V2X Communication Test Tool for Scenario-Based Assessment of Truck Platooning

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Abstract: The EU-funded ENSEMBLE project* designs, realizes, tests and validates novel multi-brand platooning technology for trucks in a consortium consisting of all European truck OEMs, first-tier suppliers, branch organisations and academic and research institutes. This paper describes the project's approach towards (intermediate) testing of the V2X communications, specifically focusing at Hardware-in-the-Loop (HiL) testing through the use of a custom V2X Test Tool developed in ENSEMBLE. The tool enables scenario-based assessment of truck platooning with the newly defined platooning protocol and (pre-standard) V2V messages. Next to V2V message conformance testing, it offers V2X communication functional testing and performance testing capabilities for different platooning scenarios. The V2X Test Tool is used for verification and validation of platooning solutions, and facilitates the next steps of testing truck platooning at proving grounds and in real-life environments.

1 INTRODUCTION

The last decade platooning technology and research has made many advances, but the step towards real-life deployment of truck platooning still needs to be taken. It is the ambition of the EU project ENSEMBLE (ENSEMBLE Consortium, 2022) to use a multi-brand truck platooning approach and to define Intelligent Transport System (ITS) standards for interoperable truck platooning in Europe. For this, the specifications for a multi-brand truck platooning concept has been worked out. Important parts of the specification are newly defined protocols for the platooning interactions and V2V (Vehicle-to-Vehicle) communication message sets. A platooning "reference design" is developed to realize a generic platooning implementation (non-brand specific). This is used by the partnering truck manufacturers to prepare for the multi-brand testing and the demonstration of the ENSEMBLE truck platooning concept. All six European truck OEMs are involved in the project.

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The platooning concept describes the functional architecture together with a minimum set of requirements and specifications for the platooning operational and tactical layers. The main building blocks are the use cases, the in-vehicle system requirements, the platoon V2V communication function and platooning management and maneuvering coordination functions. V2X (X for everything) communication technology is a important enabler for safe platooning of trucks at short following distances (Ploeg, 2014). State of the art on truck platooning technology and related research projects are presented in (Willemsen et al., 2018). Generic V2X testing is addressed in (Wang et al., 2019), where (Gao et al., 2016) focuses on V2X simulation tooling for platooning applications. In (Voronov et al., 2015) the focus is on an interactive test tool enabling remote V2X communication testing, which includes specific communication Hardware-in-the-Loop (HiL) setups. Specific platooning HiL-based testing is further addressed in (Schindler et al., 2019). For scenario-based assessment (Op den Camp et al., 2021) and (Sluis et al., 2021) identify V2X testing capabilities, test scenarios and approaches for truck platooning.

Specific test tools need to be developed for the engineering activities (verification & validation) and the

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assessments of the ENSEMBLE platooning concept. This paper explains the ENSEMBLE V2X Test Tool developed for testing the V2V communication function and platooning protocol interactions. It identifies V2V testing capabilities, suitable test scenarios and challenges which needs to be addressed as part of truck platooning assessments. The V2X Test Tool enabled the OEMs to develop and test their (mono-brand) implementations against the ENSEMBLE reference design, and already locally prepare for multi-brand testing.

The remainder of this paper is organized as follows. Section 2 describes the truck platooning concept with the platooning protocol design. Section 3 gives the main assessment methods of truck platooning, and Section 4 describes in detail the developed platooning V2X Test Tool and its capabilities. And Section 5 concludes with our findings and outlook for future work.

2 TRUCK PLATOONING CONCEPT

Truck platooning can potentially make road transport safer, cleaner and more efficient (ACEA, 2017). V2X communication plays an important role in enabling vehicle platooning. Two or more vehicles equipped with automated driving support systems are linked together via V2V communications. Figure 1 gives a high-level overview of the ENSEMBLE platooning layers as defined in (Willemsen et al., 2022). The reference design to be implemented and tested is defined as a "Platoon Support Function" (PSF) for the driver, who also acts as back-up and is responsible for monitoring the driving task. In addition a Platoon Autonomous Function (PAF) has been defined, which does not rely on a driver as back-up (in the following vehicles) so a high level of automation is needed and therefore it is currently not part of the reference design.

Referring to Figure 1, the vehicle control component is part of the *operational layer*; it is responsible, with its actuators and controllers, for the execution of the vehicle and platoon maneuvering like accelerating, braking, and steering. The vehicle sensors used as input for the PSF are also part of this operational layer.

The PSF resides mainly at the *tactical layer*, which is for decision-making and coordination of the platoon. The PSF supports platoon manoeuvres like platoon forming (joining/leaving the platoon), keeping "platoon cohesion" (for example on hilly roads) and keeping the desired speed and inter-vehicle distance when platooning. Finally, another important part of the tactical layer is the platooning protocol used for supporting the platooning interactions.

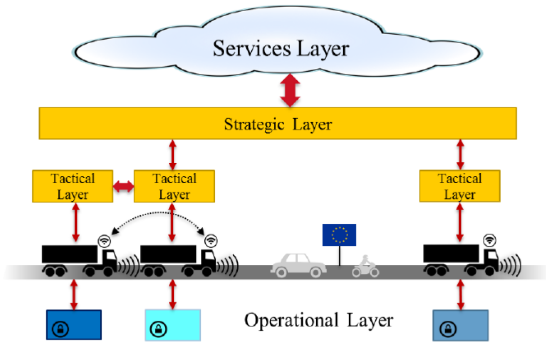

Figure 1: Illustration of the ENSEMBLE Platooning layers (Willemsen et al., 2022).

The *strategic layer* supports the high-level decision-making related to (route) planning, scheduling, optimisations for travel time, traffic situations etc. This layer connects to the service layer at which logistics operations can interact.

2.1 V2X Platooning Protocol

One of the key goals of the ENSEMBLE project is stating the specifications for a V2X communication protocol to enable inter-operable platooning using wireless communication (Atanassow and Sjöberg, 2022). These specifications describe how vehicles inform each other about their platoon capabilities, and define the V2V message set and respective data formats for the exchange of data supporting the defined platoon manoeuvres (e.g. driving in the platoon, joining a platoon).

The V2V messages used are:

- The Cooperative Awareness Message (CAM) (ETSI, 2019b) for broadcasting vehicle information. Within ENSEMBLE, the original CAM is extended with an *isJoinable* field to announce that a vehicle can be part of a platoon, provided that all prerequisites for safe platooning are met.
- The Platoon Management Message (PMM) for managing a platoon (Atanassow and Sjöberg, 2022). The PMM is a newly defined message using event-based communication for handling *Join Request*, *Join Response* and *Leave* interactions. The interactions which are part of the *Join* actions also involves sharing specific platoon capabilities amongst the members and setting up a secure (encrypted) communication channel for the platoon.
- The Platoon Control Message (PCM) for intra-platoon exchange of operational and tactical data

to support the PSF (Atanassow and Sjöberg, 2022). As PMM, the PCM is a newly defined message; PCM message exchange takes place over the secure communication channel. Every platoon member transmits PCMs at a high update rate (20 Hz) and the information is used for vehicle control functions like adaptive cruise control (ACC), emergency braking and platoon maneuvering (normal platooning, platoon cohesion).

Figure 2 gives a simplified view of the V2V message exchange between two vehicles, from joining a platoon, actual platooning, up-to leaving the platoon.

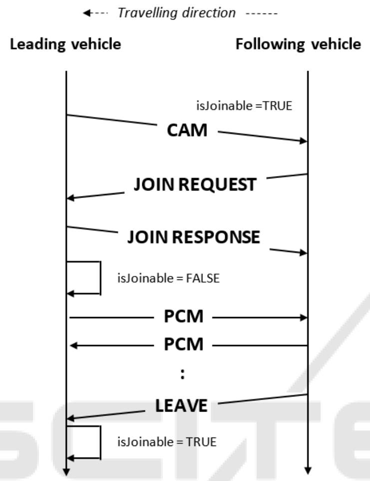

Figure 2: Platooning interactions from joining to leaving (Atanassow and Sjöberg, 2022).

The interaction starts from an *IDLE* mode situation and the *Leading Vehicle* (LV) announcing that it can be part of a platoon by setting the boolean flag *isJoinable* in its CAMs to True. A vehicle indicated as *Following Vehicle* (FV) receiving the CAMs from the LV, and interested to platoon can send out a PMM ”Join Request”. Meeting certain conditions the vehicles transmitting or receiving a *Join Request* will move to a *JOIN* mode (*isJoinable*=False for other idle vehicles).

Once the LV has decided that it accepts the FV for joining, the LV transmits a (positive) *Join Response* (PMM) containing additional platoon information, a security key and all the information needed to set-up a secure channel for PCM exchange. The LV also starts transmitting its PCMs and when it receives PCMs from the FV it will move to *PLATOON* mode. The FV also moves to *PLATOON* mode when the LV starts its PCM transmissions. The role of the FV then changes to *Trailing Vehicle* (TV) as it is the last vehicle of the platoon, but this is left out of the figure. Note that vehicles in *PLATOON* mode are always transmitting and receiving PCMs.

Just like the LV previously, the (now) TV can again transmit CAMs with *isJoinable*=True, allowing other vehicles to join the platoon from behind. In that case, a candidate vehicle (i.e., a third vehicle wanting to join the two-vehicle platoon) then interacts with the TV of the platoon, and not directly with the FV.

A vehicle ends up in *LEAVE* mode either when PCMs have not been received from the other vehicle(s) during some predefined time period, or because the ego-vehicle decides to leave the platoon which is shared by transmitting a PMM *Leave* message ending PCM transmissions.

In addition to the message set and protocol interactions, a V2X security framework for platooning is specified in (Atanassow et al., 2022). Starting point for this is the existing public key infrastructure (PKI) developed for C-ITS (ETSI, 2017b). All broadcast messages are signed and verified using temporary authorization tickets. (This mechanism is to a large degree application agnostic.) For secure end-to-end platooning, application-specific encryption is used for all PCMs to provide additional confidentiality. PMMs are used for the exchange of the platooning security keys and their updates (security keys are updated regularly).

The security framework adds, next to the offered protection, also a layer of complexity. For reasons of simplicity, platooning security is considered out-of-scope in this paper, because on the PSF tactical level this does not change the protocol operational logic or platooning interactions.

2.2 Platooning Scenarios

The ENSEMBLE platooning protocol is designed to support the interactions of the PSF. The defined set of platooning use cases are described in (Willemsen et al., 2022), together with specifications on platoon characteristics, relevant high-level platooning maneuvers, Human Machine Interface (HMI) interactions and environmental conditions. The scenario definitions include information of the maneuvers, the specific Operational Design Domain (ODD) conditions and relevant ”events” (for example cut-in vehicle, emergency braking, system failures). A use case is a combination of a scenario description together with a set of initial and final conditions, and a defined set of interaction sequences.

The supported high-level maneuvers in the platoon are:

- Platoon engage: Platoon Join, Merge in between
- Platooning: Steady-state Platooning, Platoon gap adaptation.

- Platoon Disengage: Platoon Leave, Platoon Split.

These are the main platooning maneuvers as part of the PSF which are supported by the V2V platooning protocol, and these are also the relevant test scenarios considered for the V2X Test Tool.

The "Joining from behind by a single vehicle" scenario is used as an example test case of a Platoon engage manoeuvre. In Figure 3 the Start situation is the ego vehicle as a *Candidate Member* (CM) and is driving behind an truck (LV) that is joinable for platooning (announced via its CAM). Like mentioned before,

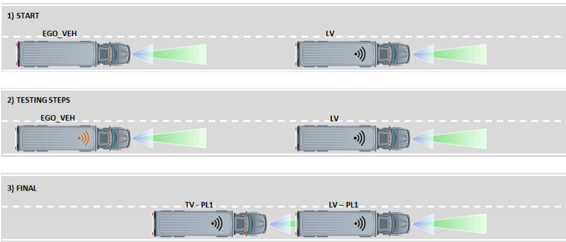

Figure 3: Join from behind by a single vehicle scenario.

some pre-conditions have to be met for the ego vehicle and LV. The platooning systems needs to be operational, the vehicles are in communication range with no other vehicles in-between. The ego vehicle driver activates the platooning function. As the ego vehicle is receiving the *isJoinable* information from the LV, the system can start the joining procedure. In Step 2, the ego vehicle request to join by transmitting PMM *Join Request*. The LV receives the *Join Request* message, evaluate the correct joining conditions and sends a PMM *Join Response* (accept) message. In step 3 the engage action is finalised, the ego vehicle and LV are ending the join procedure with the exchanged PCMs which are used to close the distance-gap to an agreed time-headway value. The ego-vehicle is part of the platoon (PL1) and is now the *Trailing Vehicle* (TV) of the platoon. It can now itself transmit *isJoinable* announcements via its CAMs.

3 ASSESSMENT METHODS OF TRUCK PLATOONING

The scenario-based assessment methodology of (H2020 Project HEADSTART, 2020) mention four main testing methods: Virtual Testing (VT), XiL-based (for everything-in-the-loop), Proving Ground (PG) and Field testing (FT). The methodology is used for safety assessment of Connected and Cooperative Automated Driving applications, and uses the truck platooning application as a selected use cases for assessment. V2X communication is normally not part of the available scenarios descriptions and extensions are needed to include V2X communication in the used testing methods. In the following sections each testing methods is briefly described for the truck platooning scenarios.

3.1 Virtual Testing

To test scenarios virtually, a framework for enabling the execution of the appropriate scenario descriptions is needed. This top-level is needed for control and management of the virtual testing environment. Also it contains scenario modelling functions with elements for the static environment (for example highway road layout) and the dynamic environment (for example other vehicles). Then for the PSF, different functional blocks can be identified for:

- Driving functions.
- Vehicle dynamics.
- Sensors.

The driving function relates to the PSF and other automated driving functions. This also includes the platooning decision-making functions based on sensor inputs. The sensor block gets all its input from the virtual environment. The model accuracy highly depends on the provided fidelity of the sensor data. The actions coming from the driving functions are passed to the vehicle dynamics block, that contains the virtual vehicle model as part of the PSF.

3.2 XiL-based Testing

X-in-the-loop (XiL) based testing is a method of testing that combines VT with real hardware implementations. The amount of virtual and real elements can vary greatly: from only having a single platform, sensor or actuator as part of a Hardware-in-Loop (HiL) set-up, up to having a complete vehicle-in-the-loop (ViL). The XiL-based testing is often a good compromise between proving ground testing which is very realistic and VT that allows for testing a higher number of scenarios. Our work focus on testing the V2X communication functions as part of the PSF. The V2X Test Tool includes the communication hardware, often called on-board unit (OBU) with the V2V communication software supporting the PSF tactical functions. Specific test scenarios have been developed for assessing the supported PSF maneuvers, the related platooning protocol interactions and V2V message exchanges. The platooning scenarios enables V2V assessments for: conformance testing of the V2V platoon messages; functional testing of the platooning protocol; and performance testing of the V2V communication and the PSF at tactical layer level.

3.3 Proving Ground Testing

Proving Ground testing is a key part for assessing the performance of automated driving systems. For truck platooning full system performance can be evaluated as part of the single vehicle, and with the vehicle as part of the platoon, in a real-world environment. This is not possible with the VT and XiL-based solutions, PG testing is often the first opportunity to do platooning testing with actual driving vehicles and execute scenarios with platoon specific manoeuvres (example Platoon Join). Execution of the platooning scenarios and related test cases are always in the context of optimization costs and effectively using available PG time and resources.

3.4 Field Testing

Field Testing or open road testing often follows successful PG testing. For truck platooning, its aim is to test the PSF in the real world and evaluate the platoon maneuvering in its defined ODD. Route selection is important to have suitable roads with the correct required infrastructure elements. For truck platooning, the test plan and test case definitions need to address the local regulations and exemptions required to be able to execute PSF testing on public roads.

4 V2X TEST TOOL FOR PLATOONING

In order to meet the requirements for early XiL-based testing of communication and interaction protocols within ENSEMBLE, a V2X Test Tool has been designed, realized and deployed. The next sections describe its design guidelines, architecture and various components.

4.1 Design Guidelines and Architecture

For the design of the V2X Test Tool, the following considerations and guidelines were adhered to:

- Portability: The V2X Test Tool must run on various hardware platforms and under various Operating Systems (Windows, Mac, Linux). For this reason, a Java-based system was designed. This requirement was particularly important as the tool was intended to be run by the project partners on-site.
- Ease of Use: The software should be easy to use, in order to accommodate the diverse nature of the end users. For this requirement, it was important to realize that end users come from varying backgrounds (control, software engineering, automotive, ...).
- Single-Screen Status and Control: The control and status reporting of the V2X Test Tool should be implemented using a single ”all-in-one” screen, to the extent possible.
- Modularity: The software should be designed and realized in agreement with modern software-engineering views on modularity, object orientation and information hiding. This requirement hopefully assists in smooth integration of other applications and/or modules.
- Reuse of existing hardware and software: To the extent possible, the V2X Test Tool should be constructed using existing (TNO or open-source) reusable software components and libraries.
- Version Control: The V2X Test Tool was realized while the ENSEMBLE platooning protocols had not fully crystallized yet. It was therefore crucial for the V2X Test Tool to be able to run different revisions of the platooning protocol, even side-by-side.
- Low Cost (to the end user): Through the use of Java technology instead of the perhaps more common MATLAB/Simulink environment, the end user saves on licensing costs and is given the flexibility to quickly (re)deploy the tool. All that is needed is a Java©virtual machine.

In view of the fact that TNO has had an experimental On-Board Unit (OBU) in operational use for several years, it was decided to reuse reuse this component. The OBU allows for reception and transmission of ITS-G5 frames in the ITS-G5A Band (and others) (ETSI, 2020), using a UDP-based protocol to transfer payload and frame control data to and from the clients.

The V2X Test Tool architecture is shown in Figure 4. The box on the left represents the V2X Test Tool Java software, consisting roughly of a Graphical User Interface and running a single instance of a V-ITS-S (Virtual ITS Station) and multiple so-called V2X Tests. The top-right shows the OBU connected to the V2X Test Tool. The bottom right shows the Device Under Test.

4.2 On-Board Unit

The On-Board Unit provided with the V2X Test Tool in the ENSEMBLE project is shown is Figure 5. In

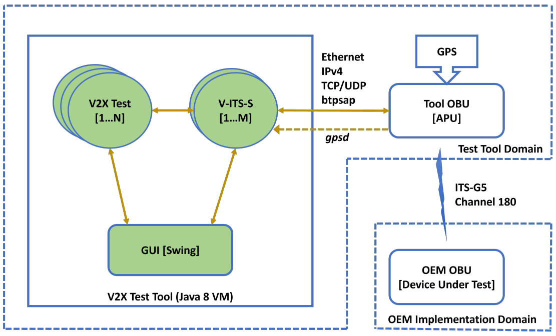

Figure 4: The V2X Test Tool architecture.

its most common setup it consists of an PCEngines APU board running a modified Linux kernel that allows for operation of a standard PCI Express WLAN card on ITS-G5. On top of that, a software component named *btpsap* implements the GeoNetworking (ETSI, 2017a) and Basic Transport Protocol (BTP) (ETSI, 2019a) as well as the security functions within GeoNetworking (encapsulation into and decapsulation out of a security envelope and signing and verifying messages). The *btpsap* software communicates with its client over a TCP connection and one or more UDP streams. The interface definition of *btpsap* is publicly available (de Jongh et al., 2018), which allows for third-party alternative implementations based on for instance cellular communications.

Figure 5: The On-Board Unit deployed with the V2X Test Tool.

4.3 V2X Test Tool Capabilities

The tool has the following capabilities:

- Sending and receiving CAM, CAM+ (with *isJoinable* extension) and platooning-specific messages: PMM, PCM. Both the CAM/CAM+ and PCM message rates are user configurable.
- Logging messages.
- Presenting decoded messages in real-time.
- Defining so-called Virtual ITS Stations that are capable of interacting with the System under Test (SuT), e.g., by pretending to be a following vehicle wanting to join the SuT in a platoon.
- Maintaining a Local Dynamic Map on each V-ITS-S.
- Running a simplified (e.g., by omitting several sanity checks) platooning controller on each V-ITS-S.
- Using a variety of sources for the position of a V-ITS-S, e.g. making it follow another V-ITS-S through the use its received CAM messages.
- Run multiple versions of the platooning protocol.
- Perform platooning test scenarios (join, leave, platoon), in the different roles (LV, FV, TV, CM).

Currently, the V2X Test Tool focuses at logical interactions needed to test the platooning protocol. Issues related to the wireless medium (packet loss; transmission latency) are currently not in scope. It is conceivable, though, to define packet-loss test scenarios.

4.4 Virtual ITS Station

A key feature of the V2X Test Tool is that of a *Virtual ITS Station (V-ITS-S)*. A V-ITS-S represents a station in software with options to connect to for instance a real-world GPS sensor or OBU. That way, the software implementing the V-ITS-S can be subjected to a variety of tests. A simple test, for instance, is to check whether the GPS sensor data (like position fixes) are properly encoded in transmitted CAM messages.

The V-ITS-S implementation is highly modular, allowing for application-specific modules providing custom message sets and/or application logic. For ENSEMBLE, a dedicated platooning module was developed with support for CAM+, PMM and PCM messages (in various stages of development) and for platooning (V2X) protocols.

The primary use of a V-ITS-S is to test platooning implementations of project partners on site using (e.g.) a laptop running JAVA connected to a supplied OBU. We were therefore able to test, in an early stage, the non-trivial ASN.1 encoding and decoding of the platooning messages, and at least ensure *message interoperability*.

4.5 Position and Time

The provisioning of position and time estimates to V-ITS-S instances, to the OBU and to the V2X Test Tool itself is of crucial importance. At the same time, given the flexibility of the tool, some noteworthy variations in the setup are possible. An example of the appearance of Position and Time controls in the GUI of the tool is shown in Figure 6.

For time, a V-ITS-S can use either the system time or connect to a *gpsd* (Various, 2022b) instance. In either case, time-warping is implemented; allowing for a fixed offset with the real time. This has proven useful for replaying scenarios with trace data like message exchanges. Using the system time is the easiest setup and most appropriate for systems that already have time synchronization set up at the required stratum level (e.g., through *ntpd* (Various, 2022c) or *chronyd* (Various, 2022a)). Using *gpsd* as a source for both position and time is most convenient for connecting the V-ITS-S with the external OBU. Due to its reliance on accurate position and time in order to run GeoNetworking, the OBU is already equipped with a GPS receiver and running *gpsd* instance. As warping in time, *position warping* is supported as well, translating each position update to a different area on the globe.

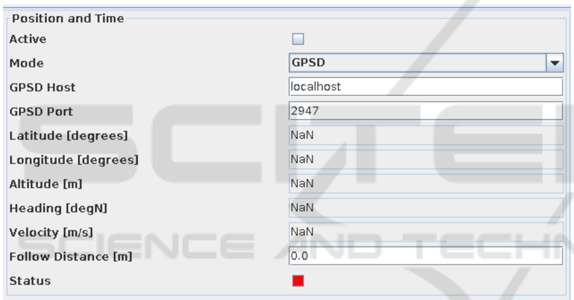

Figure 6: The Position and Time panel in the V2X Test Tool GUI.

Two interesting alternatives for position update are file-based updates (successive positions are taken from file) and *follow mode*, in which position updates are such that it "follows" another station at a certain distance. This is particularly useful for bench-testing controllers in distance-dependent applications like platooning.

4.6 Local Dynamic Map

In the V2X Test Tool, each V-ITS-S is equipped with a *Local Dynamic Map (LDM)* (ETSI, 2014), a table holding recently heard stations through (for instance) CAM messages. Since by virtue of (ETSI, 2019b), ITS Stations are obliged to always send CAMs, it is relatively easy to maintain a view on the "local neighborhood" in each V-ITS-S . By its very nature, the LDM is application-agnostic, yet the implementation allows for application-specific extensions (message sets, flags, . . .).

In the LDM, ITS stations are indexed by their ITS Station ID. An example of the appearance of the LDM in the GUI of the tool is shown in Figure 7.

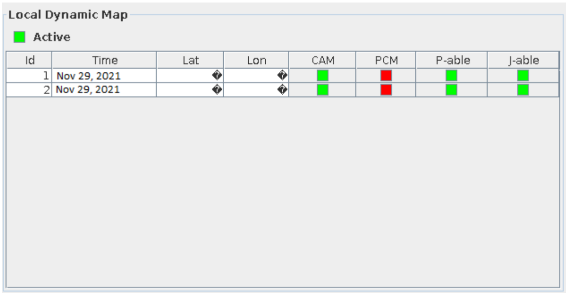

Figure 7: The Local Dynamic Map in the V2X Test Tool GUI.

4.7 Test Scenarios

The V2X Test Tool supports the following (automated) test scenarios:

- Sending and receiving CAM(+) messages.
- JOIN: The V-ITS-S attempts to join the ITS Station the SuT represents. After successful completion of the join request and join response message exchange, the V-ITS-S starts sending, as required, PCM messages and expect PCM messages from the station it joined.
- BE_JOINED: The V-ITS-S prepares to be joined from behind by the SuT. For instance, it signals its willingness to be joined in the CAM+ messages it transmits. It then expects a join request, checks the request and if applicable, sends a positive response. It then checks for subsequent transmission of PCM messages by the DUT.
- LEAVE: The V-ITS-S leaves the platoon it is currently part of (it may be in front or behind the SuT station).

4.8 Abstract Platooning Model

As mentioned earlier, the V2X Test Tool has a specific module for platooning support. The module, however, was realized using a more abstract platooning model than the one designed in ENSEMBLE.

In the first model, the concept of platooning is seen, from a V2X perspective, as a highly controlled temporary unidirectional association between *two* stations, the *front* and *rear* vehicles, respectively. The main protocol components then become the *join* and *leave* operations, and the duties that come with the association once created, like sending dedicated state messages (PCMs in the case of ENSEMBLE).

The platooning model in the tool focuses on the separate communication interactions between a station and its predecessor and successor (whenever applicable). In the bottom line of the platooning pane in the V2X Test Tool, shown in Figure 8, the platooning state of the front and rear controllers are shown through indicators (Platooning State [local]). The indicator in the middle signals that platooning is complete in former sense: both front and rear controllers are connected to another station, and the platoon is in steady state (no ongoing join or leave actions).

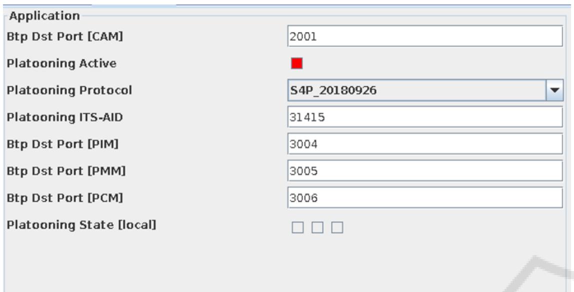

Figure 8: The Platooning (application) pane in the V2X Test Tool.

The main advantage of using a somewhat more abstract model for platooning is that it allows for quick adaption to changes in the concrete (ENSEMBLE) platooning protocol, as long as the protocol fits in the model. In particular, we rarely needed changes in the V2X Test Tool GUI despite the frequent changes in the ENSEMBLE protocol. Finally, it allowed the use of the V2X Test Tool while *designing* the protocol itself. Certain protocol features during design could thus be evaluated in an early stage.

5 FINDINGS

The ENSEMBLE V2X Test Tool was designed, realized and deployed in an early stage of the specification of truck platooning in ENSEMBLE. It proved its use as a verification and validation tool, for debugging and testing, conformance testing of the V2V platooning message sets, and also served as a protocol-assessment tool. As mentioned earlier, the tool proved a great help to ensure message interoperability at a relatively early stage of the ENSEMBLE project. It is essential to have such a tool, because current available commercial V2X communication tools does not support the non-standard project-defined platooning message sets, or the relevant test scenario for platooning.

Other advantages include its use as a debugging tool in Field Testing (since the tool features frame capturing and analysis). Also it is possible to use the tool for performance analysis, for example by using stress testing scenarios with: high message loads; higher updates rates; high number of Station ID's; etc. Another option for performance analysis is creating failure scenarios by using wrong messaging (format, timing, protocol logic, message drop, etc.) for testing the robustness of the platooning protocol and higher application layers. The main performance results from the ENSEMBLE project are available in (Kalose and Goos, 2022); reflections on the v2x protocols can be found in (Mascalchi et al., 2022).

Finally, the development of the V2X Test Tool itself required an early in-depth analysis of the ENSEMBLE protocol, which resulted in useful feedback during protocol design. In a way, it forced the early implementation of the ENSEMBLE message sets and protocol logic long before the finalization of the platooning specifications.

In the near future, we hope to fully implement the security features of the ENSEMBLE protocol, in particular transmitting and receiving the symmetrically encrypted PCM message. Together with security test scenarios for the validation of the security functionality and for identifying possible vulnerabilities and threats. Thus offering useful verification and validation feedback as a security engineering tool for taking mitigating actions against security threats. Also, we intend to reuse the V2X Test Tool in future Cooperative Automated Driving and ITS projects aiming at development and implementations of novel message sets and protocols. And to extend it with subsequent suitable testing scenarios supporting the cooperative interactions.

The source code for the V2X Test Tool is available upon request for research purposes.

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