NEW TEST AND EVALUATION METHODS FOR FUTURE CAR2X COMMUNICATION BASED DRIVER ASSISTANCE

Markus Glaab
Alois Mauthofer
carhs.communication GmbH
Germany
Udi Naamani
Connected Vehicle Proving Center
USA
Paper Number 09-0447

ABSTRACT

Wireless communication technologies between cars and infrastructure (Car2X communication) will play a major role for future driver assistance. Many new applications and services in the fields of vehicle safety, comfort and infotainment will be possible. New test and evaluation procedures are required to cover future cooperative traffic scenarios with many cars and infrastructure equipment involved. An enrichment of real test situations with simulated environment scenarios (“Extended Reality”) is proposed as an approach to develop and test such systems. An integrated development and test environment provides a flexible and configurable combination of both, real and simulated units including OnBoardUnits, RoadSideUnits, MonitoringDevices and on-board displays with modules e.g. for wireless communication (WAVE, DSRC, WLAN, UMTS), positioning (GPS), vehicle and infrastructure interfaces (CAN-Bus), which can be combined in any manner. Based on the integrated architecture a real Car2X testing scenario consisting of a car communicating with RoadSideUnit(s) providing traffic sign and traffic light information was first developed and tested in full simulation mode in the lab. Then the same scenario was validated in a real test car on the real test track of the Connected Vehicle Proving Center in USA still with a simulated infrastructure environment. Based on that received information warning messages appeared on the on-board display. Active driver assistance functions can be triggered as well. The novel approach allows evaluation of the technology benefits and effectiveness with significantly reduced efforts as compared to traditional operational testing methods. This paper will cover the technology employed; the assistance and safety scenarios evaluated and give an outlook on the future use of the technology in combination with field operational tests.

INTRODUCTION

Future Driver Assistance Systems in vehicles will also be based on advanced technologies like Car2X communication techniques. Adding wireless communication to cars enables multiple new opportunities for enhancing safety, mobility, energy efficiency and driving experience in vehicles, which never existed before. But this also has implications on the requirements for test and evaluation procedures. When considered in a very simplified fashion Car2X communication maybe mistakenly viewed as just another type sensor which is simple and well known in the art testing and evaluation methods. However, when considered from a more detailed point of view, it becomes apparent that a significantly more complicated scope of testing and evaluating is required: Now a car exchanges information with other cars (C2C) or roadside (C2R) or the infrastructure (C2I). For example it might get the information regarding an accident or glazed frost hundreds of meters ahead. These sample use-cases illustrate that the sources of relevant quantities for test and evaluation of those Driver Assistance Systems are not anymore a physical or a controlled part of the vehicle. Hence the vehicle with its assistance systems can no longer be tested stand-alone. This kind of vehicle has to be tested in a complete environment consisting at any times of many other cars and Road-Side-Equipment (RSE) such as traffic lights, equipped with communication technology. In terms of cooperative systems it has to be considered that the environment of the vehicle operates within is not static. The behavior of the vehicle itself influences its environment. It may cause traffic lights to change the current and programmed phase or it may cause other cars and their driver assistance systems to react on the current situation. The new requirements illustrated above have to be considered and evaluated during all development-stages: from the research and development of applications to their final test and evaluation it is highly desired to use the cost effective simulated environment on a development PC at early stages and introducing progressive levels of reality with real vehicles and a real environment. Thus simulation tools are indispensable for the development of future Driver Assistance Systems under complex and dynamic traffic scenarios that...
include many communication units. Common
simulation tools are commonly used for simulating
the communication network (e.g. ns-2 [1]) or the
traffic flow (e.g. VISSIM [2]). But these tools
usually run in simulation-time and not in real-time.
They cover only parts of a whole Car2X scenario
and are not designed for the combination of
communication networks, traffic and individual
Car2X scenarios. Optimized vehicle
communication technologies are still a part of
research and standardization processes both in
Europe [3][4] and the United States [5][6].
Nevertheless, even at an early stage, verification
and validation capabilities help research scientists,
communication engineers and developers of driver
assistance systems (which are basically the users of
those communication technologies), because they
provide possibility of immediate feedback.

DEVELOPMENT ENVIRONMENT VIILAB

The software package viilab (vehicle infrastructure
integration laboratory) [7] has been especially
designed for the requirements of Car2X application
developers. viilab is an integrated development and
test environment designed to support the whole
development process of Car2X-based driver
assistance systems from the initial idea up to pilot-
series.

Basic Architecture

The development environment viilab is based on a
modular software-architecture (see figure 1).

Figure 1. viilab architecture.

There are basically two types of modules: (1)
Modules to connect the environment such as
communication modules (DSRC, WLAN, etc.),
vehicle modules (CAN-Bus, GPS, Display/HMI,
etc.) and infrastructure modules (traffic light
adaptor, traffic control adaptor, traffic monitoring
camera, etc.). (2) Logic modules (a.k.a. decision
modules) which implement the driver assistance
functionality and handle all information from the
other modules. The viilab kernel manages the
lifetime (startup and shutdown) and scheduling of
all software modules and functions as their runtime
environment.

Unit Set-up

The different types of units and their specific
behaviors are achieved by assembling the necessary
environmental modules with the related logic
module. For instance a typical OBU has a
communication module, a CAN-Bus module, a
GPS module, a display/HMI module and a logic
module. The logic module contains the driving
assistance application(s). The logic module deals
with all the OBU modules, processes the received
data, calculates the results/outputs and overall
defines the behavior of this specific OBU. A
typical RSU for an intersection for example,
consists of a communication module, a traffic light
and traffic control module and the appropriate logic
module to handle these information-sources.
Figure 2 illustrates a sample configuration for an
OBU and a RSU.

Scenario Set-up

A typical Car2X-scenario consists of many
elements. Since a running viilab-unit is only a
single process, a scenario is simply a combination
of units each represented by a process. Depending
on the needs and the stage the development
process, the combination of all those units can
easily run on only one computer or, if so desired,
on many different computers (see chapter
simulation enhancements).

Rapid development support

Viilab incorporates two parallel concepts: It
supports the rapid development and prototyping of
Car2X applications and at the same time enables
the low-level coding and thus highly efficient
development of algorithms and/or for integration of new hardware. The first concept – rapid development – is realized by a scripting language which has been specifically adapted to the needs and requirements of communication based driver assistance systems. It is often used to realize parts of the unit-logic, e.g. to for the combination of vehicle communications events with vehicle electronics. The scripting option is mostly attractive for actuating elements in each part of the Car2X-application that are under development where it is highly desirable and efficient to easily implement changes without any compiling effort. The second concept – highly efficient low-level code development – is realized by the fact, that viilab offers a C/C++ API which is designed to further be used for effective implementation of hardware modules.

viilab user interface

To complete a working Car2X system a user interface must be provided. In-car displays can be rapidly developed and customized with a specific viilab GUI development environment called viilab user interface (vui). vui uses SOAP/TCP based information transfer which enables remote display access. This also enables a distributed installation, where the GUI may run on a different device to avoid high processor loads on critical communication events due to display updates. vui is based on the Gecko Rendering Engine and XUL technology. This approach allows a highly flexible development process and a strict separation between design, layout and user interaction. Just as viilab it supports different operating systems, e.g. Linux and Windows (XP, Vista). To simplify handling of states, vui provides a configurable storyboard concept. A control file specifies states and their transitions, significantly exceeding the possibilities provided by a classic state machine. Therefore changes in order of display states can be immediately applied without a requirement to modify any source code.

SIMULATION ENHANCEMENTS

The architecture of viilab which was discussed in the previous chapter also leads to transparency of the module implementation and operating mode. As the software-interfaces for each module like a positioning module for example stay the same, regardless of the specific implementation of the module there is no possibility for the other modules to realize weather the positioning data provided through the interface is real or simulated.

Simulation of Position Data

Most Car2X-Applications are location based. Therefore position data is very commonly essential. In reality the position of a vehicle can be detected by receiving the signals of the Global Positioning System (GPS) by using of a GPS-receiver device. For simulation on a computer other sources of real GPS data have been developed. At the moment there are four possible ways for GPS data input as figure 3 illustrates.

![Figure 3. Options for the vehicle position data source.](image)

One option is to play back GPS data that was recorded in a vehicle during real and actual test drive. Except for simulation purpose recording and playback of position data is necessary for reproducibility. In terms of continues changing of GPS signal there is no possibility to accomplish exactly the same test-drive twice. The position data of the vehicle can also be fully simulated by a driving simulator with the car driving on a virtual test track. For simple investigations the creation of programmed virtual GPS data is sufficient, for example when a car is driving only straight forward.

Simulation of Communication Range

Similar to this inter-module-transparency feature, viilab supports also transparency between units. Because the connection between units is via communication interface, a unit is not able to realize if the received messages are generated by a real or a simulated unit. To prepare the simulation modes (see next chapter) where many units are running on one machine a “Virtual-Air”-functionality has been introduced: All units, running on one workstation, could always exchange Car2X-messages because they are connected via the communication device. This is unrealistic because in full reality, communication between vehicles (OBU) and infrastructure (RSUs) are effected by the actual environment they operate within. For example, an OBU and a RSU might be outside of the wireless communication range depending on the wireless technology, the communication protocol and the environment. Therefore the “Virtual-Air” calculates with the mentioned parameters the possible connection distance and decides depending on the current unit distances if units are within connection range. Only when communicating units are within that range messages are exchanged between them.
Monitoring

A simulation of a Car2X scenario with all the different modules and across various OBUs and RSUs can become complicated to follow and trace actual sequences of events. A mechanism to visualize the complete set of this important information is needed. A viilab Monitoring application (MON) has been developed which displays the current position of the units and hence (a defined clipping of) the scenario. Following the principles of the viilab architecture the MON is also a specific assembling of modules with the viilab kernel: A communication module used for receiving the positions of the other units, a display module that functions as connector to the display-application, and a logic module that refines the positions for the display-application.

SIMULATION MODES

With all the previously explained design-decisions and tools the integrated development environment viilab allows a variety of different simulation modes. They differ on the level of “virtuality”. Scenarios and all Car2X components involved may be simulated, components may be simulated, real or partially real and some components maybe simulated and others real, etc. Two simulation modes and their domain will be explained below using the example of an intersection scenario which is illustrated in figure 4.

Figure 4. viilab intersection scenario.

Full Simulation Mode

In the full simulation mode all viilab processes (units) are fully simulated and are all running on one computer in the laboratory. In the example three cars with OBUs and one RSU are simulated. The positioning is simulated as well as the connection-range due to the fact, that it is a full simulation, without real positioning hardware and any wireless-connections. A MON unit is used to monitor the scenario. In this mode basic algorithms and driver assistance systems can be developed and tested without any financial or safety risk. The intersection-scenario in the full simulation mode is illustrated in figure 5.

Figure 5. viilab intersection scenario.

The OBUs of the three cars amongst others have the following functionalities: Displaying of traffic signs, pedestrians and current traffic light Signal, Phase and Timing (SPT). Additionally there is a RSU running, sending out traffic sign information, SPT messages, and a virtual pedestrian. These messages sent by the RSU are received by the OBUs. Beside the 3 OBUs and 1 RSU there is a fifth viilab-process running – the MON process. Finally there are three vui running, each of them connected to one OBU. The vui as in-car-display / HMI visualize the driver assistance function. Other possible “outputs” like a vibrating-steering-wheel for warning purposes, usually activated via CAN-Bus are not part of this full simulation mode.

Extended Reality Mode

The novel test and evaluation method for future Car2X Communication based Driver Assistance is the “Extended Reality” method. It means the enrichment of real test situations with simulated environment scenarios. Since as was explained and demonstrated so far simulated units are transparent to their environment a real unit can not distinguish between real and simulated units within its communication-range. This offers a large variety of “virtuality”-grades or in other words a large variety of “Extended Reality”-situations.

Using the same given intersection scenario example (see figure 4) one of the three OBUs now is used in a real car. It uses now a real positioning hardware and it is connected to the vehicle (e.g. via CAN-Bus). The other two OBUs, the RSU and the MON can either run similar to the full simulation mode on the same machine or run on different machines. For example, these modules may be executed on an additional Notebook inside the car and be connected to the real OBU via communication.
technology. Now one real test-car is part of the scenario. The functionality of the driver assistance system that is under development can be tested and evaluated. Now in-car equipment, e.g. a Head-Up-Display, a vibration-steering-wheel, or other actuators can be integrated and tested.

Figure 6. viilab “Extended Reality” simulation: A real vehicle with a simulated Car2X environment.

The level of “Extended Reality” is adjustable. For safety purposes testing in the real test-car may initially start with a simulated positioning. Hence the car can remain stationary but the actuators inside the car for example as well as the vui can be set to react in reality. The modular and scalable viilab architecture allows a smooth transition from a fully simulated scenario to a complete real scenario through a step by step replacement of simulated components or units by real ones. It must be pointed out, that the Car2X-application - the driver assistance system – stays completely the same: There are no changes needed to algorithms or other developed modules from a full simulation, through the “Extended Reality” method, to a completely real test drive. Thus using the viilab development environment the testing and evaluating of any Car2X communication application can be performed without a disruption to the development process in a short time and at low risk for driver and hardware. This “Extended Reality” method and approach enables best in calls Design for Testability (DFT) practices and a Test Based Development (TBD) processes. It shortens or even eliminates expensive, time consuming and generally not efficient and ineffective testing phases (pre-alpha, alpha, beta, etc.) that are normally executed after an application was already fully developed. With the “Extended Reality” method, the Car2X application under development is tested, evaluated, verified and validated in parallel to the development processes. Development process will start in the full simulated mode to evaluate and verify the base design requirements and will end with in the full “Extended Reality” mode. Verification and quality feedback is provided to application developers and product managers in real time, leading to a higher quality and better accepted Car2X application the first time. Less time is spent on quality assurance testing and Alpha/Beta tests and the number of iterations and expensive version releases is dramatically reduced.

EXEMPLARY DEVELOPMENT PROCESS

A typical development process will be described next based on real projects at the Connected Vehicle Proving Center (CVPC) [8] in Michigan, USA. In addition to a sophisticated Connected Vehicle laboratory that includes vehicle electronics laboratory, access to an Anechoic Chamber, a Cray Computer laboratory, a Network Operations Center, a Vehicle 3D simulator, large garage and a Test Operations Center, the CVPC is engaged in building Connected Vehicle proving grounds on the Michigan International Speedway (home of the NASCAR races) private grounds and is operating a several test and evaluation sites on public roads in South East Michigan (Greater Detroit Area). Based on real data of infrastructure components of the test and evaluation site which the CVPC operates at the intersection of 9 mile road and Hwy 10 (“the Lodge”), the existing actual testbed was mapped as a fully simulated scenario for viilab. The testbed route was transferred as a track for a driving simulator, which generates realistic driving behaviour of the simulated car. With this simulation environment new functionalities, specific to the actual and real test area, have been developed: For Example new traffic signs have been implemented such as a US-bridge-height (going under the Southfield freeway), two traffic light RSUs adopted to USA-compliant SPT messages (without a red-orange-phase), a stop sign, a parking lot sign and more. All displaying units were configured and adapted to the USA language, standards and preferences. Figures 7, 8 and 9 are showing screenshots of the MON and the vui connected to the simulated OBU of one car (the car is monitored as a green dot).

Figure 7. Displaying of max bridge height going under Southfield freeway.
The simulated car uses simulated positioning data out of a driving simulator. After developing the driver assistance system in the full simulation mode for the 9-mile testbed an “Extended Reality” test was performed. In particular the test was not performed on 9-mile testbed were the roads and traffic patterns are known and well documented but on open public roads that are not a part of any testbed setup. The test took place at Traverse City, Michigan as part of the 2008 Management Briefing Seminars [9] which is a conference dedicated to Auto Industry Executives. Traffic signs and a traffic light RSU providing the SPT messages were realized as “Extended Reality”. This generated the simulated environment to an actual car as if there were real RSUs along the public roads, sending out information messages.

As is illustrated in figure 10 there is little difference, from point of view of a driver testing and evaluating the driver assistance system, between testing the Car2X application in complete reality or a with “Extended Reality” enhanced actual road.

OUTLOOK

Car2X applications are built upon existing technologies and no new invention of technology. Still Car2X systems are complex. They introduce a challenging integration of multiple enabling technologies like Vehicle Electrical Control Units, Vehicular communication networks, driver assistance computing hardware, aftermarket equipment, inter-car communication systems, mobile communications systems, intelligent transportations systems and roads. The enabling infrastructure requires cooperation across industries. Many of the required technologies are still a subject to research and required interfaces are still being defined and standardized. New test and evaluation methods like “Extended Reality” are proposed to ease the development process of these multi-discipline, complicated, driving assistance systems. The continuous improvement of simulation capabilities to support a Car2X development environment is vital. To help mitigate the complexity real test-beds were and are constructed around the world. In Germany a test-bed is currently under development within the SIM-TD Project [10]. In the US a large test-bed was created as part of the US Department of Transportation Prove of Concept (POC) project which was concluded, in Michigan, last year. The Connected Vehicle Proving Center operates multiple physical test-beds as part of its Car2X testing and evaluation capabilities, some on public roads and some on private roads. However, physical, full reality test-beds are not a replacement to simulation. While test beds are excellent for overall solution evaluation and final operational testing, they are less suitable and more cumbersome for functional testing through the development process. The role of simulation and its advantages in an application development process are well documented and today are basic capability in any field. The use of simulation at certain stages of the development process is by far more productive, enhanced further by the “Extended Reality” method that allows taking advantage simultaneously of both: the simulation and the testbed. The mapping of these testbeds into a simulation environment like viilab is necessary to support developers of Car2X applications. Enhancement of simulation tools is a key and required. Like the rest of Car2X applications development aspects, simulation tools dedicated for Car2X applications need to continue evolving.
soon as new expertise becomes available or an interface is standardized it has to be introduced into the simulation system. The mutual progress and development of simulation tools and physical test-beds are crucial to provide an effective development environment. The combination of both into a common development process, using a method like the “Extended Reality”, yields best development process as was already proven in many other fields of application development, some less complex than Car2X.

SUMMARY

The development of future Car2X communication based Driver Assistance poses a complex problem with regard to testing and evaluation. New test and evaluation methods help to meet those new demands and support a more efficient, simplified development-process. The viilab “Extended Reality” simulation is a powerful tool to rapidly develop and test Car2X communication applications and services for traffic scenarios at low risk for driver, hardware and budgets. It is possible to develop and test the applications and algorithms in detail highly efficient. In particular, a smooth transition from complete virtual simulation on one computer to a complete testing-scenario on many units can be accomplished without disruption to the development process. Application developers can better engage in Test Based Development methods where they can test and evaluate their efforts as they progress. Finally the discussed simulation methods pave the way for testing of future driver assistance systems with regard to the currently proposed testbeds.

REFERENCES