Efficient Traffic Simulator Coupling in a Distributed V2X Simulation Environment

David Rieck
Fraunhofer Institute for Open Communication Systems
Kaiserin-Augusta-Allee 31, 10589 Berlin, Germany
david.rieck@fokus.fraunhofer.de

Björn Schünemann, Ilja Radusch
Technische Universität Berlin
OKS / Daimler Center for Automotive IT Innovations
Ernst-Reuter-Platz 7, 10587 Berlin, Germany
{bjoern.schuenemann, ilja.radusch}@dcaiti.com

Christoph Meinel
University of Potsdam
Hasso-Plattner Institute
Prof.-Dr.-Helmert-Straße 2-3, 14482 Potsdam, Germany
meinel@hpi.uni-potsdam.de

ABSTRACT

For the simulation of all aspects of V2X Communication scenarios, different simulators have to be combined and an interaction among them at runtime of the simulation has to be enabled. Hence, we have developed the V2X Simulation Runtime Infrastructure (VSimRTI) which couples discrete event-based simulators, e.g. for communication network, traffic, and V2X application simulation. The flexibility of VSimRTI allows us to vary the composition of integrated simulators depending on the specific requirements of a scenario. Moreover, optimistic synchronisation mechanisms enable us to decrease simulation time. In this paper, we combine both traffic simulators VISSIM and SUMO. VISSIM is used to achieve a highly accurate simulation of the most interesting region, whereas the more efficient traffic simulator SUMO simulates surrounding areas. We shall show that this simulator coupling reduces the overall simulation time without any decrease in accuracy. This work has been carried out within the PRE-DRIVE C2X project.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*;
I.6.7 [**Simulation and Modeling**]: Simulation Support Systems—*Environments*

SIMUTools 2010 March 15–19, Torremolinos, Malaga, Spain.

General Terms

Design, Experimentation, Performance

Keywords

V2X Communication, Vehicle-2-X Communication, Simulation, VSimRTI, Traffic Simulator Coupling

1. INTRODUCTION

The simulation of V2X Communication scenarios involves various aspects, in particular, a microscopic traffic simulator is used to simulate the movements of the vehicles. Moreover, a communication simulator simulates the wireless communication among the vehicles and an application simulator provides the environment for the execution of real V2X applications. Hence, different simulators have to be combined and an interaction among them at runtime of the simulation has to be enabled [17, 18]. Several existing simulator couplings are adapted to specific simulators and cannot be exchanged [15]. This is not satisfying for the simulation of a wide field of different V2X Communication applications, since requirements for each simulator coupling vary depending on the simulated scenarios. To master this challenge, we have developed the V2X Simulation Runtime Infrastructure (VSimRTI) [14, 15]. Our simulation infrastructure allows the integration of discrete event-based simulators, e.g. for network, traffic, and environment simulation. We couple simulators and provide the flexibility to exchange them depending on the specific requirements of a simulation scenario. The VSimRTI system architecture is inspired by the IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) [8]. However, the complexity of the HLA standard and its implementation would have exceeded the scope of a V2X simulation framework. Instead, a subset of the standard and some of its fundamental concepts were used to realize our V2X simulation framework. So, a lightweight framework for simulation integration was cre-

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

ated that facilitates the simulation of V2X communication scenarios. VSimRTI offers services to handle synchronization, communication as well as the life cycle management of the coupled simulators. Optimistic synchronisation mechanisms allow to decrease the overall simulation time[12, 13].

VSimRTI has been used for the simulation of various V2X Communication applications so far, e.g. the simulation of a new V2X-based algorithm that can be used by navigation systems to calculate routes circumnavigating congested roads [20].

Moreover, VSimRTI permits several new aspects for the simulation of V2X Communication scenarios. Hence, it is possible to combine different simulators of the same scope, e.g. two different traffic simulators. This approach allows us to combine the strengths of these simulators. For example, one simulator can be optimized for highways while another one is able to simulate realistic inner city scenarios. So, each simulator can be employed for the region it is optimized for. A further advantage of this coupling is the possibility to increase simulation performance. In developing a simulator, a trade-off between accuracy and efficiency has to be made. In general, a simulator with a high accuracy is weak in efficiency whereas an efficient simulator is less accurate. To increase the overall performance, the most interesting core region of a scenario can be simulated by an accurate simulator while the efficient simulator is used for the remaining areas.

For this paper, we combine the traffic simulators VISSIM [11] and SUMO [9]. VISSIM is used to achieve a highly accurate traffic simulation of the core regions, whereas the more efficient traffic simulator SUMO simulates all surrounding areas. We shall show that this simulator coupling reduces the time needed for the simulation without suffering a decrease in accuracy in the core regions. The paper is structured as follows. Section 2 compares the features of both simulators VISSIM and SUMO and discusses their strengths and weaknesses. In Section 3, we explain our concepts for the simulator coupling. To evaluate the improvements that can be achieved, several simulations have been performed. The corresponding simulation scenario is described in Section 4 and our evaluation results are presented in Section 5. Finally, Section 6 concludes the paper and Section 7 gives an outlook on future work.

1.1 Related Work

Siegel and Coeymans present an approach to combine macroscopic and microscopic traffic simulations [4]. Combining these different traffic simulation concepts allows us to simulate large traffic networks and achieves a high accuracy in higher interest areas. In general, both macroscopic and microscopic traffic simulations have different application domains. So, a macroscopic simulation is used for capacity planning, whereas a microscopic simulation allows to plan intelligent traffic systems. As a result, the combination of both can be used to design large city networks, i.e. by using macroscopic models in early stages and microscopic models for detailed planning later on.

To simulate the message transmission between communicating vehicles in V2X communication scenarios, the macroscopic simulation is not suitable because both the sender and receiver positions are missing. Thus, only rough estimates could be made about the transmission of a V2X message. Therefore, macroscopic traffic simulations are not adequate in the scope of V2X Communication.

[3] introduces the Mobile Wireless Vehicular Environment Simulation (MoVES) framework for a parallel and distributed simulation of vehicular wireless ad hoc networks (VANETs). The proposed framework supports an extensible and scalable simulation of vehicular scenarios with wireless communication and mobile services/applications. MoVES provides a platform for microscopic modelling and simulation-based analysis of V2X communication scenarios.

2. SIMULATOR FEATURES AND SIMULATION REQUIREMENTS

2.1 Comparison of Traffic Simulator Features

As described above, we have combined the traffic simulators VISSIM and SUMO. In this section, we shall compare the two traffic simulators in order to highlight their strengths and weaknesses with regard to Vehicle-2-X communication simulations.

In Table 1, a brief overview about the important features of both VISSIM and SUMO is given. While SUMO is an open source project that can be adjusted as needed and runs on various platforms, VISSIM is closed source and only runs on Windows platforms. Both simulators use a car-following driver model, but with different implementations and parameter sets. While SUMO uses a simplified approach with only five different parameters of the Krauß car-following model [10], VISSIM uses the more detailed Wiedemann car-following model [22] which has nine different parameters for the description of vehicle and driver behaviour.

A potentially interesting feature of VISSIM is the possibility to simulate multi-model traffic, i.e. VISSIM is not only able to simulate vehicles, but also pedestrians and bicycles. The simulation of these additional traffic participants can be used to simulate more detailed models, e.g. complex intersections can be evaluated involving the flow of pedestrians. A further advantage of VISSIM is its capability to allow 3D visualizations. Thus, complex traffic characteristics can be clearly represented. Due to its huge market share and its wide distribution especially in federal projects, VISSIM supports several common standards and external formats, e.g. for external traffic light signal control.

The strength of SUMO, on the other hand, is its simulation execution speed. Large city-sized areas with a high number of vehicles can be simulated on a standard desktop PC. But, the fast simulation speed is partly due to the simplified driver model of Krauß [10]. Here, the calculation costs of vehicle movements are minimized by minimizing the influencing parameters.

Due to its active open-source community, SUMO has been evolving continuously. So, feature requests are mostly implemented within a short period of time.

2.2 Local Simulation Requirements

In general, there are many aspects to consider when a traffic simulator is to be deployed in a V2X simulation environment. In the following subsections, we are to give an overview about issues that are relevant for the planning of a simulation.

2.2.1 *Modeling of the Road Network*

Typically, simulators have special features to model specific road network elements, e.g. the traffic simulator VIS-

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

Table 1: Overview about Important Features of VISSIM and SUMO [19, 5, 2]

	VISSIM [11]	SUMO [9]
License	commercial	open source, GNU General Public License (GPL)
Operating system	Microsoft Windows	cross platform
Time step resolution	up to 1/10 sec	1 sec
Driver model	Wiedemann [22]	Krauß [10]
Left-hand driving support	yes	no
Visualization capabilities	2D and 3D visualization, graphical network modelling	2D only, no editing
Multi modality	pedestrians, public transport, bicycles	public transport
Road network elements	traffic lights, parking lots	traffic lights
Evaluation capabilities	pollution rates, travel times	pollution rates, travel times

SIM is capable of simulating roundabouts [19], which is more difficult to model in other common traffic simulators such as Corsim, SimTraffic, or SUMO. In these simulators, a node and link concept is used to represent the road network. Instead, VISSIM uses the link and connector principle for representing the road network. Every road is modelled as a link and so are rounded roads. These links are interlinked via connectors that can have different shapes. Therefore, the modelling of roundabouts in VISSIM is more comfortable than in other traffic simulators.

2.2.2 Available Traffic Data

There is no standardized data format for all traffic relevant data. Instead, every simulator uses its own representation for simulation input and output data. Some traffic simulators provide interfaces to import data from other traffic simulator formats, e.g. SUMO is capable of reading VISSIM data. But, this import is limited and does not work with all traffic networks. If traffic data only exist in the format of a particular traffic simulator and an export of that data is not possible, the choice of the best suitable simulator regarding the simulation aspects could be strongly limited.

2.2.3 Required Simulation Accuracy

Depending on the simulated scenario, the required level of detail could vary for different parts of the simulation area. So, for example, for the evaluation of a V2X application that influences the traffic passing an intersection, a detailed simulation of the intersection is required. The region around does not need such an elaborate simulation. Here, a more efficient but less precise simulation would be sufficient. In other words, use cases exist where the simulation of a large surrounding area is only used to produce the input for a small embedded area that requires a high simulation accuracy. Thus, a possible solution is to use a traffic simulator with a high accuracy for the inner area, whereas the vicinity instead is simulated by a simulator optimized for efficiency.

According to the aspects discussed above, the combination of different traffic simulators can improve both the overall simulation accuracy and efficiency if a simulator is used for each region that fits best to the requirements of this particular part of the overall area.

3. TRAFFIC SIMULATOR COUPLING

The aims of traffic simulations can vary and result in different simulation scenarios and requirements. For example, an aim of a simulation could be to analyse a specific traffic situation on a highway crossing or on an urban main road. More complex simulations can contain areas with different road networks, such as a scenario where a highway leads into a city area. Here, both the highway and the city area simulation have to fulfil different requirements. Since each simulator has its own strengths and weaknesses, the coupling of different traffic simulators has the benefit that the most suitable simulator can be used for each of the different regions, so, a simulator which is specialized in simulating the dynamics of traffic congestions can be used to simulate areas with bottleneck roads. A further simulator, optimized for simulating traffic lights, complex intersections, and public transportation systems, can simulate the inner city traffic. Hence, both simulators would only simulate those parts of the scenario which they are optimized for and the combination of these different simulators leads to an increase in accuracy in the overall simulation in contrast to using one simulator for the entire area only.

3.1 Our Coupling Concept

As mentioned before, we use the Vehicle-2-X Simulation Runtime Infrastructure VSimRTI [15] to couple communication network simulators, traffic simulators, and other V2X-related simulation components. The VSimRTI is responsible for starting and stopping the simulators and it handles synchronization and interaction among them. Interaction is realized by a message subscription mechanism, i.e. each simulator can subscribe to specific messages types, e.g. messages about vehicle movements. When a simulator sends a message, this message is forwarded by VSimRTI to all simulators which have subscribed to the relevant message type.

One design decision taken in our traffic simulator coupling concept is to hide the different interpretations of the simulated vehicles, made by the different traffic simulators, from the other simulation participants. Therefore, a message is modified before it leaves one of the traffic simulation federates. Thus vehicle IDs, which changed when a vehicle entered a new simulator, are mapped back to their original values. As a result, vehicle parameters are consistent for

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

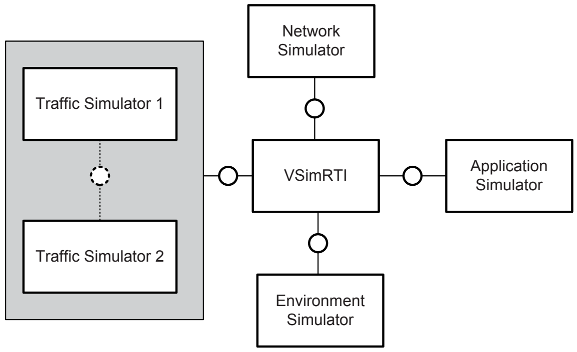

Figure 1: Federation group and virtual communication between simulators (dotted line)

the non-traffic simulator federates during the overall simulation. The details of this concept are explained in the following Section 3.2.

In Figure 1, our concept for coupling traffic simulators is depicted in general. The simulators use the overall message concept for their communication. The traffic simulators have no knowledge about being coupled with other ones. In their point of view, they run a self-contained simulation. Vehicles coming from areas simulated by other simulators are added by the VSimRTI to the then responsible traffic simulator. In the same way, vehicles are removed when they leave the simulation area of a simulator. The traffic simulators form a federation group, in which the message concept is used for communication and synchronization between each other. External communication to the VSimRTI, e.g. to the other federates, is only sent from the federation group as a whole.

3.2 Interactions among Traffic Simulators

In Figure 2, an example communication between two traffic simulators and the simulation runtime infrastructure is depicted. All participants use messages to communicate, e.g. a *TimeAdvance* message to trigger the following simulation step and *VehicleAdd*, *VehicleRemove*, and *VehicleUpdate* messages to inform each other about vehicle positions and changes. In this example, a vehicle is going to leave the first simulator during time step 101. The first traffic simulator notices that and sends a *VehicleRemove* message to inform the Runtime Infrastructure VSimRTI. This message is forwarded by the VSimRTI to the second traffic simulator, which inserts a corresponding vehicle in its simulation area.

The movements of all vehicles are visible to the non-traffic simulator federates. But, additional challenges have to be solved to enable V2X simulations. In the point of view of an application or communication simulator, vehicles have specific properties and a unique ID that must not change if a vehicle is removed from one traffic simulator and added to another one. Instead of removing and adding a vehicle during a transition from one traffic simulator to another, the transition is communicated as a *movement update* to the non-traffic simulator federates.

Thus, as introduced in Section 3.1, no vehicle change is noticeable for the non-traffic simulators. To realize this behaviour, the traffic simulation federates have to inform other

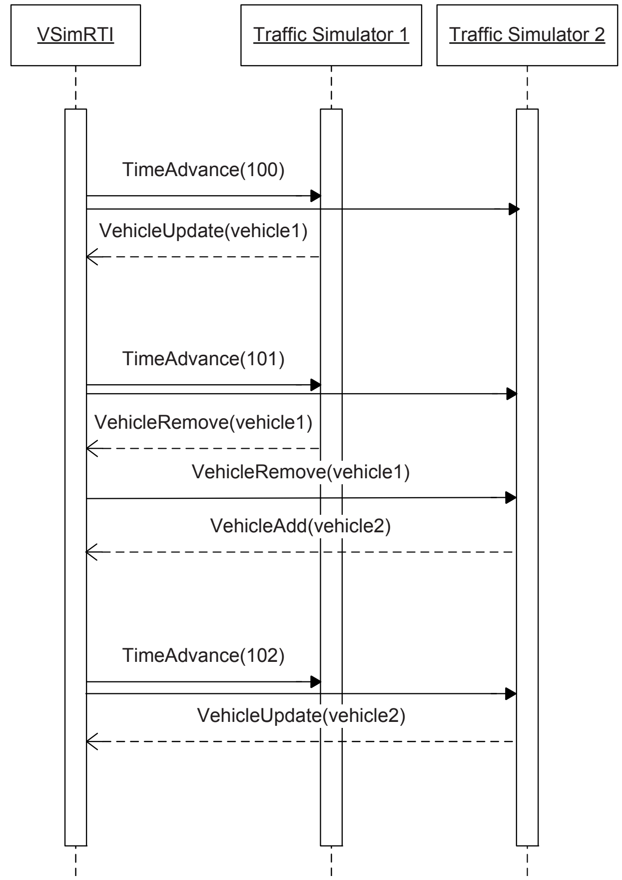

Figure 2: Example of a vehicle moving to another simulator

federates about the vehicle movement. Therefore, the traffic simulator, which added the vehicle, sends a *VehicleUpdate* message.

3.2.1 Vehicle Management

According to Fujimoto [6], no simulation federate of a distributed simulation can share state variables with other federates, i.e. simulations performed by two or more traffic simulators cannot share parts of the map. But, if a vehicle exists in more than one simulator at the same time, this leads to synchronization difficulties and inconsistencies. Consequently, the simulation management has to ensure that each vehicle is only represented in one simulator at any given time of the simulation, i.e. the transfer of a vehicle from one simulator to another one has to be coordinated. A further challenge is that a vehicle leaving the simulated area of one simulator has to be integrated into the other simulator in the following time step. Thus, the second simulator has to be informed about the new vehicle before it leaves the first simulator. If the first simulator sends the *VehicleInsert* message to the second simulator at the same time when the first simulator removes the vehicle, it cannot be guaranteed that the vehicle is inserted in the second simulator before this second one processes the next time step. To avoid this potential inconsistency, the vehicle transition process has to be started one time step before the vehicle leaves the map of the first simulator. In Figures 3 and 4, both the inaccurate

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

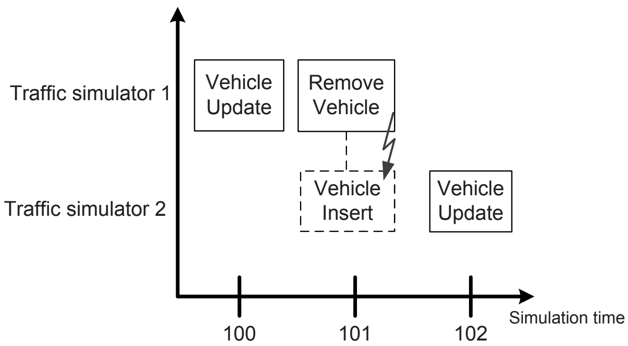

Figure 3: If the first simulator informs the second simulator about a vehicle transition at the same time while removing the vehicle, this may cause inconsistencies.

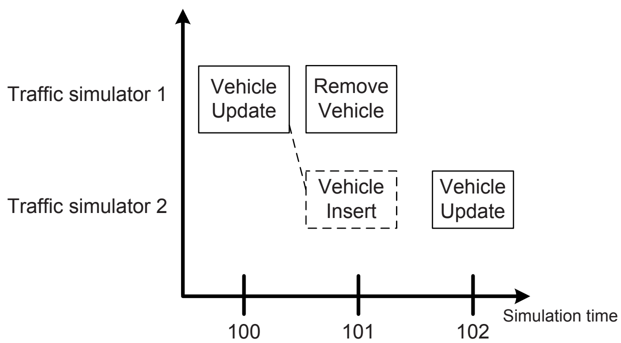

Figure 4: For a correct vehicle transition, the vehicle transition process has to be started one time step before the vehicle leaves the map of the first simulator.

and the correct vehicle transition procedure are illustrated: In Figure 3, a *VehicleUpdate* message is sent by Traffic Simulator 1 in time step 100. At the next time step, the missing vehicle is detected (*Remove Vehicle*). Then, the missing vehicle has to be inserted in the second traffic simulator at the same time step to avoid inconsistencies. This procedure is not possible if the second traffic simulator has already advanced to the next time step 102. In Figure 4, the correct order is depicted: The vehicle insertion in the second simulator is detected early enough so that the simulator can include this state change in its calculation for time step 101.

To detect the time when a vehicle will leave the map of a simulator, the vehicle's speed and direction are used. With the help of these parameters, the vehicle's position during the next time step is calculated assuming that speed and direction remain constant between the two time steps. If the calculated position is outside of the simulated area, the according messages for initiating the transition are sent. Then, the calculated position is communicated to the simulator that is responsible for the area of the new position and this calculated position is used as the new input position of the vehicle at the next time step. However, this procedure can cause some inaccuracy in rare cases. Since the vehicle's movement between the two time steps of the transition is

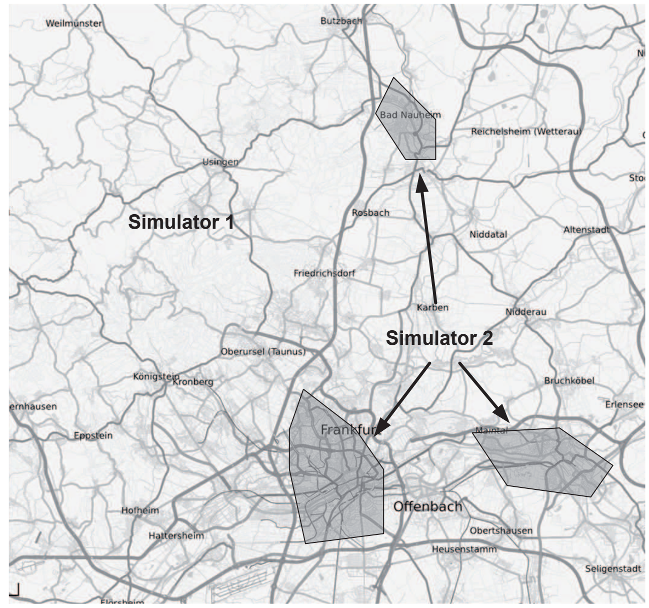

Figure 5: Simulator 2 simulates three non-connected parts of the map, whereas Simulator 1 is responsible for the whole area that comprises these three parts.

not calculated by a traffic simulator, changes of the vehicle's speed and direction are not considered, e.g. if a vehicle brakes or accelerates between these time steps, this change will be ignored. To decrease the effects of this inaccuracy as much as possible, the most interesting areas of an overall simulation should not be located at the map borders of the simulators.

3.3 Generalization and Timing Granularity

With our approach it is also possible to integrate more than two traffic simulators in a simulation architecture as long as the maps of the simulators do not overlap. Moreover, one simulator is not limited to simulate one piece of the map, e.g. in an architecture with two traffic simulators, one simulator can simulate three non-connected parts of the map, whereas the other one is responsible for the whole area that encloses these three parts, as depicted in Figure 5. A further benefit of our approach is that the traffic simulators can use different granularities for their internal timing, e.g. the traffic simulator SUMO can run in one second time steps while VISSIM uses a time resolution of 1/10 second in the same simulation scenario.

4. SIMULATION SCENARIO

4.1 Scenario Description

To test our traffic simulator coupling concept, we coupled both state-of-the-art traffic simulators VISSIM and SUMO. The simulation scenario was chosen according to the strengths and weaknesses of these simulators. Whereas SUMO is quite fast and can simulate a huge number of vehicles simultaneously, VISSIM's strength consists in the simulation of complex road networks with sophisticated intersections and traffic lights which often exist in inner city areas. To have an adequate road network, we decided to use the area around

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

Figure 6: City of Frankfurt/Main and surroundings: white areas are simulated by SUMO, dark grey areas are simulated by VISSIM

the city Frankfurt/Main in Germany with a size of approximately 60 x 45 square kilometres. Frankfurt/Main is surrounded by highways that are connected to several other roads leading into the city. In the neighbourhood of Frankfurt/Main, three smaller cities Giessen, Mainz, and Darmstadt are situated. Consequently, we simulated those four cities Frankfurt/Main, Giessen, Mainz, and Darmstadt by VISSIM, whereas all surrounding areas were simulated by SUMO. Figure 6 illustrates the division of the areas in detail.

Much importance was attached to a complex intersection in the inner city of Frankfurt/Main called Ludwig-Erhard-Anlage which is depicted in Figure 7. Due to the complexity of the intersection, i.e. different traffic participants like trams, vehicles, and pedestrians are involved, complex traffic light combinations occur, and difficult road structures exist, the scenario could only be modelled by VISSIM. A simulation of this intersection by SUMO was not possible. As a result, a simulation of the overall scenario with SUMO as single traffic simulator was not feasible, either. Moreover, since VISSIM provides several tools and features for a more comfortable modification of complex intersections, e.g. evaluation mechanisms for the adjustment of traffic light phases, the simulation of complex intersections by VISSIM was preferred.

4.2 Simulation Series

To measure the benefit of the simulator coupling, we performed two different series of experiments. In the first series, we simulated the overall simulation scenario with VISSIM as the single traffic simulator. The second series was performed as described above with the coupling of VISSIM and SUMO.

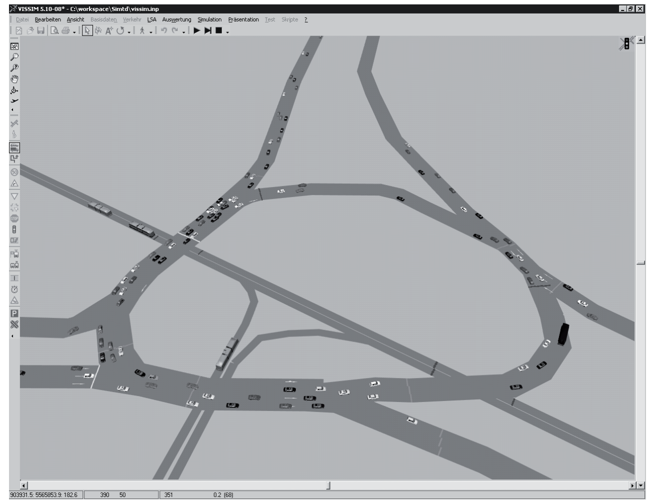

Figure 7: Complex intersection Ludwig-Erhard-Anlage in the inner city of Frankfurt/Main

In every simulation run, a scenario time of 800 seconds was simulated. To minimize external influences and noise, six simulation runs were performed for each scenario. Vehicle traces and V2X message exchanges were recorded for later analyses.

4.3 Simulation Setup

For the coupling of the simulators and for synchronization and interaction management, we used our Vehicle-2-X Simulation Runtime Infrastructure VSimRTI, described in Section 1. In both simulation series, the communication simulator JiST/SWANS [1] and the V2X extensions of Ulm University [16] were used to simulate the wireless transmission of V2X messages between vehicles and between vehicles and ITS Roadside Stations. Furthermore, the open source simulation tool eWorld[1] was used to convert the OpenStreetMap [7] road maps to both formats of VISSIM and SUMO and to integrate additional information like obstacles and bad weather conditions in the simulation scenario. The traffic simulator SUMO was coupled with VSimRTI via its Traffic Control Interface TraCI [21]. For the coupling of VISSIM, we used its COM interface and its External Driver Model. V2X applications were embedded in the VSimRTI's own application simulator.

The VSimRTI and all simulation tools except VISSIM were installed on the same Linux machine. Due to the restriction of VISSIM to Windows platforms, this simulator was deployed on another computer running a Windows operating system. The Linux machine was a QUAD-CORE XEON X3363 server with 2.8GHZ/6MB processor and 12 Gigabyte RAM. The installed operating system was Gentoo Linux with kernel version 2.6.30.5. On the Windows system, XP Professional SP3 was installed. The machine was equipped with a single core XENON X5365 CPU with 3.0 GHz/2x4MB and two Gigabyte RAM. For the traffic simulations, we used the SUMO version 0.11.01 and the VISSIM version 5.10-08.

[1]http://eworld.sourceforge.net/

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

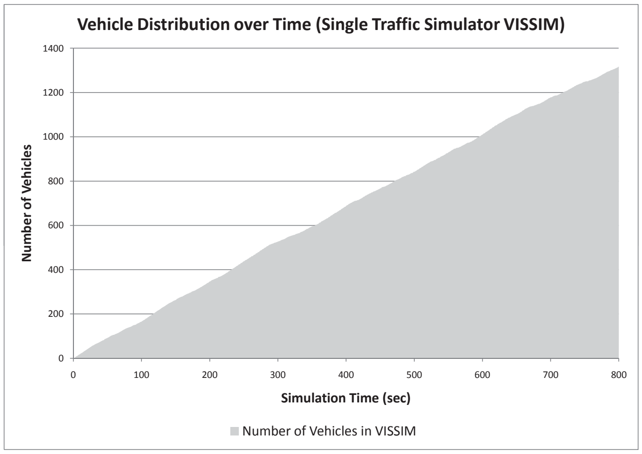

Figure 8: Inlet of vehicles during the simulation with VISSIM as single traffic simulator

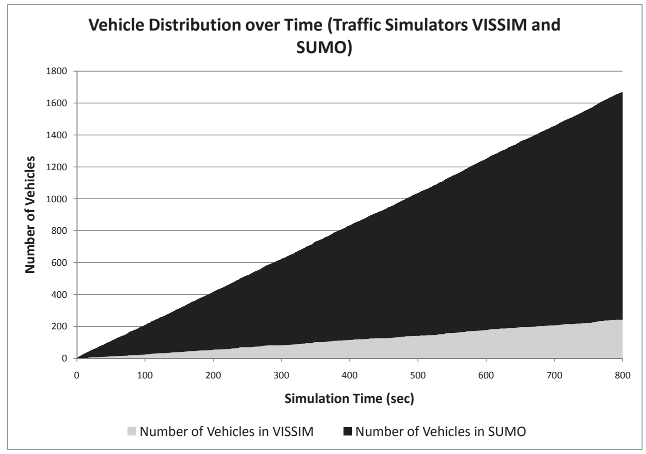

Figure 9: Inlet of vehicles during the simulation when coupling both traffic simulators VISSIM and SUMO

4.4 Scenario Preparation

In order to have identical road maps in VISSIM and SUMO, we used OpenStreetMap (OSM) data for both traffic simulators and converted the data into VISSIM as well as SUMO formats. To cut the OSM data to the needed size, we worked with the tool Osmosis[2].

For scenario definition, SUMO uses a set of XML files, which define road network, vehicle routes, traffic lights, and trips. The data conversion can be done semi-automatically by the export features of eWorld. In contrast, VISSIM uses a proprietary road map format and offers rudimentary support for the input of road networks files only. Therefore, we developed own tools for the data transformation from OSM into VISSIM.

5. EVALUATION

5.1 Vehicle Flow

In the first simulation series with VISSIM as single traffic simulator, a constant vehicle inlet of about 100 vehicles per minute was generated during the overall simulation runtime. As a result, the number of simulated vehicles increases continuously up to 1300 vehicles at the end of the simulation.

In the coupling of both traffic simulators VISSIM and SUMO, a vehicle inlet of about 100 vehicles per minute into the SUMO was generated. Vehicles driving in one of the four big cities were here simulated by VISSIM. During the simulation, the overall vehicle number increased up to 1400 vehicles in SUMO and up to 250 vehicles in VISSIM. Figures 8 and 9 show the detailed vehicle inlet in both simulation series.

5.2 Performance

In the following sections, we shall describe our performance results for both simulation series: for VISSIM as the single traffic simulator and for the coupling of VISSIM and SUMO. Special attention is paid to the simulation real time factor. A real time factor of 1 means that the overall simulation runtime is equal to the simulated time, e.g. a 10 minute simulation scenario is simulated in 10 minutes. A real time factor greater than 1 means that the overall simulation runtime is less than the simulated time, e.g. a 10 minute simulation scenario is simulated in 5 minutes if the simulation real time factor is 2. If the simulation real time factor is less than 1, more time for the runtime of the simulation is needed than the simulated time. As a result, no coupling with real time critical components is possible, e.g. with hardware test beds or the real world.

Because of the limited number of six simulation runs for each scenario, there are some deviations in the graphs depicting the dependency of the real time factor against the number of simulated vehicles. To show the trends of the measurements more clearly, we also display the moving average with a period of 20 for each curve.

5.2.1 VISSIM as Single Traffic Simulator

In Figure 10, the simulation real time factor against the number of vehicles simulated by VISSIM is depicted. Here, the overall simulation performance falls below a real time factor of 1 at a number of ca. 400 to 500 vehicles, i.e. that a simulation in real time can only be performed if the number of simulated vehicles does not exceed 500 vehicles. This is not suitable for time critical simulations that have to run in real time.

5.2.2 The Coupling of both Traffic Simulators VISSIM + SUMO

The performance results of the simulator coupling are shown in Figure 11. With an increasing number of vehicles, the performance also decreases. But, in contrast to the first scenario, the overall performance decreases more slowly. As a result, we have a real time factor greater than 1 during the overall simulation. When the maximum of about 1700 simulated vehicles in SUMO and VISSIM is reached at the end of the simulation, the real time factor is about 1.2. At that time, the number of vehicles simulated by VISSIM increases to 240 vehicles. At this point, the performance is similar to the performance of the VISSIM-only simulation with the same overall number of vehicles. This result shows that the performance of SUMO in the coupling scenario has only minor impact on the overall simulation performance.

[2]http://wiki.openstreetmap.org/index.php/Osmosis/

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

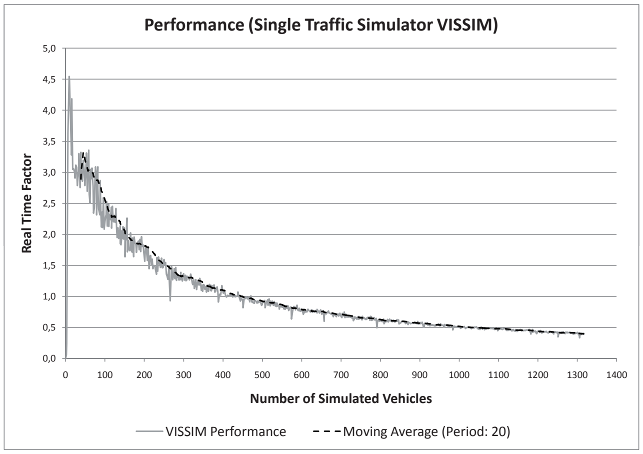

Figure 10: Simulation Results - VISSIM as single traffic simulator

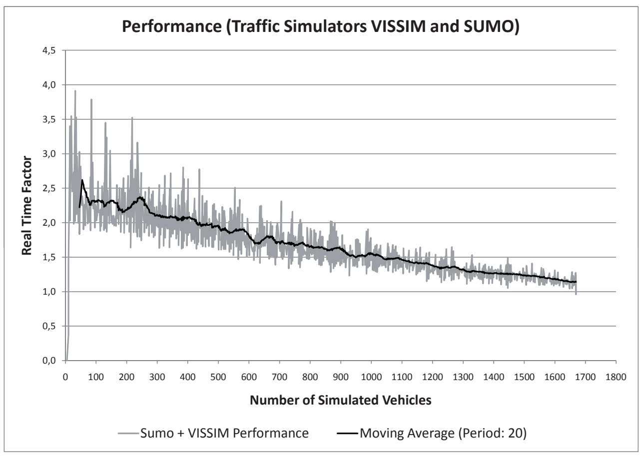

Figure 11: Simulation Results - coupling SUMO + VISSIM

5.2.3 Comparison

In Figure 12, the performance results of the two series are compared. Up to a number of about 150 vehicles, the simulation with VISSIM as the single traffic simulator is faster. For more vehicles, the coupling of VISSIM and SUMO yields a higher performance. Consequently, the coupling of VISSIM and SUMO helps to obtain an overall real time factor greater than 1 even though a huge number of vehicles is simulated.

6. CONCLUSION

In this paper, we have introduced a concept for the coupling of different traffic simulators to simulate one overall V2X scenario. This coupling has the benefit that the most suitable simulator for each of the different regions is used. The coupling concept was implemented in our V2X Simulation Runtime Infrastructure (VSimRTI). To show the advantages of our concept, we have analysed the performance of a V2X scenario simulation where both the traffic simulators VISSIM and SUMO were combined. VISSIM was used to achieve a highly accurate simulation of the most interesting region, whereas the more efficient traffic simulator

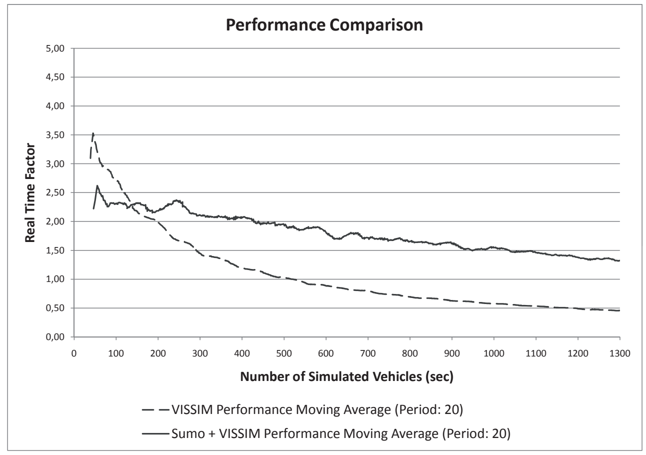

Figure 12: Simulation Results - Single traffic simulator VISSIM and coupling SUMO + VISSIM

SUMO simulated all surrounding areas. Our results show that this simulator coupling reduces the overall simulation time leading to a decrease in accuracy.

In the simulations with VISSIM as the single traffic simulator, the real time factor was only greater than 1 if a small number of vehicles was simulated. As a result, no coupling with real time critical components, e.g. with hardware test beds or the real world, was possible here. In contrast, the real time factor of the coupled simulation was greater than 1 all the time even though a huge number of vehicles was simulated. This is suitable for simulations that have to run in real time. The traffic simulator coupling concept, described in this paper, provides a solution to enable huge, but time critical-traffic simulations.

7. OUTLOOK

In [12] and [13], we showed that optimistic synchronisation of simulators decreases the overall simulation time. Thus, we plan a distribution of computational complexity from one to multiple traffic simulators in order to fully exploit the performance potentials of optimistic synchronization. A promising approach, therefore, includes a multi-instance traffic simulation that is realized by the concepts introduced in this paper.

Moreover, we plan to couple traffic simulators with real traffic and test beds. In our simulation architecture VSimRTI, real traffic data can be integrated in the same way as traffic simulators as long as no coupled simulator runs more slowly than in real time. This approach can be used for local traffic predictions of the near future. We plan to evaluate how simulations, which are connected to the real world in a V2X-based traffic system, can help increase traffic efficiency.

8. ACKNOWLEDGMENTS

This work has been carried out in the PRE-DRIVE C2X project[3] co-funded by the European Commission Information Society and Media in the 7th Framework Programme and supported by EUCAR.

[3]http://www.pre-drive-c2x.eu/

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640

9. REFERENCES

[1] R. Barr, Z. J. Haas, and R. van Renesse. Jist: an efficient approach to simulation using virtual machines: Research articles. *Softw. Pract. Exper.*, 35(6):539–576, 2005.

[2] L. Bloomberg and J. Dale. Comparison of vissim and corsim traffic simulation models on a congested network. *Transportation Research Record: Journal of the Transportation Research Board*, Volume 1727 / 2000:52–60, 2007.

[3] L. Bononi, M. Di Felice, G. D'Angelo, M. Bracuto, and L. Donatiello. Moves: A framework for parallel and distributed simulation of wireless vehicular ad hoc networks. *Comput. Netw.*, 52(1):155–179, 2008.

[4] J. S. J. E. Coeymans. An integrated framework for traffic analysis combining macroscopic and microscopic models. In *Transportation Planning and Technology*, volume 28, pages 135 – 148, 2005.

[5] M. Fellendorf and P. Vordisch. Validation of the microscopic traffic flow model vissim in different real-world situations. In *80th annual meeting of the Transportation Research Board Compendium of Papers*, 2001.

[6] R. M. Fujimoto. *Parallel and Distribution Simulation Systems*. John Wiley & Sons, Inc., New York, NY, USA, 1999.

[7] M. Haklay and P. Weber. Openstreetmap: User-generated street maps. *Pervasive Computing, IEEE*, 7(4):12–18, Oct.-Dec. 2008.

[8] Institute of Electrical and Electronics Engineers. *IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)–Federate Interface Specification. IEEE Standard 1516.1*. IEEE, New York, NY, USA, 2000.

[9] D. Krajzewicz, M. Bonert, and P. Wagner. The open source traffic simulation package sumo. In *RoboCup 2006*, 06 2006.

[10] S. Krauß, P. Wagner, and C. Gawron. Metastable states in a microscopic model of traffic flow. *Physical Review E*, 55(304):5597, May 1997.

[11] N. E. Lownes and R. B. Machemehl. Vissim: a multi-parameter sensitivity analysis. In *WSC '06: Proceedings of the 38th conference on Winter simulation*, pages 1406–1413. Winter Simulation Conference, 2006.

[12] N. Naumann, B. Schünemann, and I. Radusch. Vsimrti - simulation runtime infrastructure for v2x communication scenarios. In *Proceedings of the 16th World Congress and Exhibition on Intelligent Transport Systems and Services (ITS Stockholm 2009)*. ITS Stockholm 2009, September 2009.

[13] N. Naumann, B. Schünemann, I. Radusch, and C. Meinel. Improving v2x simulation performance with optimistic synchronization. In *Services Computing Conference, 2009. APSCC 2009. IEEE Asia-Pacific*, pages 52–57, Dec. 2009.

[14] T. Queck, B. Schünemann, and I. Radusch. Runtime infrastructure for simulating vehicle-2-x communication scenarios. In *VANET '08: Proceedings of the fifth ACM international workshop on VehiculAr Inter-NETworking*, pages 78–79, New York, NY, USA, 2008. ACM.

[15] T. Queck, B. Schünemann, I. Radusch, and C. Meinel. Realistic simulation of v2x communication scenarios. In *APSCC '08: Proceedings of the 2008 IEEE Asia-Pacific Services Computing Conference*, pages 1623–1627, Washington, DC, USA, 2008. IEEE Computer Society.

[16] E. Schoch, M. Feiri, F. Kargl, and M. Weber. Simulation of ad hoc networks: ns-2 compared to jist/swans. In *Simutools '08: Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops*, pages 1–8, ICST, Brussels, Belgium, Belgium, 2008. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[17] B. Schünemann, K. Massow, and I. Radusch. A novel approach for realistic emulation of vehicle-2-x communication applications. In *Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE*, pages 2709–2713, May 2008.

[18] B. Schünemann, K. Massow, and I. Radusch. Realistic simulation of vehicular communication and vehicle-2-x applications. In *Simutools '08: Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops*, pages 1–9, ICST, Brussels, Belgium, Belgium, 2008. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[19] M. Trueblood and J. Dale. Simulating roundabouts using vissim. In *Urban Streets Symposium*, 2003.

[20] J. W. Wedel, B. Schünemann, and I. Radusch. V2x-based traffic congestion recognition and avoidance. *Parallel Architectures, Algorithms, and Networks, International Symposium on*, 0:637–641, 2009.

[21] A. Wegener, M. Piorkowski, M. Raya, H. Hellbrück, S. Fischer, and J.-P. Hubaux. TraCI: An Interface for Coupling Road Traffic and Network Simulators. In *11th Communications and Networking Simulation Symposium (CNS'08)*, 2008.

[22] R. Wiedemann. Simulation des straßenverkehrsflusses. In *Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe, Heft 8*, 1974.

Digital Object Identifier: 10.4108/ICST.SIMUTOOLS2010.8640
http://dx.doi.org/10.4108/ICST.SIMUTOOLS2010.8640