Smart Highway: An Interoperable V2X Testbed for Connected and Autonomous Mobility Services in Belgium

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Abstract

For advancing the research and development of cooperative, connected and autonomous mobility (CCAM), the Smart Highway testbed has been developed and deployed, aiming at providing the possibility for measuring vehicle-to-everything (V2X) communication protocols. This testbed is deployed across the E313 highway near Antwerp, Belgium offering features such as edge computing, precise positioning, and V2X connectivity. Several use cases have been developed, tested, and evaluated, showcasing the cutting-edge features of the Smart Highway testbed. Aiming to make the provided CCAM services accessible all-over the European Union member countries, cross testbed testing has been performed, validating the interoperability of the Smart Highway testbed.

Keywords:

Vehicular communication infrastructure, testbed, V2X, CCAM, connected cars, ITS-G5, C-V2X, edge, cloud

Introduction

The Smart Highway testbed has been deployed in Belgium [1], built under the Smart Highway and Concorda project[1]. The testbed is focusing on vehicular communications use cases, ready for 5G technologies and beyond, and enabling features such as edge computing concept and network virtualization planned for future AI-driven use cases [2]. Trials have started since April 2019, where the feasibility of the use cases have been publicly demonstrated on top of the infrastructure [3]. The testbed consists of cars with On-Board Units (OBUs) and Roadside Units (RSUs) installed along the highway as roadside infrastructures.

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[1] https://concordaproject.eu/

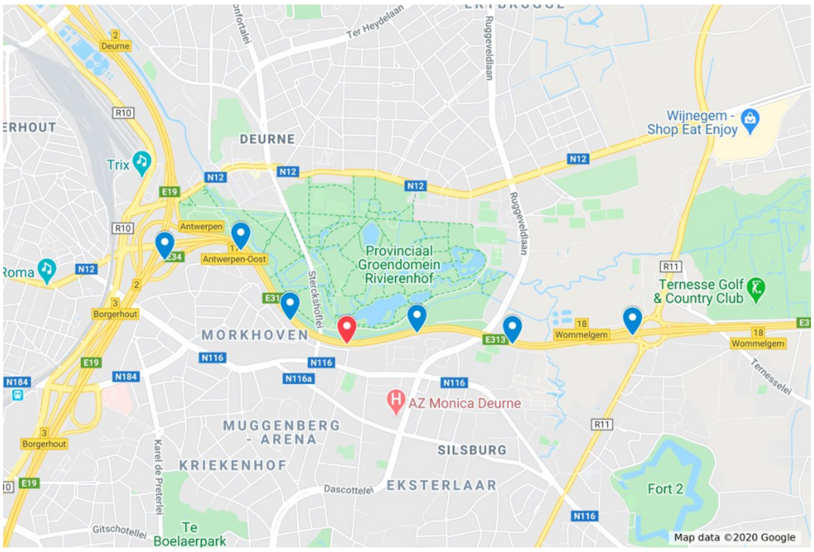

Figure 1 – Location of the testbed with RSUs installed in E313 Highway, Antwerp

In terms of connectivity, our testbed has been equipped with Software Defined Radio (SDR) modules. It allows for flexible switching between technologies, supporting new upcoming standards, and anticipating the technology unavailability. With the presence of SDR platforms in the testbed, the testbed will be able to support 5G and beyond capabilities, as well as 6G in the near future. With both 3.5 and 5.9 GHhz bands supported in the platform, it is possible to do measurements and evaluation in Cellular V2X (C-V2X). This opens research opportunities for investigating the coexistence with other standardised technologies.

In addition to the connectivity feature, the Smart Highway testbed can provide edge computing services for the CCAM vertical. The RSUs are connected to the backend via a fibre connection. This allows for the connection to the traffic management centre in order to provide traffic services in the car through the dashboards, for instance. Furthermore, data can be propagated in the network from the backend towards the RSUs in a geo-aware manner. As an example, when there is an accident, the RSU that is informed about the accident via short range communication technology, can send the data to the backend, and afterwards the data is propagated into the RSU near the accident location for faster notification of cars in the vicinity. In addition, edge features are supported by the fact that RSUs are equipped with server class computing units. Services deployed on the testbed can enjoy the full potential of cloud and edge capabilities, paving a way towards flexibility in terms of latency.

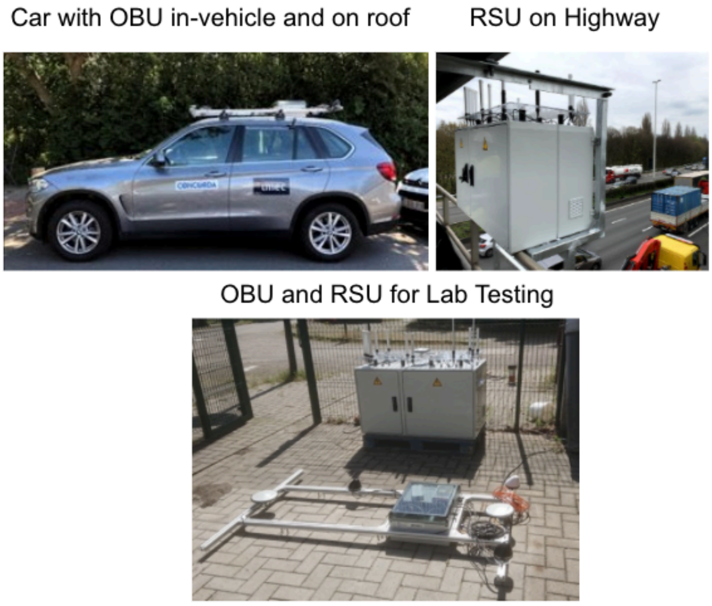

Figure 2 – Smart Highway Testbed

Precise positioning is also a feature offered in the smart highway testbed. Equipped with GNSS receivers, the testbed is further enhanced with RTK correction signals that are calculated at RSUs.

With these sets of features, the testbed, which is located at the E313 highway, can be further extended to the urban road network. The plan is to make it interconnected to the Citylab testbed [4]. This will allow testing of V2X connectivity and functionalities in a mixed environment. Currently, the test site comprises a track around 4 km, stretching from the Ring of Antwerp towards Wommelgem, above an intersection. This can open up more use cases since the RSU can serve suburban roads, offering features not only for cars but also vulnerable road users (VRUs), such as cyclists or pedestrians.

Smart Highway Testbed Architecture

The main components of the Smart Highway testbed architecture are RSUs, OBUs, and the backend.

RSUs

The RSUs are capable of interchanging data with vehicles, using several V2X communication technologies, including short-range ITS-G5 and C-V2X PC5, and long-range C-V2X Uu. The test site consists of 7 RSUs installed on the gantries along the E313 highway spanning a 4 km track. Since the deployment is outdoors, a custom enclosure box has been designed, capable of protecting sensitive components such as the computational units and the wireless modules. An additional RSU was built for laboratory testing. This RSU has been deployed at the Campus Groenenborger of the University of

Antwerp and allows the development and pre-testing of new functionality and services before migrating them at the highway. In addition to commercial off-the-shelf (COTS) communication modules, SDR boards are also deployed, allowing for V2X related research beyond standardized and commercial solutions.

Figure 3 – Road Side Unit

The different components of the RSU, as well as the most important connections between them, are shown in the figure below.

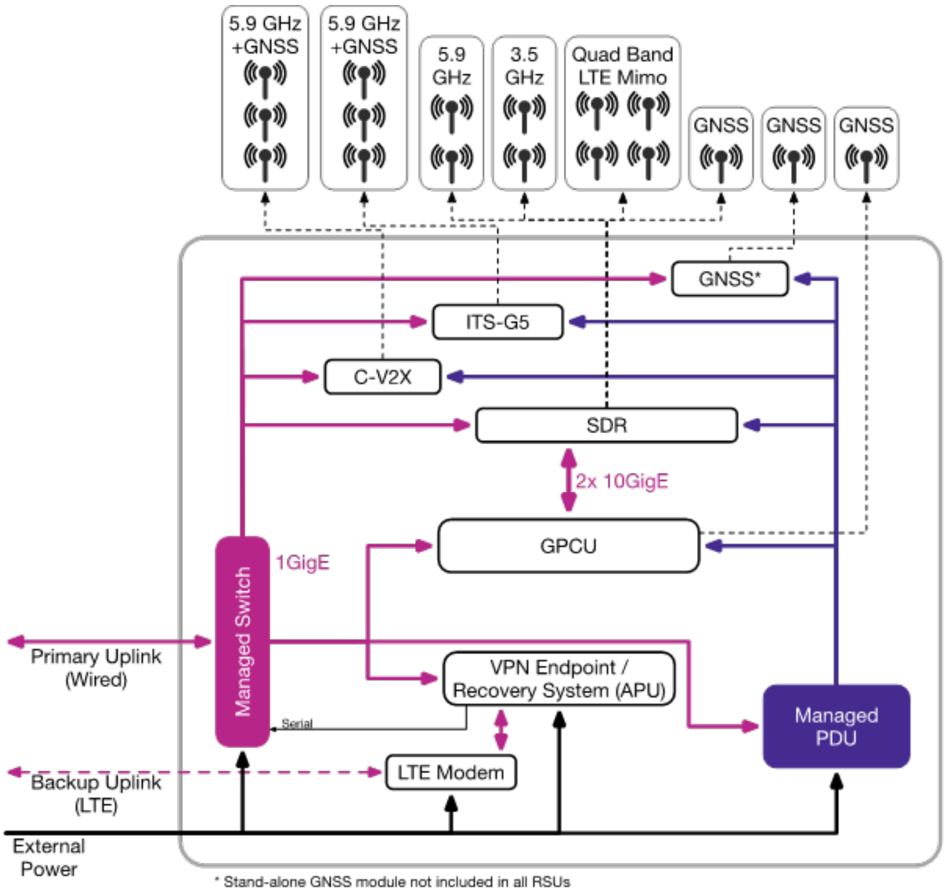

Figure 4 – RSU Architecture

The processing component in the RSU is the GPCU (General Purpose Compute Unit), that can provide powerful computation. This serves both as a node for edge computing use cases as well as a controller for experiments involving any of the wireless communication inside the RSU.

OBUs

Real vehicles are deployed for V2X experiments, equipped with an OBU. The on-board unit (OBU) is a unit added to existing vehicles to allow full control over the in-vehicle connectivity and in-vehicle infrastructure. It contains sensing and processing hardware along with V2X-communication hardware to provide an interface with the Smart Highway infrastructure. The OBU architecture is split into two separate units. The two OBU units and their components are shown in the figure below.

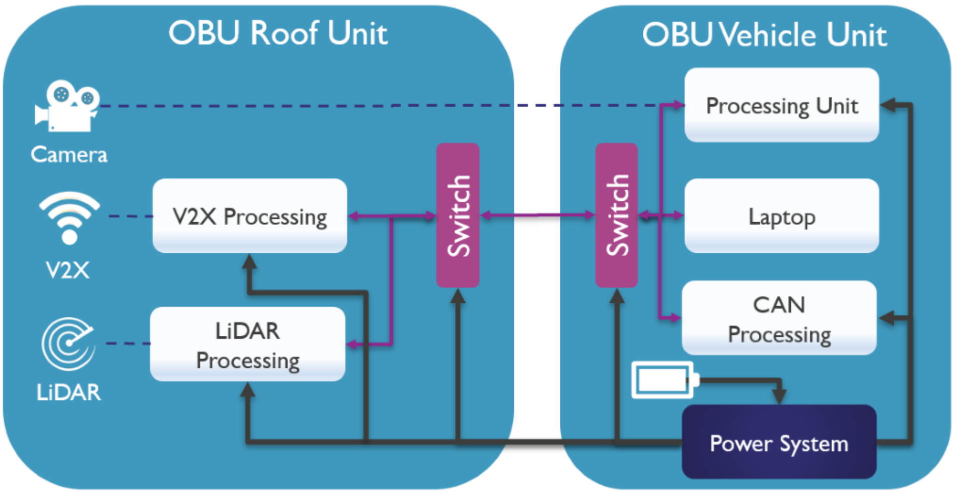

Figure 5 – OBU Architecture

The first OBU unit is installed inside the vehicle and contains all the main processing components, power system and in-vehicle sensor processing (e.g. CAN processing), as in-vehicle unit. This OBU is also powered by a power system that can provide energy to the OBU for several hours without using any power from the vehicle. The main processing unit is a processor in combination with a dedicated GPU. The GPU is used for sensor processing. This processing component can thus provide edge computing capabilities.

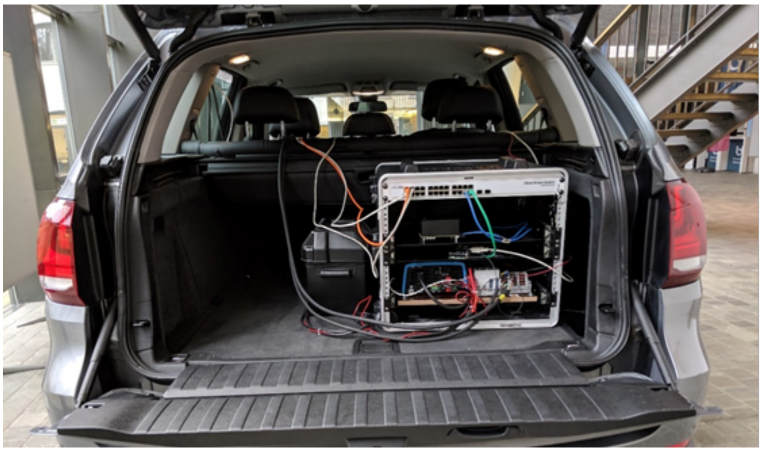

Figure 6 – In-Vehicle Unit

The second OBU unit is installed on the roof of the vehicle and is only connected to the vehicle OBU with an Ethernet connection, power connection and camera connection (depending on the camera setup used in the vehicle), as the roof unit. The roof unit contains all the V2X communication hardware and the processing units of sensors that are mounted on top of the vehicle. The V2X modules consist of ITS-G5 and C-V2X modules running on 5.9 GHz band. For the long-range part, this OBU has also a 4G LTE module able to be connected to a mobile network. Furthermore, this unit has LiDAR mounted, as well as GNSS receiver that is accurate within 5 nanoseconds, providing a more precise time synchronization. This GNSS receiver are also able to localize within 1cm.

Figure 7 – Roof Unit

Cloud based Backend

On the backend, we have deployed a system to handle the data in the cloud. Data management has been implemented, allowing the testbed to have the data to be queried and interfaced with other traffic data backends to exchange information. This allows for the integration with a traffic authority to provide traffic information on the testbed. The backend is connected via fibre to the RSUs. The OBUs can connect to the backend via the MNOs networks, as shown in Figure 8 on the architecture.

Furthermore, we have also implemented a publish/subscribe service in the testbed. This service provides data communication between different entities, such as OBUs and RSUs over cellular networks. By implementing a standardized and secured message exchange framework using a message broker system, the deployment and evaluation of C-ITS services and CCAM can be realised. This service is based on MQTT, and allows interconnectivity using the standardized IF2 Intercor interfaces [5].

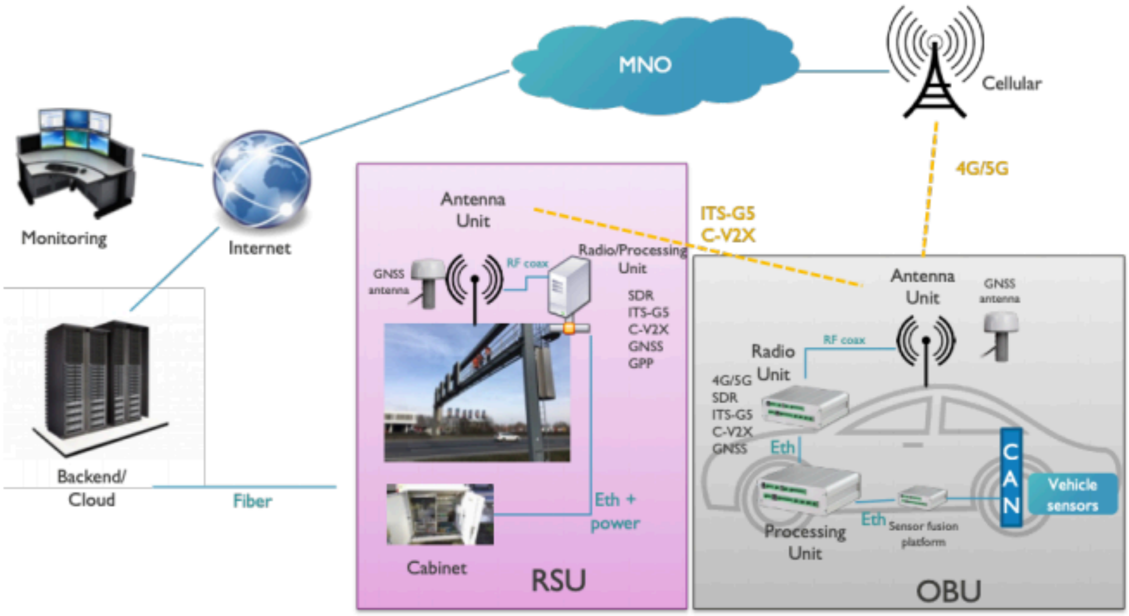

Figure 8 – Smart Highway Architecture

V2X Measurement between OBU and RSU

By the time that the testbed became available in Spring of 2019, several test campaigns have been performed aiming to evaluate the performance of the different V2X technologies in real-world environment. different During these test campaigns, both short- range and long- range communication technologies have been evaluated,measuring the performance of ITS-G5, C-V2X PC5, and C-V2X Uus. This provides a benchmark for different use case scenarios.

For both the C-V2X PC5 and ITS-G5 technologies, the logging of the packets is being done on every module, upon a transmission or reception event. Additionally, logging is being done at the communication units that are connected with each V2X module. The communication unit in OBU is an Intel NUC. At the RSU, this is a server system (GPCU). At the NUC or GPCU-level, logging of the 4G transmission and reception is being done as well. Figure 9 shows the logging points for both short range (C-V2X and ITS-G5) and long range (4G) technologies.

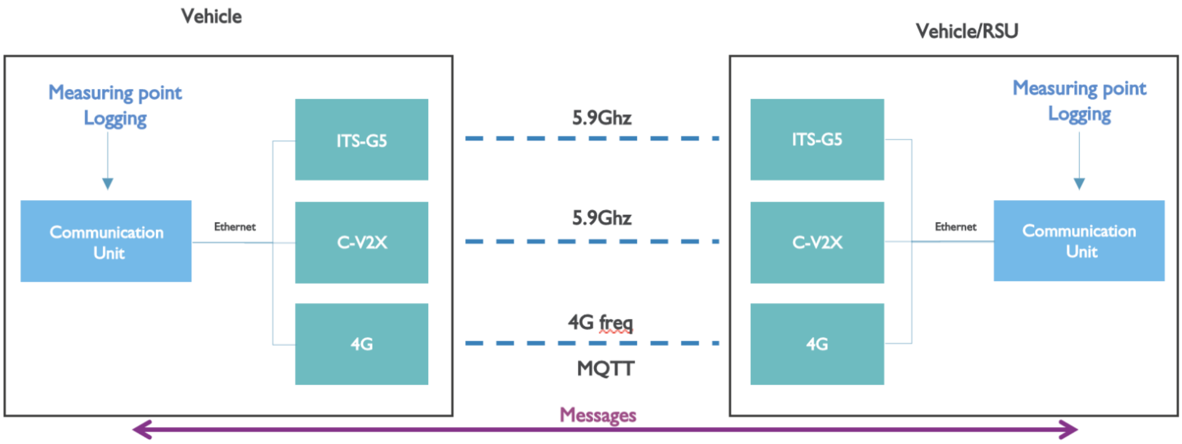

Figure 9 – Messaging between Units

In one of the first test campaigns, we have tested the connectivity of OBU towards the RSU in terms of relative distance and the elapsed time of the experiment. The test campaign was done with one of the RSUs at the E313 highway. During this test campaign, we tested the connectivity on the testbed using ITS-G5 andC-V2X PC5 communication technologies. An example result is shown in Figure 10.

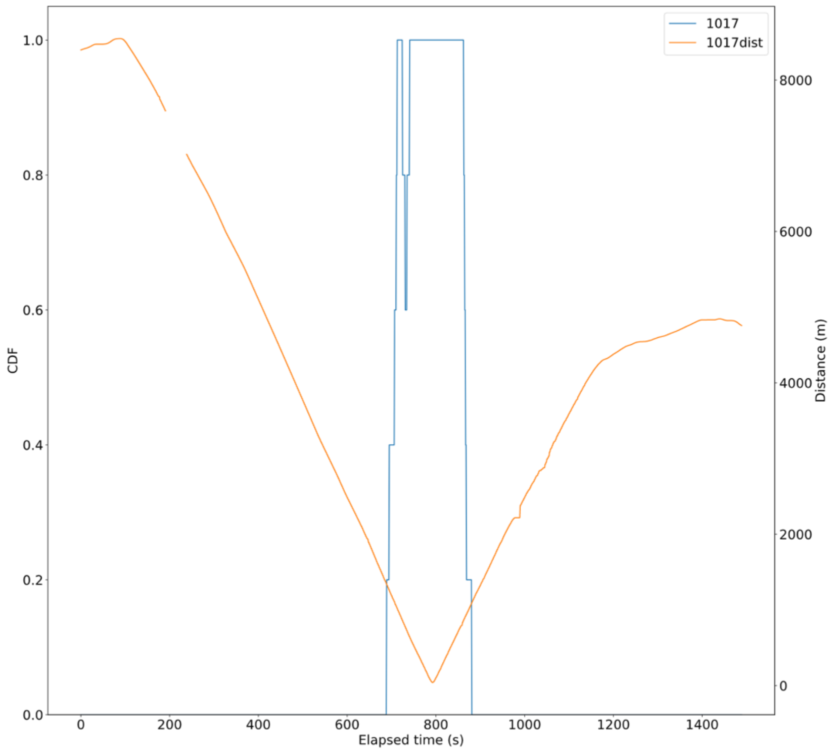

Figure 10 – CDF on Distance and Time between OBU and RSU

Interoperability with Netherlands Pilot Site

In an effort to make the testbed usable and open to the V2X community, we have conducted a feasibility study on the interoperability of the testbed. The cross-site testing was performed at the A16 highway near Dordrecht, Netherlands. There, we have tested the capability of receiving Infrastructure to Vehicle Information Messages (IVIM) using ITS-G5 technology. Several virtual scenarios were tested (e.g., speed limits and lane closure).

The interoperability was made possible thanks to the Intercor IF2 interface, which interconnects the backend system between the Netherlands test site and the Smart Highway testbed in Belgium. Via the IF2, messages can be interchanged between the test sites in a secure and standardized way. As an example, Figure 11 shows the packet loss between an RSU and the OBU that was measured during a drive test at the A16 using ITS-G5 technology.

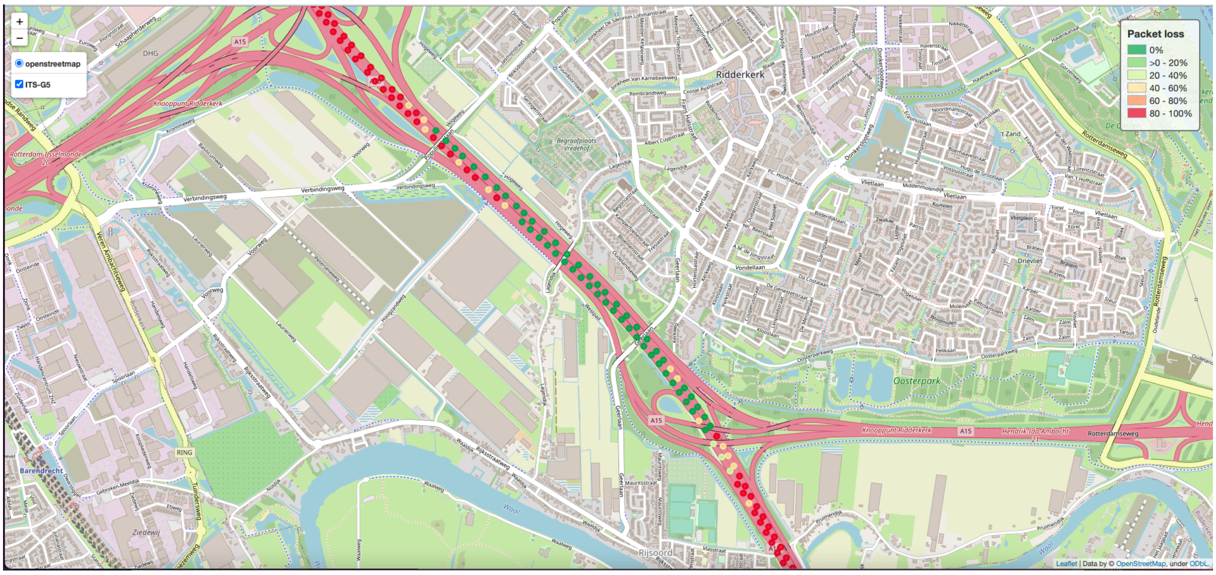

Figure 11 – Packet Loss on an RSU during the Test Campaign in Netherlands Test Site

Conclusion

In this paper, we have presented the Smart highway testbed, along with its main features. The testbed architecture has been described, including the V2X connectivity and edge processing components. The testbed supports V2X related field testing in the real-world conditions of a highway environment. This allows for investigating the connectivity behaviour between vehicles and roadside infrastructure. In addition, in order to make the testbed available to the V2X research community, we have looked into interoperability with other testbeds. We have performed cross-site tests in the Netherlands, where we have shown that it is possible to test use cases between testbeds.

In the future, we aim to enhance the testbed providing support 5G and beyond capabilities. In addition, in order to make the testbed remotely accessible, we aim to deploy a platform to easily configure the testbed. The testbed will be embedded with a toolkit that allows experimenters to control the RSUs and OBUs in order to provide maximum flexibility for experimentation in the future.

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