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Extending a holistic microscopic IVC simulation environment with local perception sensors and LTE capabilities

Hendrik-Jörn Günther [a], Julian Timpner [a], Martin Wegner [a], Raphael Riebl [b], Lars Wolf [a]

[a] Institute of Operating Systems and Computer Networks – Technische Universität Braunschweig, Germany
[b] Technische Hochschule Ingolstadt – Research Centre, Germany

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A B S T R A C T

Today's Advanced Driver Assistance Systems (ADASs) commonly require a description of a vehicle's surroundings. This description is gained by employing local perception sensors mounted to the vehicle in order to measure distances and velocities of objects in the vehicle's vicinity. Whereas today's vehicles solely depend on their on-board sensors, tomorrow's vehicles will additionally be equipped with heterogeneous communication technologies with the aim of realizing cooperation among road participants. What is more, combining local perception sensors and Inter-Vehicle Communication (IVC) (*collective perception*) allows vehicles to share their mutual sensor data—resulting in an even more complete representation of a vehicle's surrounding. Research in the area of heterogeneous cooperation between Intelligent Transport Systems (ITSs) raises the need for an holistic simulation framework capable of answering a diverse set of questions. This contribution provides several extensions to the publicly available microscopic simulation framework *Artery* which itself is based on *Veins*: local perception sensors and a Long Term Evolution (LTE) communication stack. To demonstrate *Artery's* capabilities, we set up several simulation scenarios with heterogeneous network nodes (vehicles) to reproduce local traffic phenomena on an Original Equipment Manufacturer's backend.

1. Introduction

Today's Advanced Driver Assistance System (ADASs) try to simplify the task of driving a vehicle and therefore aim at increasing the traffic safety. Most of the ADASs in today's vehicles, such as an Adaptive Cruise Control (ACC) system or a Lane Keeping System (LKS) rely on information gathered by on-board sensors. Depending on the manufacturer, different sensor technologies are used within vehicles. Whereas most often, an ACC employs information from a Radio Detection and Ranging (Radar) sensor in order to adapt the time-gap to the leading vehicle, the LKS uses the on-board camera behind the rear-view mirror in order to detect the lane markings. Irrespective of the employed sensor technologies within a vehicle, the objective of using on-board sensors is to collect information about the objects in the immediate vicinity of the vehicle.

In addition to the local perception sensors available today, future vehicles will be able to communicate with each other—therefore substantially increasing their perception range. The technology for realizing the communication between the vehicles is commonly known as Vehicle-to-X (V2X)-communication, whereas *X* can be replaced by an arbitrary communication partner which is capable of the employed technology. The current standardization processes for most markets envisage the use of a Dedicated Short Range Communication (DSRC) technology based on the IEEE 802.11p standard [1]. Depending on the employed protocol stack and the target market, either Cooperative Awareness Messages (CAMs) [2] or Basic Safety Messages (BSMs) [3] will be disseminated by the road participants in order to announce themselves in the network. Since the self-publishing vehicles in the network make use of their internal sensor systems, the exchanged messages convey more precise information about the dynamic state of the vehicle than if measured from a different vehicle's local perception sensor. The drawback of the technology—as for any other communication technology relying on the presence of a network—is the so-called network effect: A minimum number of users, the so-called *critical mass*, is required in order to have a measurable advantage of using the technology [4].

1.1. Heterogeneous vehicular communication

A particular topic of research to partially counteract the network effect is called *collective perception*. The idea behind this con-

E-mail addresses: guenther@ibr.cs.tu-bs.de (H.-J. Günther), timpner@ibr.cs.tu-bs.de (J. Timpner), wegner@ibr.cs.tu-bs.de (M. Wegner), raphael.riebl@thi.de (R. Riebl), wolf@ibr.cs.tu-bs.de (L. Wolf).

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cept is to share the information gathered about objects perceived by the local perception sensors of other V2X vehicles within the DSRC network. Therefore, also non-communicating vehicles will be recognized by V2X vehicles—even when they are located outside of the required line-of-sight connection of the vehicle's local perception sensor [5]. For this purpose, a new message format, called Environmental Perception Message (EPM), which includes a list of all perceived objects of a vehicle, has been developed and analyzed within a IVC network [6,7].

What is more, today's infotainment functions increasingly rely on *backend services*. Examples such as the Volkswagen (VW) Car-Net, BMW Connected Drive, Audi Connect, and others provide convenience functions such as online services (weather, parking availability, etc.) and remote controls (e.g., battery management and air conditioning). Vehicles typically establish a connection to an Original Equipment Manufacturer (OEM) backend via a cellular network. The European initiative "eCall" [8], seeking to bring rapid assistance to motorists involved in an accident, mandates OEMs to integrate cellular radios into all new cars from 2018 on. Thus, eCall will likely be the enabling technology for the large-scale proliferation of backend services in the automobile.

As stated above, cellular networks will be employed to connect to OEM backends. Both technologies, DSRC and cellular networks, can be combined to result in new applications and research areas. Within this contribution, we focus on the combination of both communication technologies for realizing novel backend services. Especially those applications that require a minimum market share of an OEM to be effective, profit from the presence of both communication technologies. The vehicles of a particular OEM that are connected to the manufacturer's backend may transmit aggregated received V2X information (as described by the European Telecommunications Standards Institute (ETSI) EFCD Facility [9]) in order to increase the information content on the backend. Next to the aggregation of either CAMs or BSMs, the messages related to the concept of *collective perception* serve as an additional data source for resembling the current traffic situation on an OEM's backend. The backend's enriched information base can be used by the OEM to offer novel driver information systems such as enhanced route guidance.

1.2. A simulation framework for heterogeneous IVC

Analyzing the effects and challenges introduced with both technologies requires an holistic simulation framework capable of simulating heterogeneous vehicular networks. Furthermore, dedicated vehicular and backend applications need to be realized. An additional requirement to depict today's applications as well as the concept of *collective perception*, is the simulation of local perception sensors attached to vehicles. Hence, this contribution focuses on the development of a simulation framework capable of simulating the aforementioned technologies and concepts. Additionally, the framework will be freely available.

As part of this contribution, the proposed simulation framework has been used to simulate all of the above: Vehicles will use their local perception sensors to disseminate information about their environment (*collective perception*), aggregate all intercepted V2X messages and transmit this information to an OEM backend. The objective of the simulation is the analysis of the required market shares of both communication technologies to accurately reproduce the current traffic situation on the backend. This information may in turn be employed to, e.g., accurately redirect vehicles to avoid traffic jams.

1.3. Outline

Excerpts of this work have been published as contributions to workshops [10,11]. This contribution focuses on the introduction of local perception sensors into the simulation framework.

The remainder of this contribution is structured as follows. Section 2 provides an overview of related work regarding alternative simulation frameworks and prospective benefiting backend applications. The components for the realization of local perception sensors are detailed in Section 3. Section 4 covers the introduction of LTE to the framework. The setup of the performed simulations is described in Section 5. The evaluation and discussion of our findings of the first simulation is performed in Section 6 and Subsection 6.3, respectively. Section 7 summarizes our findings and provides an outlook to future research.

2. Related work

The area of inter-vehicle communication is an extensive topic of research. One key asset for studying the different aspects of IVC is the availability of a powerful simulation framework. The following section provides an overview on the topic of microscopic IVC simulators as well as backend applications.

2.1. Microscopic IVC 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 stand-alone network simulation, the movement of the network nodes may be random or based on recorded vehicle traces without the option of changing the movement patterns due to the interaction of an ADAS application. On the other hand, when developing novel ADASs applications, the limitations of the inter-vehicle network may not be considered. A summary regarding the possible approaches of combining both requirements is provided in [12].

One approach for integrating both perspectives is proposed by the popular open-source *Vehicles in Network Simulation (Veins)*[1] framework [13] for which several extensions are publicly available. The *Veins* project introduces the combination of the two dedicated simulators OMNeT++, for network simulations, and Simulation of Urban Mobility (SUMO) [14], for microscopic traffic simulations. *Veins* implements SUMO's control protocol Traffic Command Interface (TraCI) in OMNeT++ and therefore realizes the on-line 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) [15] DSRC communication stack based on IEEE 802.11p [16].

An extension for the Veins framework, called *Artery*,[2] is presented in [17]. *Artery* 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* employs *Vanetza*, an implementation of the ETSI ITS G5 protocol stack alongside the

[1] http://veins.car2x.org/.
[2] https://github.com/riebl/artery.

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