Towards a Multi-Protocol Microscopic IVC Simulation Environment for ADASs

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***Abstract*—Most of today's ADASs rely on the data of local perception sensors. With the introduction of Vehicle-to-X (V2X) communication, the perception range of next generation vehicles will be extended even further. In addition to the introduction of local perception sensors in Veins, we present *ArteryLTE*, a holistic simulation environment for using the vehicle position data from the microscopic traffic simulator SUMO in combination with ETSI ITS G5 and LTE enabled vehicles, as well as a backend. We use the proposed simulation framework to present preliminary results for detecting lane-level traffic phenomena.**

I. INTRODUCTION

Until a few years ago, simulations within the field of automotive research have been focusing on very specific problems regarding the development of components of vehicles. For the analysis of parameters regarding the powertrain, for example, dedicated simulation tools that provide very detailed models of Internal Combustion (IC) engines are used. Engineers focusing on the development of the chassis use different types of simulation tools in order to determine the stresses and forces acting on the vehicle's structural elements during operation. These approaches have in common that they can be simulated and analyzed separately as their interactions can be somewhat simplified. However, these simulation models always try to model the behavior of a single vehicle or components within the vehicle with respect to external influences. When it comes to the simulation of actively intervening Advanced Driver Assistance System (ADAS) such as an Adaptive Cruise Control (ACC), at least one more vehicle within the vicinity of the simulated vehicle needs to be taken into account.

New assistance systems under development today will be based on V2X communication and will gain major momentum within the next years. As outlined above, most of today's tools for the development of ADASs are unable of providing a framework for the analysis of communication-enabled assistance systems. Next to the already existing factors influencing the working principle of today's ADASs, V2X enabled ADASs are also affected by the properties of the employed communication technologies. Therefore, the development of ADASs also advances into the area of different communication technologies. As a consequence, new development tools are required that provide both, the option of simulating the Inter-Vehicle Communication (IVC) as well as the ADAS applications.

With the option of actively exchanging messages between vehicles, cooperation between road participants may be realized. Therefore, ADASs based on V2X communication do not only have a value for the customer, but may also improve traffic flows. Hence, the simulation framework needs to provide the option to analyze both: the interaction of the algorithms on the vehicles on a sub-microscopic level, i.e., on the vehicle level, as well as on the microscopic level to analyze their effect on the traffic efficiency.

This paper focuses on the realization of a holistic simulation framework capable of simulating different communication technologies as well as realizing different implementations of ADAS applications. Section II provides a short overview of the related work regarding simulation tools and their applications. Furthermore, the section introduces our contribution towards the consolidation of different simulation approaches within a common framework, with a strong focus on the integration of local perception sensors. In Section III we also present a particular application of our work, by introducing a backend to our simulation framework. Section IV summarizes our future research.

II. SIMULATION FRAMEWORK

As described in Section I we propose a holistic simulation framework called *ArteryLTE* which is capable of simulating ADAS applications and IVC networks on both, the sub-microscopic and microscopic level.

A. Microscopic vehicular network simulation

Depending on the research question, either the network between the vehicles has to be simulated—therefore taking into account that the applications running on the vehicles are not considered—or, in the other case, the focus lies on the simulation of the ADAS application, therefore neglecting the inter-vehicle network. Regardless of the research question, the inherent simplifications make it challenging to analyze their mutual effects. On the one hand, in the case of the standalone network simulation, the movement of the network nodes may be random or based on recorded traces without the option of changing the movement patterns due to the interaction of an ADAS application. On the other hand, when developing a novel ADAS application, the limitations of the inter-vehicle network may not be considered. A summary regarding the possible approaches of combining both requirements is provided by Sommer et al. [1].

One approach for joining both perspectives is proposed by the popular open-source *Vehicles in Network Simulation (Veins)* framework [2] for which several extensions are publicly available. The *Veins* project[1] introduces the combination of the dedicated network simulator OMNeT++ with the dedicated traffic simulator Simulation of Urban Mobility (SUMO). *Veins* implements SUMO's control protocol Traffic Command Interface (TraCI) in OMNeT++ and therefore realizes the online import and manipulation of the vehicles simulated by SUMO through functionalities implemented in OMNeT++. What is more, Veins also provides an implementation of the US Wireless Access in Vehicular Environments (WAVE) Dedicated Short Range Communication (DSRC) communication stack based on IEEE 802.11p.

B. ADAS application development

Riebl et al. [3] present an extension for the Veins framework, called *Artery*[2], which focuses on the implementation of applications (so-called Artery services) for the vehicles within the simulation. The modular architecture of Artery enables heterogeneous vehicle capabilities, by dynamically configuring both, the penetration rate of a communication technology as well as the applications the vehicles are capable of. Furthermore, Artery introduces *Vanetza*, an implementation of the European Telecommunications Standards Institute (ETSI) Intelligent Transport System (ITS) G5 protocol stack alongside the WAVE stack provided by Veins. As part of this extension, Artery also includes a service for disseminating Cooperative Awareness (CA) messages according to the standard [4].

C. LTE support

One project, focusing on the introduction of another communication technology, is *VeinsLTE* [5]. The extension introduces the capability of heterogeneous communication technologies on mobile network nodes. Next to Veins' original WAVE stack, *VeinsLTE* employs *SimuLTE* [6], a complete representation of an Long Term Evolution (LTE) stack within OMNeT++. *VeinsLTE*, however, lacks the option of simulating a different set of applications per vehicle as well as the ETSI ITS G5 protocol stack for direct V2X communication. As part of our research, we combined *Artery* and *VeinsLTE*, therefore circumventing these shortcomings. Instead of the *decision maker* provided by *VeinsLTE*, *Artery*'s middleware is extended by the option of choosing either the ITS G5 or the LTE stack for communication. Upon message generation, the *Artery* services provide information to the middleware in order to choose the appropriate communication technology. We named the combination of *Artery*'s flexible application layer and the LTE communication stack *ArteryLTE*, which will be publicly available[3].

D. Backend Support

As we intend to embed a backend service into our simulation, a static network node is introduced to the network which is connected to the eNodeBs of the LTE network. The overall architecture of our simulation framework is depicted in Figure 1. Located within the presented cell of the eNodeB are two vehicles 1 and 2 which are equipped with both, an LTE and an ITS G5 stack. The location and dynamic status of the vehicles are extracted from SUMO via the TraCI protocol. Each vehicle can be provided with different Artery services A, B or C. The *Artery* middleware on the vehicles is responsible for selecting the appropriate communication stack. When transmitting data via LTE to the backend of an Original Equipment Manufacturer (OEM), a Transfer Control Protocol (TCP) connection between the eNodeB and the backend is used.

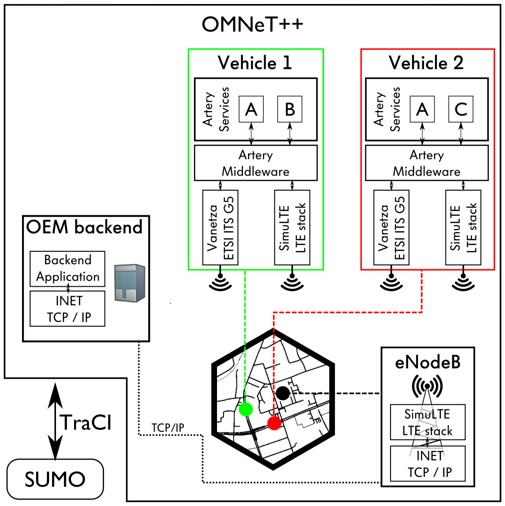

Figure 1: Architecture of the *ArteryLTE* simulation environment.

E. Local perception sensors

When developing novel ADAS applications based on V2X communication, the key difference to today's applications is the vehicle's capability of perceiving objects that are located outside of the perception range of its local perception sensors. However, the information received by V2X communication can be enriched by fusing these information with the data obtained by the vehicle's local perception sensors. Moreover, locally perceived objects may be shared with other vehicles, to provide a more detailed description of the vehicles' environment, as introduced by Günther et al. [7].

The basis for the local perception system within *Artery* is the Global Environment Model (GEM), which acts as a global database for all objects within the simulation and therefore resembles a map of all objects within the simulation on a global scale. Whenever a node is introduced, a Global Environment Model Object (GEMO) is added to that database. A GEMO mainly consists of the pointer to the mobility model of the vehicle within the simulation as well as some further information required to describe the object, such as its geometric dimensions, attachment points for local perception sensors as well as a list of vehicles that have knowledge about that particular GEMO. Whenever a vehicle changes its dynamic properties due to a new simulation step from SUMO, the corresponding GEMO is also updated. The GEM acts as the backbone to the perception system within the simulation. The determination of the presence of an object within the perception range of a sensor is performed by the GEM.

Whereas only one instance of the GEM exists within the simulation, every vehicle equipped with a local perception

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[1] http://veins.car2x.org/

[2] https://github.com/riebl/artery

[3] https://github.com/ibr-cm/artery-lte

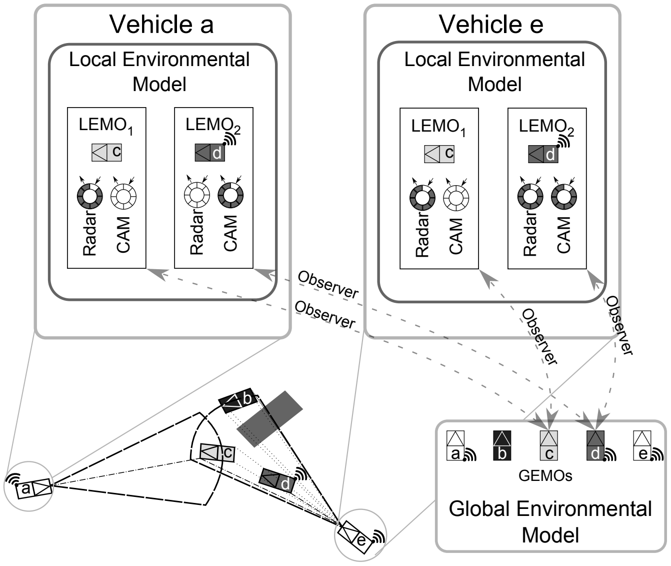


Figure 2: Creation of Local Environment Model Objects (LEMOs) for observed vehicles (📶 indicates a V2X enabled vehicle)

sensor creates its own instance of a Local Environment Model (LEM), as depicted in Figure 2. As every vehicle maintains its own LEM, it acts as a database for all objects that are known to the specific vehicle only. The LEM is part of the Facilities offered by the *Artery* framework and can therefore be accessed by any *Artery* service. Whenever a measurement is performed by the sensor, the objects within its perception range are added as Local Environment Model Objects (LEMOs) to the database within the LEM, as depicted in Figure 2 for vehicles a and e. In analogy to the GEMO, each LEMO also knows about the pointer to the mobility model that belongs to the observed vehicle. Whenever a vehicle is first measured by a perception sensor, i. e., the vehicle has not been sensed by the measuring vehicle before, a new LEMO is created for that vehicle.

Next to the pointer to the mobility model of the described vehicle, the LEMO also consists of several circular buffers, each assigned to a perception sensor of a vehicle, as depicted in Figure 2. The buffers are responsible for storing the measurements of a perception sensor to the observed vehicle at the time of measurement. This feature allows for the creation of a history of measurements for a LEMO, whereas the length of the history, i. e., the number of measurements stored for each object, is variable. The history for each object may be used by a vehicle in order to transmit aggregated information to an OEM backend via an LTE connection.

Every LEMO within the LEM database exists for a limited amount of time only. Whenever the vehicle has not been perceived again by any sensor of the perceiving vehicle within this limited amount of time, it is removed from the LEM. This allows for the continued consideration of vehicles within the algorithms of Artery services, even if the observed vehicle temporarily is not within any line-of-sight of the sensor, i. e., when obstructed by a crossing vehicle. Each sensor is defined as a separate class, by deriving from a base sensor class. The base class provides virtual functions which have to be defined by the sensor according to its properties, such as the variables that can be measured by the sensor. A radio detection and ranging (radar) sensor, for example, will return the relative velocity and distance to the observed object, whereas a camera will also return the orientation of the observed object as well as its geometric dimensions.

III. SIMULATION RESULTS

As an example application for the proposed *ArteryLTE* framework, we run a high-resolution telemetry service on the backend in order to detect lane-level traffic phenomena.

A. Setup

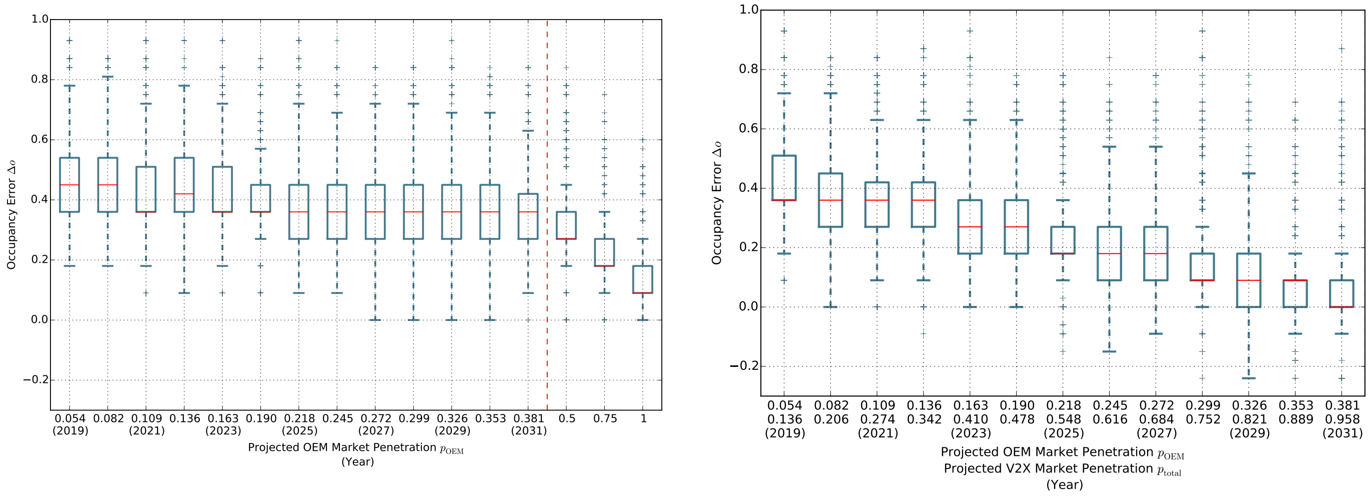
The vehicles in the simulation can be equipped to either communicate (a) with a backend via LTE, (b) with other vehicles via ETSI ITS G5, or (c) both. Vehicles of Type (a) send their dynamic state (i. e., their current position, speed, etc.) with a given frequency f_{lte} to the OEM backend only. Type (b) vehicles broadcast CA messages according to the generation rules specified in the standard [4] and therefore represent those vehicles from other OEMs. Just like the vehicles of Type (a), Type (c) vehicles, in addition to broadcasting CA messages, also send a status update to the OEM backend at a rate of f_{lte}. In addition to their own dynamic state, the status updates include an aggregation of all received CA messages of all V2X vehicles in their vicinity since their last communication attempt with the backend.

To achieve a higher than lane-level resolution of local traffic phenomena, every lane is subdivided into lane sections of 50 m each. As each vehicle should at least report its status once per section, the minimum update frequency should be $f_{\text{lte}} = {}^{1}/_{3.6}\,\text{Hz}$, due to a nominal speed limit of 50 km/h. As the driver imperfection in the simulation might lead to vehicles exceeding the speed limit, they alternatively report their status every 50 m.

In our simulations, we aim to determine the required market penetration rates of LTE and ITS G5 communication technologies to achieve a sufficient accuracy in the description of the current traffic situation estimated on an OEM's backend. For this purpose, we conducted two simulation stages and performed the analysis from the perspective of a backend:

Stage 1: The purpose of this stage is to establish the minimum required market penetration rate of the LTE backend communication in order to enable the envisioned service. We conducted 16 simulation runs, varying the penetration rates p_{oem} for the vehicles equipped with the LTE backend communication capabilities according to extrapolated market penetration rates of the Volkswagen (VW) group. Hence, the backend will only receive information transmitted by vehicles of the VW group.

Stage 2: In order to determine the additional impact of Vehicle-to-Vehicle (V2V) communication, the second stage adds Type (b) vehicles according to the assumed total market penetration rate p_{total}. These vehicles transmit CA messages within their local communication range. Consequently, the VW group vehicles are now of Type (c) and therefore transmit the collected CA messages to the OEM's backend as well. This causes a virtual increase of the number of vehicle positions in the backend, therefore yielding a larger database for estimating the current traffic situation.



(a) Stage 1

(b) Stage 2

Figure 3: Comparison of occupancy errors $\varDelta o$ per simulation stage.

B. Data Analysis

To assess the accuracy of the telemetry service, we opted for the occupancy of lane sections as a relevant evaluation metric. The occupancy o of a section s is defined as the overall space occupied by vehicles on s relative to the length of s. o_{backend} is based on the positions of vehicles reported to the backend by OEM vehicles (Type (a) or Type (c)). o_{TraCI} is based on the actual position of every vehicle as obtained via TraCI. As o_{TraCI} represents the ground truth, we determine the error $\varDelta o$ of the telemetry service as the difference between the two values: $\varDelta o = o_{\text{TraCI}} - o_{\text{backend}}$

C. Findings

Figure 3 shows the distribution of the occupancy error $\varDelta o$ for increasing market penetration rates p_{OEM} (Figure 3a) and p_{total} (Figure 3b). Figure 3a shows that with an increasing market penetration rate p_{OEM} of Type (a) vehicles, the occupancy error $\varDelta o$ decreases. However, it becomes clear that with the OEM's maximum penetration rate $p_{\text{OEM}} = 38.1\,\%$ (achieved by the end of 2031), $\varDelta o$ is not significantly lower than at the time of market introduction in the year 2018. Even with a (very large) theoretical market share of $p_{\text{OEM}} = 75\,\%$ a median occupancy error $\varDelta o$ of about $20\,\%$ occurs. This shows that using the fleet-data from one OEM alone will not be sufficient for realizing the envisioned telemetry service.

Figure 3b shows the leverage of introducing V2V communication. An OEM market share of $p_{\text{OEM}} = 38.1\,\%$ now corresponds to a total V2V market penetration of $p_{\text{total}} = 95.8\,\%$. As shown in Figure 3a, increasing p_{OEM} alone has no significant impact on the occupancy error $\varDelta o$. However, under the assumption of a parallel introduction of V2V technology to the market, the potential for a high-resolution Floating Car Data (FCD) aggregation can be fully leveraged.

IV. NEXT STEPS

As part of this paper, we gave an overview of the existing approaches for combining network simulation and traffic simulation for the purpose of analyzing V2X communication based ADAS applications. Additionally, we present *ArteryLTE*, a holistic simulation environment for using the vehicle position data from the microscopic traffic simulator SUMO in combination with ETSI ITS G5 and LTE enabled vehicles based on Veins. As an extension to the framework, we focus on the sustainable introduction of local perception sensors for the vehicles—a feature not yet existing within the Veins community. Preliminary simulation results show the effectiveness of a dual simulation stack within the vehicles with respect to future backend applications. Our future work will focus on employing the local perception sensors to enrich the database on the OEM's backend.

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