Simulation as a Key Technology for V2X Applications

Vehicle-to-Everything (V2X) is regarded as a key technology for higher safety and efficiency in road traffic but makes high demands on development and validation. Complex interactions, particularly between road users, can be modeled in real-world tests only to a limited extent and by investing a major effort. IPG Automotive shows how by means of a new interface integrated in CarMaker V2X functions can be validated systematically, realistically, and efficiently.

© IPG Automotive GmbH

WRITTEN BY

Viktor Lizenberg
is Engineer Test Systems & Engineering at IPG Automotive GmbH in Karlsruhe (Germany).

Fabian Specka
is Manager Engineering Research & AddOn at IPG Automotive GmbH in Karlsruhe (Germany).

Henning Kemper
is Senior Specialist Editor at IPG Automotive GmbH in Karlsruhe (Germany).

The objective of V2X communication is to sustainably increase traffic safety and efficiency. It enables fast, wireless exchange of information, creating the basis for interaction between road users. V2X applications provide situation-independent assistance to drivers and vehicles.

Essentially, V2X applications coordinate actions and reactions in the context of perception, environment detection, and cooperative driving. That primarily includes the dissemination of information and warnings regarding priority rules, traffic jams, or danger points. The development of respective functions is a current research subject in which concept design, implementation, and practical testing of prototypical applications are of paramount importance – one example is the autotech.agil project [1].

Stage	Goal	Typical Messages (ETSI / SAE)
Day 1 (Awareness Driving)	Increase of situational awareness through regular exchange of status and event information	Cooperative Awareness Message (CAM) [3], Decentralized Environmental Notification Message (DENM) [4], Basic Safety Message (BSM) [5], Signal Phase and Timing Message (SPAT) [5], Map Data Message (MAP) [5]
Day 2 (Sensing Driving)	Extended environment perception through sensor data sharing	Collective Perception Message (CPM) [6], Radio Technical Commission for Maritime Services Corrections Message (RTCM) [5]
Day 3+ (Cooperative Driving)	Coordinated driving maneuvers through exchange of driving intentions	Maneuver Coordination Message (MCM) [7]

TABLE 1 Overview of the development stages according to C2C-CC (© IPG Automotive GmbH)

The greatest challenge lies in validation: V2X functions require tests in complex scenarios with several communication partners. Simulation can assist here but current approaches are usually operated in open-loop settings which is inadequate for comprehensive functional assessments. Thus, simulations in closed-loop settings are a decisive step enabling realistic modeling of the interaction between action and reaction.

In this article, IPG Automotive presents a new approach to V2X simulation permitting the closed-loop version via a configurable communication model and offering flexible interfaces for software and hardware integration. Standardized V2X protocols can be used directly or customized for specific test scenarios.

DEVELOPMENT STAGES

V2X communication is a collective term for various forms of vehicle communication, including, among other things, communication between different vehicles or between vehicles and infrastructure. According to the Car 2 Car Communication Consortium (C2C-CC) [2], the associated use cases of assisted, partially, and fully automated driving functions can typically be divided into three development stages, **TABLE 1**.

The data exchange between the communication partners occurs via standardized V2X messages. The content of these messages is specified by standardization bodies – in Europe by the European Telecommunications Standards Institute (ETSI), in the United States and in parts of Asia by the Society of Automotive Engineers (SAE).

Day 1 use cases serve to issue collision and accident warnings and transmission of traffic light phases and prioritization information. Day 2 use cases extend the scope by the exchange of data from external sensors and make a substantial contribution to increased traffic safety. This applies particularly to the protection of vulnerable road users such as pedestrians and cyclists. Day 3+ use cases are focused on maneuvers such as cooperative merging, turning, or overtaking enabled by exchanging planned vehicle trajectories.

DEVELOPMENT PROCESS

In the development of V2X applications, simulation can significantly contribute to making functional validation more efficient and economical in numerous use cases of relevance to field conditions. Virtual scenarios with variable general conditions enable a consistent test workflow and considerably reduce efforts and costs compared to real-world tests. However, this presupposes that the simulation considers realistic conditions of V2X communication. Particularly relevant in that regard is strict compliance with existing communication protocols.

V2X communication principally follows standardized regulatory frameworks that are organized as software stacks in the form of multi-layered communication protocols. **FIGURE 1** shows a typical architecture of a V2X communication stack according to ETSI [8, 9]. The facilities layer in this case processes the V2X messages (for example CAM, DENM) and provides them as a structured data source for V2X applications.

In this context, the differentiation between Software-in-the-Loop (SiL) tests and Hardware-in-the-Loop (HiL) tests is of paramount importance. With SiL, it is frequently sufficient to simulate the applications and facilities levels to comprehensively and systematically assess the behavior of the V2X applications under test. By contrast, in the case of HiL, the entire communication

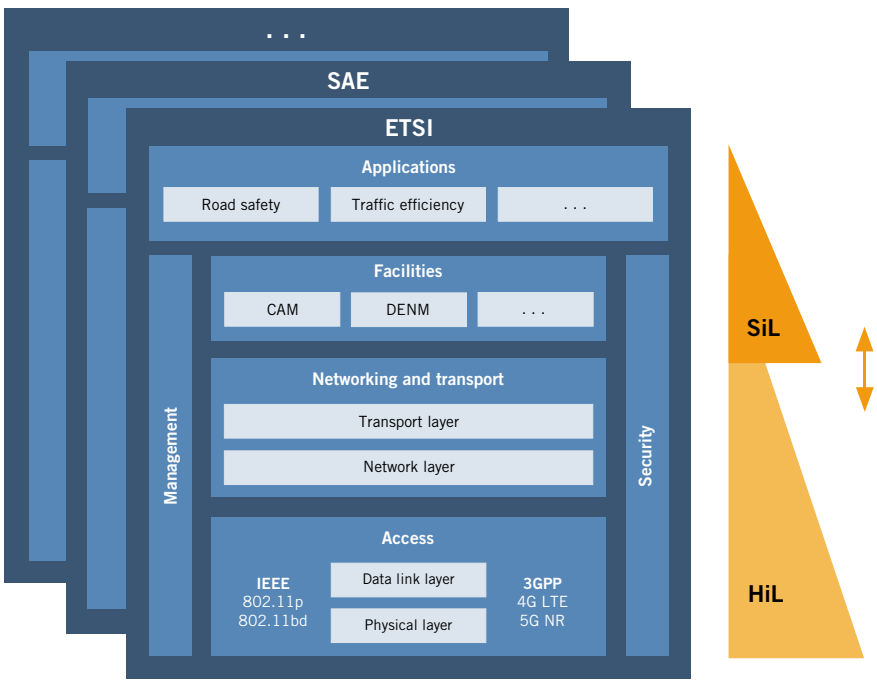

FIGURE 1 Architecture of a V2X communication stack (© IPG Automotive GmbH)

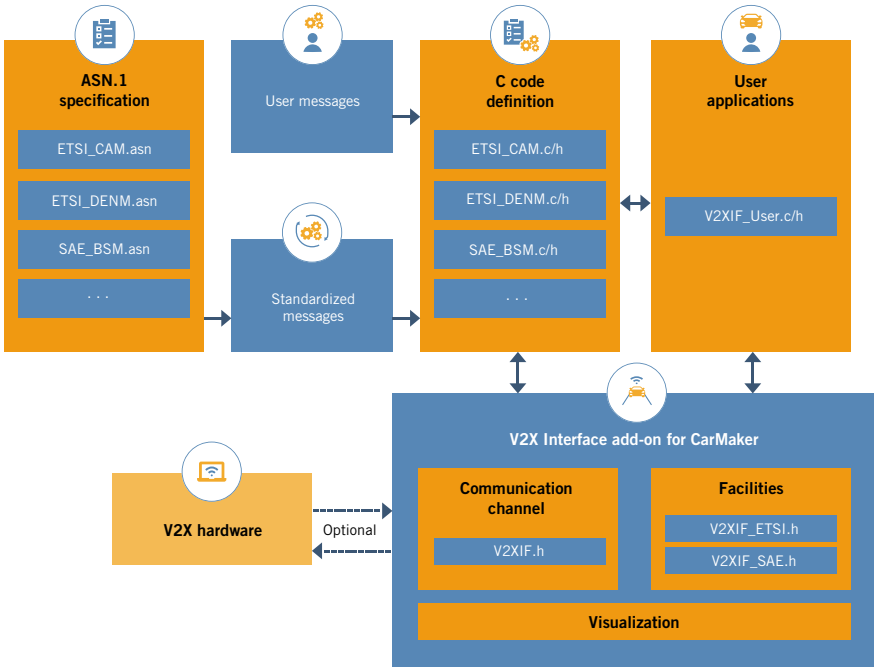

FIGURE 2 Simulation solution with the V2X Interface (© IPG Automotive GmbH)

stack, including real-world physical effects of radio wave propagation can be included. This enables a more comprehensive and realistic validation.

That is why the simulation interfaces must be designed to be independent of the specific implementation of the communication protocols. Individual layers or even complete stacks can thus be exchanged. Depending on the use case, the access level can, for instance, be represented by the protocols of the WLAN-based communication (standards: IEEE 802.11p, 802.11bd) or mobile telecommunications (standards: 3GPP 4G LTE, 5G NR).

To meet the requirements mentioned before, the intuitive and user-friendly add-on V2X Interface [10] for the vehicle simulation environment CarMaker has been developed. It offers a programming interface (API) with a graphic user interface (GUI) and enables the operation of several standard-conformant V2X communication protocols within the vehicle simulation, **FIGURE 2**.

Using this approach, the V2X messages from the ASN.1 specifications are translated into corresponding C code definitions by means of the asn1c compiler [11]. As a result, standardized messages can be used or customized and completely new messages created, **FIGURE 3**. The translation process here is demonstrated using the header from the structure of a Collective Perception Message (CPM) as an example.

These V2X messages are integrated into the V2X Interface that provides the respective facilities functionality and a communication channel model – complemented by a comprehensive 3D visualization. A V2X application under test can be linked to this setup directly via the C code definitions of the messages. This creates a closed-loop interaction between the V2X application and the virtual road users in the simulation based on a standard-conformant exchange of messages for a reliable validation.

The phenomenological communication channel model integrated in the

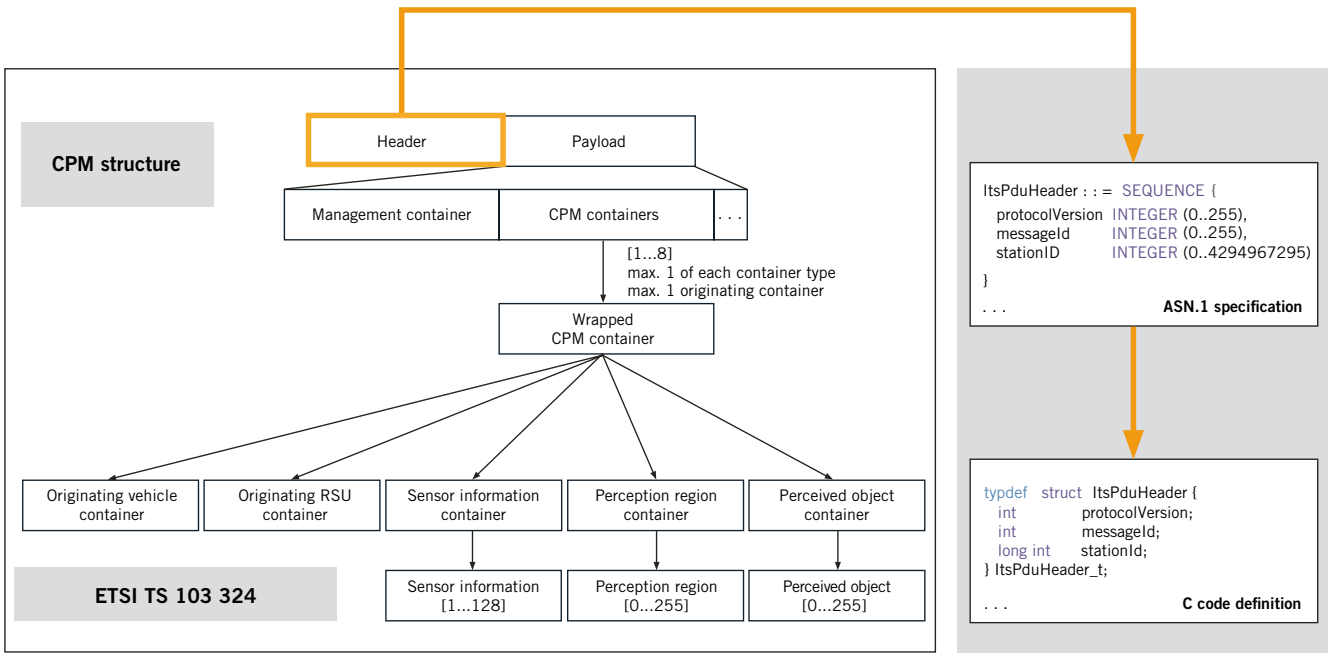

FIGURE 3 Translation of the Collective Perception Message in C code (© IPG Automotive GmbH)

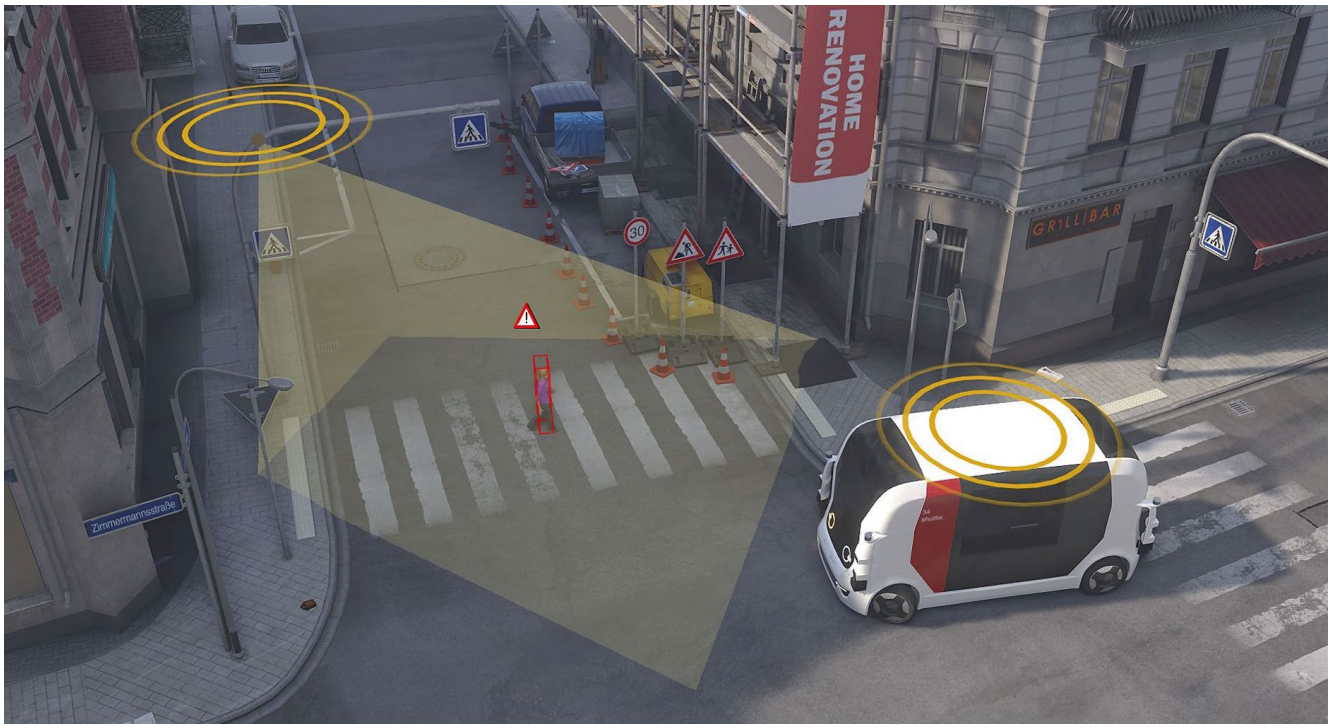

FIGURE 4 Simulation at an urban intersection with limited visibility (© IPG Automotive GmbH)

V2X Interface add-on enables the simulation of physical effects such as range, message delays, and message loss and is therefore predestined particularly for SiL setups. Optionally, for HiL setups, a V2X hardware module can be connected to represent the entire signal processing including real-world radio communications.

EXAMPLE OF A USE CASE

FIGURE 4 shows an exemplary application: At an urban intersection with limited visibility, for instance due to parked vehicles or structural obstacles, a pedestrian steps onto the pedestrian crosswalk. Initially, the person is not detectable for approaching vehicles. An infrastructure sensor installed at the intersection captures the pedestrian's motion reliably and in real time.

This information is broadcast in the form of a CPM via the V2X communication and received by an approaching autonomous vehicle. Due to the early notification, the vehicle can reduce its speed, reassess the situation, and carry out its planned turning maneuver with special caution. As a result, a potentially hazardous situation is defused before it would even be visible for the vehicle.

SUMMARY AND OUTLOOK

V2X communication plays a key role for optimizing vehicle interactions and traffic safety. With the V2X Interface, closed-loop simulations for SiL and HiL setups can be flexibly implemented. The integrated combined communication channel model and utilization of standardized V2X messages enable targeted customization to suit specific test requirements. In that way, the simulation supports realistic development and validation processes for connected driving functions.

Going forward, it is planned to extend additional V2X message content, especially for scenarios with vulnerable road users such as pedestrians and cyclists. Consequently, this approach makes a major contribution to implementing current and future V2X technologies in the context of increasing connectivity and automation.

REFERENCES

[1] autotech.agil: Architecture and Technologies for Orchestrating Automotive Agility. Online: www.autotechagil.de/en, access: August 14, 2025
[2] C2C-CC: About C-ITS. Online: www.car-2-car.org/about-c-its, access: August 14, 2025
[3] ETSI TS 103 900: Intelligent Transport Systems (ITS); Facilities Layer; Cooperative Awareness Service; Release 2. V2.2.1 (2025-02)
[4] ETSI TS 103 831: Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Decentralized Environmental Notification Service; Release 2. V2.2.1 (2024-04)
[5] SAE J2735: V2X Communications Message Set Dictionary (2024-09)
[6] ETSI TS 103 324: Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Collective Perception Service; Release 2. V2.1.1 (2023-06)
[7] ETSI TR 103 578: Intelligent Transport Systems (ITS); Vehicular Communications; Manoeuvre Coordination Service (MCS); Pre-standardization study; Release 2. Version V2.1.1 (2024-04)
[8] ETSI TS 103 898: Intelligent Transport Systems (ITS); Communications Architecture; Release 2. V2.0.0 (2022-07)
[9] ETSI EN 302 665: Intelligent Transport Systems (ITS); Communications Architecture. V1.1.1 (2010-09)
[10] Lizenberg, V.; Specka. F.; Hauenstein, J.; Mayer, M.: Using Simulation in the Development of V2X Applications. In: ELIV – 22nd International Congress and Exhibition, Bonn, Germany, No. 2441, pp. 233-242, VDI (2024)
[11] Walkin, L.: Open Source ASN.1 Compiler. Online: lionet.info/asn1c/compiler.html, access: August 14, 2025

THANKS

This research work was performed as part of the "autotech.agil" project (funding identifier 01IS22088). The authors thank the German Federal Ministry of Research, Technology and Space (BMFTR) for the financial support.

Accelerating the future of sustainable mobility

Innovative solutions for
the market of tomorrow

One drives all

Our **Integrated Drive Module** simplifies the electrification of all kinds of vehicles.

BORGWARNER