Virtual Validation of Automated, Autonomous and Connected Mobility at the University Campus of Stuttgart

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Abstract. The mobility of the future is not only relevant for passenger and goods traffic in large cities and on the highway. For an attractive and vital campus with intelligent infrastructure modern mobility is also an important precondition for achieveing excellent results in studies, research and teaching. This manuscript gives insights in current results of the Mobility Living Lab of the University of Stuttgart where the campus is going to be redesigned by an innovative mobility concept. One inherent big challenge is the development and validation of automated driving functions for the future campus shuttle and the autonomous e-scotters which can be supported by modern simulation environments like Tronis®. Especially the connectivity between the different protagonists in the campus mobility is essential e.g. for traffic safety and infotainment. Herein we present results and plans from the corresponding research projects SMART (BMBF) and AINET-ANTILLAS (BMBF / CELTIC-NEXT). We focus on the topics connectivity, automation and simulation which have been realised in collaboration between the University of Stuttgart and TWT in teaching courses. In these courses driver assistance systems are concepted, implemented and virtually validated to become employed in real scenarios in the further course of the project Mobility Living Lab.

Keywords: Virtual Validation, Autonomous Mobility, Connected Mobility.

1 Introduction

Automated, autonomous and connected mobility are being realized in complex environments. The validation of automated, autonomous and connected functions need to respect the environment itself, existing or missing infrastructures, pedestrians, traffic participants, unexpected or unusual situations, standard situations and also topics like comfort, ease-of-use and safety as well as security. At the campus of the University of Stuttgart the project “Mobility Living Lab” (MobiLab) has been set up. It has the goal to innovate automated and autonomous mobility at the Campus employing connectivity and electric driving. In this context the authors combine several research and teaching activities spanning the virtual validation of automated, autonomous and conneced vehicle functions, the physical modeling and simulation of mobile communication as well as the application of the results to a real campus.

2 Virtual Validation with Tronis®

Tronis® is a commercial tool environment based on the Unreal game engine that persues the goal of reduction of real testing efforts for the prototyping and the validation of automated driving functions. 3D scenarios can be defined including buildings, vegetation, streets, vehicles, pedestrians, physics simulation, infrastructure, traffic signs, trajectories, sensors, communication infrastructure and weather conditions. Within the context of this paper Tronis® is used as a virtual validation environment for the automated and connected mobility, for instance at the campus of the University of Stuttgart.

Fig. 1. A sample scenario in the virtual validation environment Tronis®.

Based on the capabilities of Tronis shown in **Fig. 2** the authors simulate mobile communication and the effects of Quality of Service, latency, band width or data loss with respect to the proper functioning of connected driving functions.

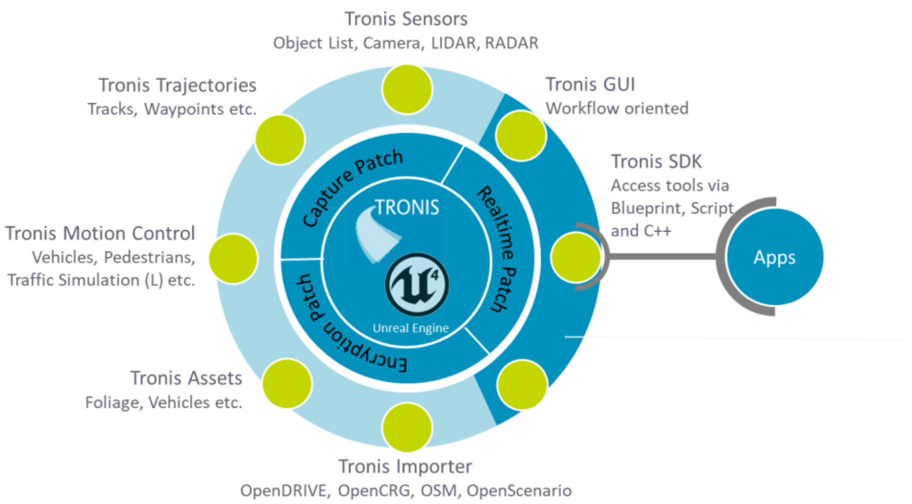

Fig. 2. Tronis® modules employed for the virtual validation of automated, autonomous and connected driving functions.

One scenario that the authors investigated in detail is a cooperative headway control in a so-called platooning scenario, where mutliple trucks are driving in a small distance to one another. In this scenario a Vehicle-2-Vehicle or Vehicle-2-Infrastructure communication has been established virtually in order to enhance information provided by the Adaptive Cruise Control (ACC). This Cooperative Adaptive Cruise Control (CACC) function has the potential to significantly increase the traffic safety as well as to optimize the traffic flow. Testing this function in real environments can not be performed in large scale thus simulation is a key factor for the development and validation of such functions. Based on the usage of CAM messages data is transmitted from the truck ahead to the successing vehicles, like velocity and accelaration of the leading vehicle. The questions to be answered were: What is the CACC function doing when the communication is interrupted? What should the function do in this case? How to circumvent issues like that?

An approach that has been investigated by the authors is how to decide for a fallback to the standard ACC function in case that the quality of the mobile communication channel undergoes jitter. Therefore the probability of a message received is estimated, i.e. each 100ms each vehicle estimates the receiving probability of message of all surrounding vehicles based on the distance, the interference and shadowing. Based on the probability it can be decided whether to fall back to the standard ACC for more safety.

A framework (see **Fig. 3**) has been generated that can be employed in several connected driving scenarios far beyond the described one which are starting to be investigated e.g. in the research project AINET-ANTILLAS (BMBF, CELTIC-NEXT) or in applications like MobiLab.

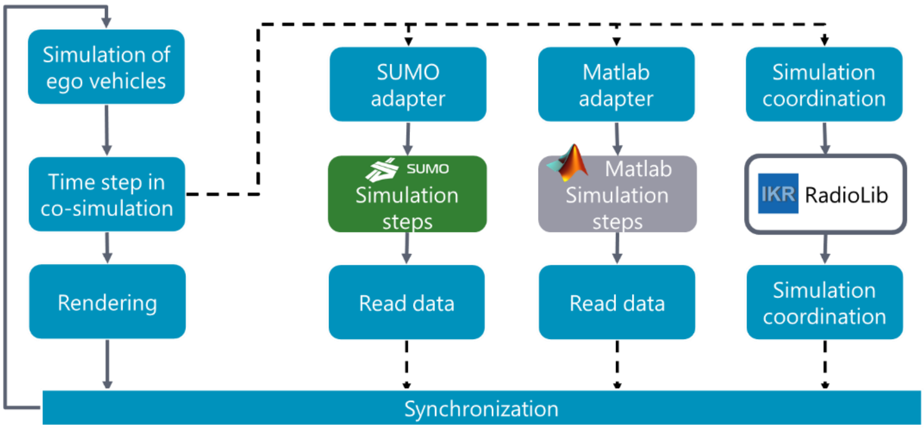

Fig. 3. Simulation framework for incorporating mobile communication models into 3D virtual validation of automated, autonomous and connected driving functions.

The next section will provide more detailed insights into the specifics of the models of mobile communication and how these models are integrated into the whole simulation.

3 Simulation of Car-to-X Communication for the Validation Environment

3.1 Car-2-X Communication and Message Types

For correct simulations of autonomous driving the radio communication between the cars themselves and the infrastructure also has to be considered. Therefore, an important aspect of the virtual validation environment is the integration of a realistic information exchange via Vehicle-to-Everything (V2X) communication together with the physically realistic car simulation (Tronis®), and the traffic simulations on the macro level (SUMO).
Generally, two different alternatives are being considered for the vehicle-to-vehicle com-munication of Intelligent Transport Systems (ITS) [1]:

- WLAN-based ad-hoc networks (using IEEE 801.11p standard
- Cellular vehicle-2-X networks (starting with LTE rel. 14 of ETSI 3GPP and further developed by the 5G Automotive Association).

Recently, the cellular approaches find increasing interest due to their inherent determinism, availability advantages and advances in signal transmission technologies (e.g., 5G New Radio).
For this purpose, ETSI considers a layered architecture for ITS communication that is shown in **Fig. 4** below:

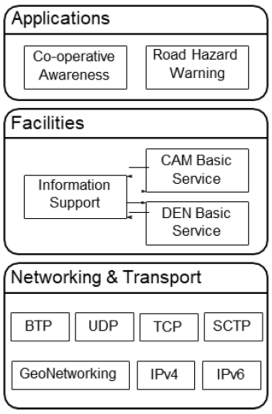

Fig. 4. Layered Architecture of ITS communication [3].

The applications like road-hazard warning and cooperative awareness (e.g., for platoon scenarios) employ the services of the Facilities layer that is providing two services and message types for information support:

- Cooperative Awareness Messages (CAM) are emitted by vehicles in regular time intervals (e.g., every 100 ms to 1000 ms) and inform the other vehicles about the position, speed, acceleration and dimensions of the emitting vehicle.
- Decentralized Environmental Notification Messages (DENM) signal safety rele-vant events – as collision warnings, traffic jam warnings, impaired road conditions to the traffic partners that can re-emit these messages then themselves.

These messages are then exchanged between the cars themselves and road-side units employing the usual networking and transport services provided by protocols like TCP/UDP an IP on the basis of radio communication links.

3.2 Channel Modelling and Resource Control

The radio signal transmission between the vehicles suffers from several effects: The received power strongly vanishes with distance, signal interference by multi-path transmission leads to nearly complete loss of signal at certain receiver positions, and the shadowing of buildings and landmarks further contributes to very unstable channel conditions. To still achieve acceptably low failure levels among the received radio frames, not only sophisticated modulation and coding techniques are being used but their parameters are also constantly adapted to the channel conditions cur-rently experienced. Therefore, the validation environment has to incorporate the usual channel models into the simulation of the mobile communication.

A peculiarity of cellular vehicle-2-vehicle communication relates to the device-to-device communication applied:

“Classical” LTE-based mobile communication uses unicasting in uplink and downlink. Radio resources – implemented by time (TTI of 1ms) and frequency multiplex (resource blocks of 180 kHz) – would then be allocated by the scheduling in the base stations to the individual mobile terminals (**Fig. 5**).

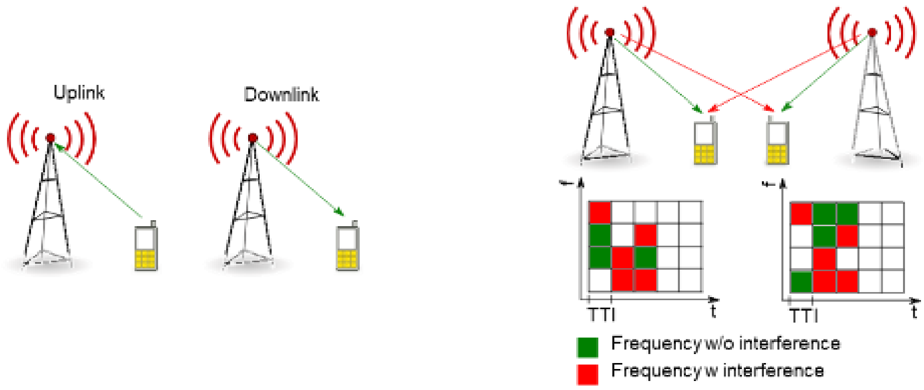

Fig. 5. Uplink / downlink communication and resource allocation in “classical” LTE.

In V2X communication however, a large part of the messages is directly broadcasted to the other (often) neighboring devices (as indicated in **Fig. 6**) and in open-field scenarios even the base stations are often completely out of reach.

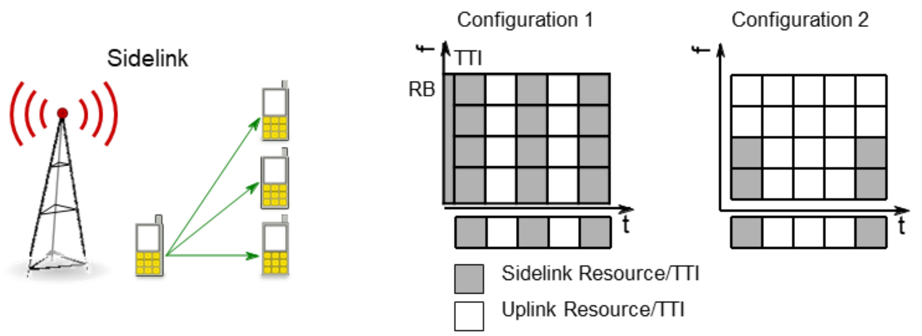

Fig. 6. Direct broadcast communication between devices and periodic resource allocation.

As also a large part of the V2X communication messages is periodically transmitted, a different resource control for this side-link communication in the device-to-device case is used – that even may be operated independently of the base station control: A periodic resource allocation map is derived from channel observation by the devices themselves. Then the devices use a semi-persistent scheduling to periodically allocate radio resources in different configurations – as also indicated in the figure above.

When base stations can also be involved, the mobile stations direct their scheduling requests to the base stations (according to the envisioned traffic characteristics) that are then evaluated and granted by the base stations in the form of periodically reserved TTIs for the duration specified by the mobile stations.

3.3 Coupling of Simulators in the Validation Environment

In the validation environment, the mobile communication features and their operation is simulated using an event-oriented approach: As indicated in **Fig. 7**, in this approach the simulated system state is only changed by events at discrete points in time and the simulated system time accordingly advances ("jumps") from event to event instead of progressing linearly. During the processing of the individual events no system time passes (only processing time of the computer is consumed). This approach is implemented by a simulation event scheduler that operates in the background of the simulator software and organizes and orders the event flow between the individual simulated entities.

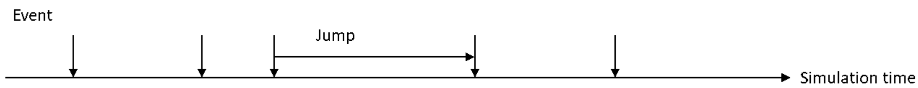

Fig. 7. Discrete event simulation approach.

Thus as a result, several different time concepts exist in the validation environment that had to be aligned by a dedicated simulation control between the different parts of the simulation environment as implemented in [4]:

- The continuous flow of real time – determining the physical effects and behavior of the vehicles
- The constant video frame-rate of the visualization (Unreal engine)
- The discrete event approach of the communication simulation

For implementation of the event-based communication simulation the IKRSimLib [5] developed by the Institute for Communication Networks and Computer Engineering of the University of Stuttgart has been used (see **Fig. 8**).

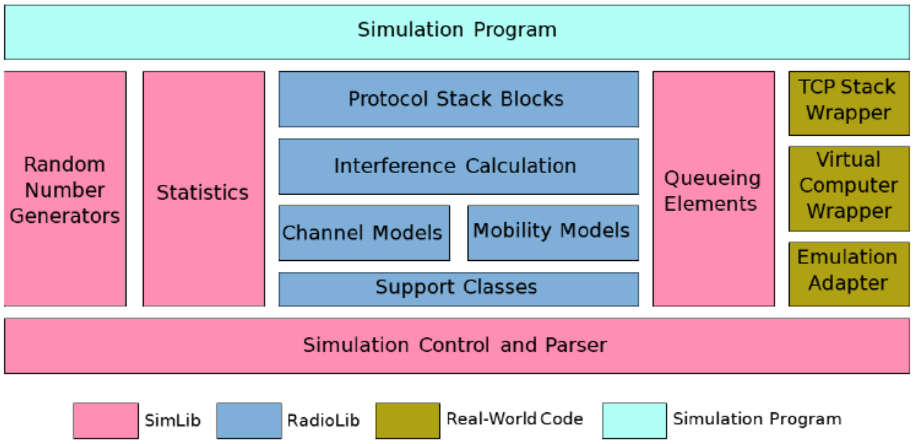

Fig. 8. IKRSimLib structure for simulation programs.

Java-based, it offers the discrete event scheduling together with the usual features of random number generation, parametrization of simulation batches and statistical evaluation. In addition, the radio channel properties were represented by efficient implementations of the channel models mentioned above – with special focus on reduced computing times to allow fast simulation [4]. Thus, path loss, shadowing, multi-path transmission can be represented realistically providing useful values for the experienced transmission error that then in turn is influencing the performance of the autonomous driving applications.

4 Integration of the Virtual Validation in Lectures

As described above, virtual validation is an important tool on the way to more and better assistance and automation functions. At the University of Stuttgart, we want to educate experts to run those tools. Therefore, we integrated our price-winning project MobiLab (Mobility Living Lab [1]) in lectures of our new M.Sc. Autonomous Systems.

4.1 The Project MobiLab

By 2035, the university wants to become climate neutral. In MobiLab, we brought together several approaches to reach that goal. The measures vary from organizational questions over the cooperation with a bike sharing service to own technical development projects.

The univesity installed a mobility manager to coordinate all activities regarding mobility at the campus. Furthermore, several stations of a bike sharing service are in operation. In general, the usage of a bike is supposed to be more comfortable in the future. Among others, the installation of parking facilities for bike and scooters shall convince students and employees to change from the car to the bike. Speaking of

scooters: Those are not the well-known electric shooters, but automated scooters developed by the experts for automatic control at our university. When not in use, the scooters can drive automated to a location, where they are most likely required. This reduces the total number of required scooters and helps to save resources.
The desired reduction of CO2 emissions is only possible, if the majority of the students and employees use public transport instead of private cars. To make the public transport more attractive, we want to implement an automated shuttle service. In a first step, we will run one vehicle to match the abilities of the vehicle with the infrastructure conditions at the campus. We also want to verify the timetable calculations.
Moreover, we will integrate the vehicle in the lectures. Students will program own algorithms for data processing, path planning and actuator control.

4.2 The New M.Sc. Autonomous Systems.

With the winter semester 2019/2020, the University of Stuttgart started the new M.Sc. Autonomous Systems. The students can choose between two profiles, i.e. Con-nected Intelligence and Intelligent Automation.
In both profiles, some lectures focus on basics like programming, AI and data processing. While the profile Connected Intelligence focusses on IT and electrotechnical aspects of autonomous systems, the profile Intelligent Automation deals with methods of controlling and automation of dynamic autonomous systems.
Apart from the basic lectures, we also offer so-called application lectures, where we cover automated driving, automated flying and automated production.

Application Lecture dealing with Automated Driving. Together with TWT, the Institute of Automotive Engineering (IFS) offers an application lecture, where the students have to program small ADAS functions. After this, they need to validate the functions in the virtual world of Tronis®.
To ensure a proper theoretical background, in every lection the students get basic information about Tronis® as well as general advices, how to program. After this, they program on their own functions like lane detection, lane keeping assistant or adaptive cruise control. The idea of this concept is, to provide guidelines as well as leaving enough space to the students for own initiatives and ideas.
In regular consultation hours, we discuss the progress and tackle issues. In web conferences, the students show their code and short video clips with the correspond-ing vehicle behavior (see **Fig. 9**).

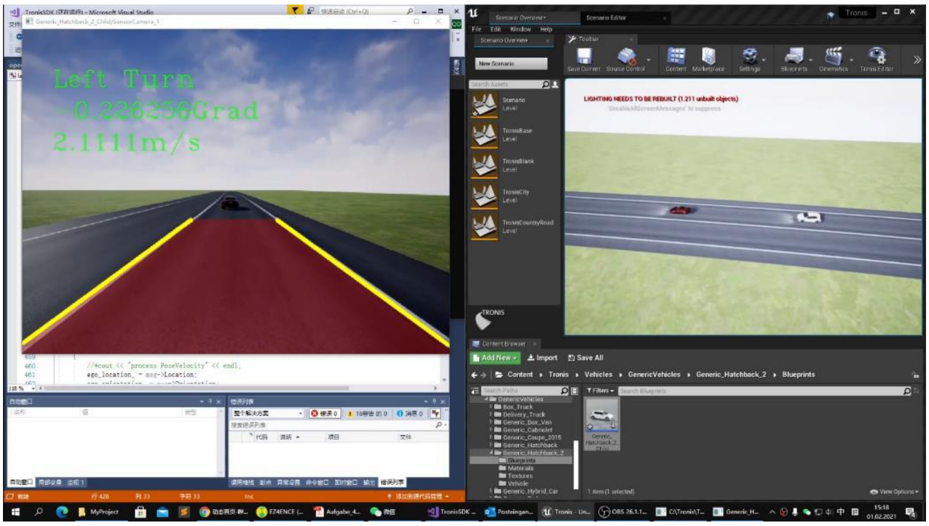

Fig. 9. Screenshot of a student's video showing the result of the programmed lane detection algorithm (left) in the given traffic scenario (right).

Integration of the campus roads and an automated shuttle in Tronis®. So far, the students create a fictitious track and use pre-defined cars. As an improvement, we plan to integrate the campus roads in Tronis®. Furthermore, we want to integrate an automated shuttle that we want to operate on our campus. After the initial operation of the shuttle, the students shall do a verification between the real and the simulated vehicle behavior.
If successful, we will have a lecture covering a significant part of the virtual validation of automated driving functions.

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