and safety applications, and some V2X schedulers will provide better features for meeting these requirements.

In this example, we replace the SB-SPS scheduler by a STDMA scheduler and again evaluate its performance for the same V2X Awareness prototype under a large-scale scenario. To illustrate the flexibility of the stub architecture, we integrate to the stub API PDR obtained from a computer-based simulation of the STDMA C-V2X scheduler. In Fig. 5, we show the obtained PDR for lower densities, and zoom in for a closer view at shorter distances. This time, it is computed by launching 10^5 packet transmissions, and depicted along with their corresponding computer-based simulations, just for purposes of validation.

In addition, it worth highlighting that our functional tool can be also employed for comparisons against commonly adopted solutions, e.g. SB-SPS scheduler, under the same and more realistic conditions, and thus the obtained results can be used as a key factor before the final adoption of these approaches in a targeted V2X application.

[3]According to the analytical model used by the OAI stub, more complex mobility or channel models may be considered as well.

V. Conclusions and Future Work

In this paper, we presented a new OpenAirInterface stub interface enabling flexible V2X application prototyping under large-scale scenarios. The stub connects C-V2X UEs prototypes at the MAC layer and emulates the underlying C-V2X software and hardware. We showed that the performance of a V2X awareness prototype running on two OAI C-V2X UEs under large-scale scenarios closely matches those from analytical or simulation models. In future work, we will further extend the emulation capabilities of the OpenAirInterface C-V2X architecture by providing emulations at the Physical layer, which will enable to test V2X scheduler prototypes under flexible V2X channel conditions.

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Disclaimer

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