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A Cooperative ITS study on green light optimisation using an integrated Traffic, Driving, and Communication Simulator

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Abstract

Cooperative ITS is enabling vehicles to communicate with the infrastructure and each other, to provide improvements in traffic safety, traffic control, and traffic management. Researchers from fields of information technology, communication, and traffic engineering are involved in the development of applications to achieve these goals. One challenge is the testing of such systems and their impact in a large scale. Real-world implementation is mostly limited to test vehicles or test stations, simulation studies lack the human factor, and driving simulation experiments are limited to a single. In this paper, we present a system, integrating a traffic and communication simulators with a multi-user driving simulator that can overcome these drawbacks and provides a low-cost testing environment for new developments V2V and V2I applications in a controlled, but realistic way.

1. Introduction

Cooperative Intelligent Transportation Systems (C-ITS) allow vehicles to communicate and exchange information with their environment. The two main streams vehicle-vehicle (V2V), and vehicle-infrastructure (V2I), are often combined as V2X, implying that the vehicle can essentially communicate with various systems via wireless technology. The aims of C-ITS are an increase in road safety, a reduction of the traffic induced environmental impact, and an improvement in traffic management.

In recent years, various research projects have contributed solutions for the fundamental technological requirements of vehicle communication. Cost-efficient positioning and radio hardware is available and standardization is underway. The focus of the work on vehicular communication shifts from research topics to preparing deployment (Weiss, 2011), where possible using existing equipment and equipment that is available to almost everyone is essential (Fukushima, 2011).

Field operational tests (FOTs) are large-scale real world testing programs aiming at a comprehensive assessment of the efficiency, quality, robustness, and acceptance of technologies used for smarter, safer, cleaner, and more comfortable transport solutions (Schuenemann, 2011). The prohibitive price of operational test beds means that computer simulations are the only viable solution for analyzing the performance (Stanica et al., 2011), and can incorporate indirect effects, such as congestion in the network at peak times. Simulations represent an essential part of the FOT chain and need to be carried out during a field operational test (Schuenemann, 2011). Currently, different kinds of simulators are necessary for the simulation of vehicular communication. According to (Schunemann et al., 2008) and (Schuenemann et al., 2008), a realistic simulation of V2X communication consists of at least three different simulators:

Traffic simulation

Since microscopic traffic simulation models consider individual vehicles in the traffic stream, the impacts on the traffic system can be estimated by simulating varying levels of communicating vehicles in the population. Traffic simulation captures the physical movement of vehicles through a road network. The level of detailed required for simulating V2X application, limits the simulation to microscopic or nanoscopic simulation models. Those models simulate individual vehicle movements through mathematical, or physically models, considering the reactions of a driver to her or his environment (Miska et al., 2012). The time-step of microscopic or nanoscopic traffic simulations is 1-10Hz, depending on the fidelity.

Communication Network Simulation

Cellular networks are usually applied in V2I solutions, whereas ad hoc networks are practically the only technology considered in V2V communications (Santa et al., 2008). These networks are simulated with communication network simulators that mimic the data transport through a chosen transfer protocol. The simulation is based on discrete events, but the results can usually be traced in high frequency, such as 10^{-6} seconds.

V2X Application Simulation

The real-world application, driven by the communication needs to be simulated as well. There are many applications such as Green Light Optimized Speed Adviser or GLOSA (Katsaros et al., 2011), Cooperative Collision Avoidance (Santa, et al., 2008) and Adaptive Route Change (Fu, 2001) which have already been studied in the related research work.

If the application triggers an automated response (i.e., speed reduction, broadcast information) this needs to feedback to the appropriate simulator, but if the result is a warning to the driver, an appropriate update needs to be generated to anticipate human behaviour. The application simulation usually is event based.

This paper uses a system that extends this set of simulators with a multi-user driving simulator to capture human response to the C-ITS application, as well as human-to-human interaction during the driving task. As Nakasone (2011) and Miska et al. (2010) have shown the response of users in a driving simulation is effected by the surrounding traffic, which could lead to biased outcomes of the simulation.

The extension is key for the evaluation of C-ITS systems based on simulation and has the potential to improve the success of FOTs significantly. The following will give a brief overview of existing V2X simulation environments and introduces the integrated traffic, communication, and multi-user driving simulator framework. Results of the green light optimized speed advisor (GLOSA) application are shown and discussed before the outlook on planned future work.

2. Existing V2X Simulation Environments

A number of projects have already combined different kinds of simulators for the simulation of V2X communication scenarios (Queck, 2008). As shown in **Table 1**, most systems are based on a fixed coupling of a traffic simulator, and a communication simulator.

Table 1: Overview of existing V2X simulation environments

System	Traffic Simulator	Communication Simulator	Application Simulator	Type
iTETRIS	SUMO	ns-3	TraCI	fixed coupling
VSimRTI	SUMO/VISSIM	JiST/SWANS & OMNeT++	VSimRTI_App	various simulators can be utilized
TraNS	SUMO	ns-2	TraCI	fixed coupling
Veins	SUMO	OMNeT++	TraCI	fixed coupling
Paramics & ns-2	Paramics	ns-2	Paramics	fixed coupling

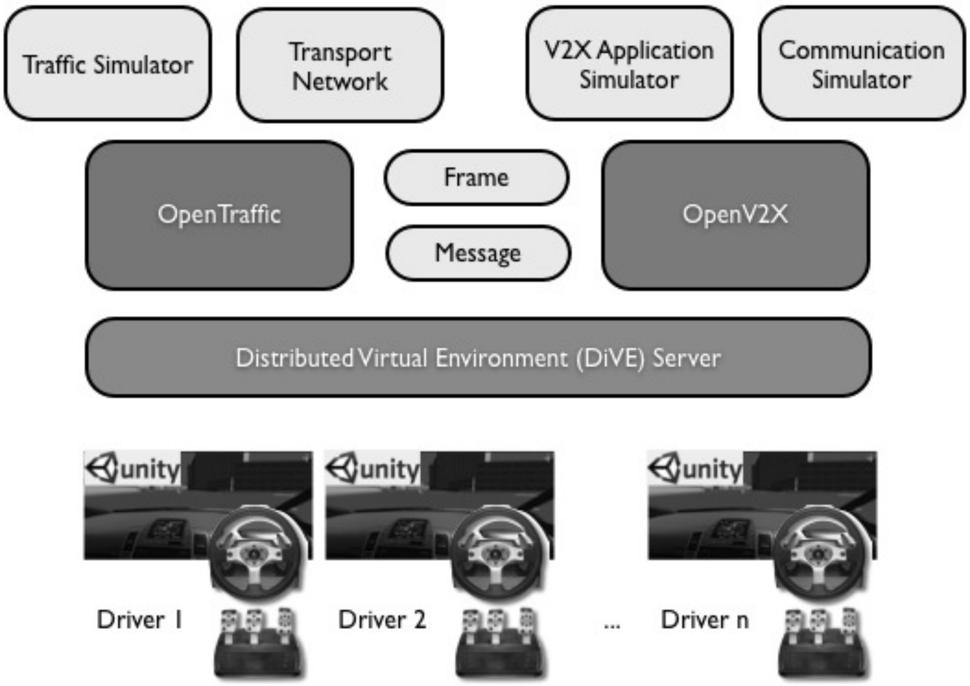
Additionally, the V2X application itself is simulated in an add-on of the traffic simulator, as the ones used provide mechanisms to do so. VSimRTI is very different in nature as it caters for a whole range of simulators. This is realized by focusing on the required services of the various simulators and the synchronization of them. Intentionally, systems that only extend one simulator with simplified capabilities in either traffic or communication simulation have not been included, as those systems do not integrate the best possible technology from both areas, which is essential when evaluating V2X systems in a simulated environment.

The proposed system in this paper follows a similar path, by building the system around standardized interfaces that build a middleware to connect the required applications. In this way, the system remains flexible, is sustainable and can easily adapt to new technology. The proposed system distinguishes itself from other related frameworks; in the way it integrates to a multi-user driving simulator. The next section will introduce the architecture of the proposed system.

3. Simulator Framework

The simulator framework used in this study is an integrated of a traffic and communication simulator, connected to a multi-user driving simulator. This setup allows having multiple human drivers participating in an experiment simultaneously and to capture not only their individual behaviour, but also their interaction among each other. **Figure 1** gives an overview of the system.

Figure 1: Simplified overview of the simulator framework, integrating a multiuser driving simulator with a traffic simulation and communication simulation



The core of the system is the Distributed Virtual Environment (DiVE) Server that coordinates the simulation among the various clients to ensure a true immersive experience for the subjects taking part in the experiment. The traffic and communication simulation are independent modules and are being synchronised through the OpenTraffic (Miska et al., 2011) middleware and the OpenV2X middleware respectively. The following will describe the OpenV2X middleware and its implementation in more detail.

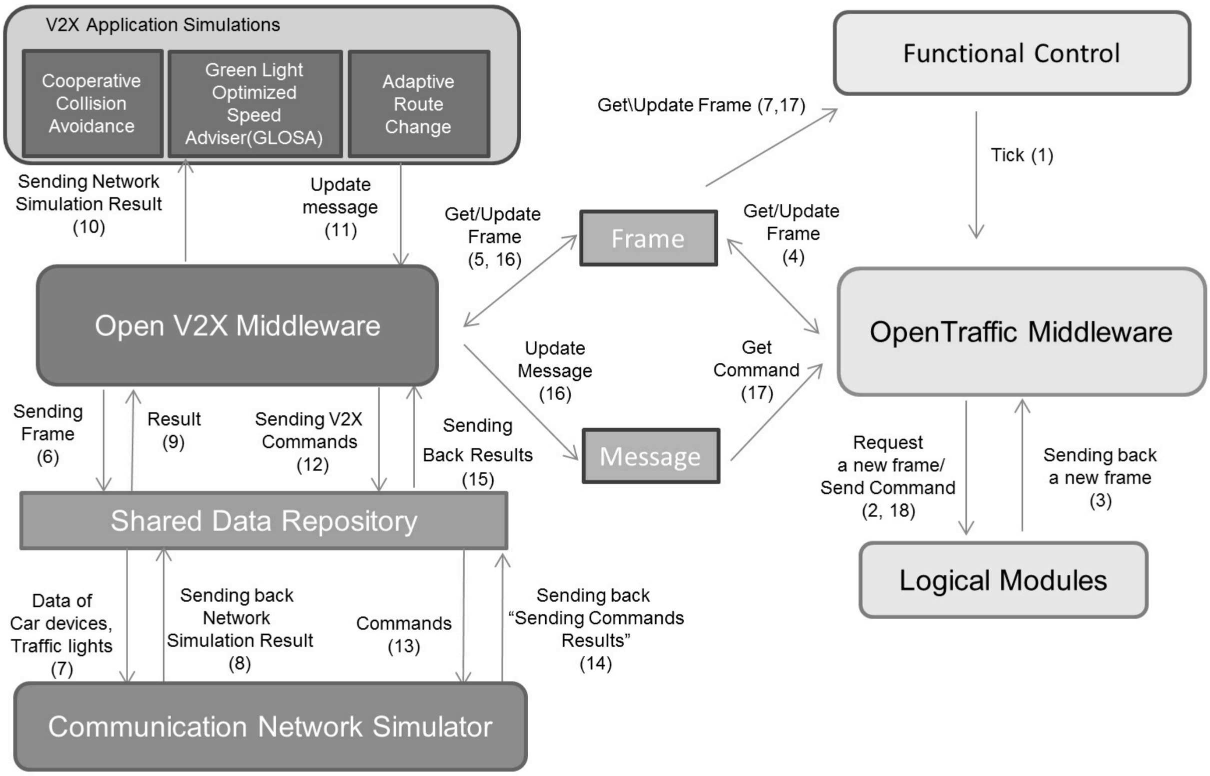
4 OpenV2X Simulation Details

4.1 OpenV2X middleware

A simulation of V2X applications follows, as most simulations, a certain workflow. They rely on information from sensors and communication channels to run algorithms to evaluate the driving situation and to give advice or take action as appropriate. OpenV2X uses a 'Message' that includes the information received from other vehicles or the road infrastructure. **Figure 2** shows the structure of OpenV2X and its functioning process indicated as numbers.

According to the diagram shown in **Figure 2**, OpenV2X middleware receive (5) a "Frame" from OpenTraffic, and sending (6) that to a shared data repository so that network simulator can access it. Based on latest "Frame" information accessed from the shared data repository, network simulator computes the connectivity among all nodes (i.e. vehicles and traffic lights in our case). Then Network simulator passes (9) the network simulation results (i.e. the connectivity among all nodes) to the OpenV2X middleware via the shared data repository (8). Then the OpenV2X middleware would inform (10) the results to V2X application. Then V2X applications conform to the OpenV2X middleware interface computes the advice to send out to the identified nodes (e.g. computer vehicles). The advice, in form of a uniform message, will then be updated (11) to the OpenV2X middleware for broadcast. Then OpenV2X middleware converts them as V2X commands and passes (12) them to the shared data repository. Then network simulator would take (13) those commands and route (14) them to the target nodes based on their actual position, by writing it in the shared data repository.

Figure 2: Architectural Design of the OpenV2X middleware including messaging (numbers indicates the processes) and how it integrates to OpenTraffic Middleware



The suggested advice by a V2X application, now in the form a command, intended for computer vehicles would be picked up (17) by OpenTraffic via (15, 16) OpenV2X middleware. Each suggestion message would then be used by OpenTraffic to control (18) the behaviour of computer vehicles simulated by the traffic simulation in next frame. Later, we would explain how the suggested advice would propagate to the human drivers on driving simulators. The result of successful or unsuccessful message delivery, including delay if applicable is returned to the shared data repository, and picked up by the middleware that will update the 'Message' element. The entire process of receiving a 'Frame' and updating the advice calculated within happens in each time-step of the whole simulation. The shared data repository, unified through a wrapper to allow various contents, is introduced to synchronize traffic simulator with the communication simulator. The shared data repository is, as mentioned earlier, usually event based and does not follow the update cycle of the traffic and driving simulation.

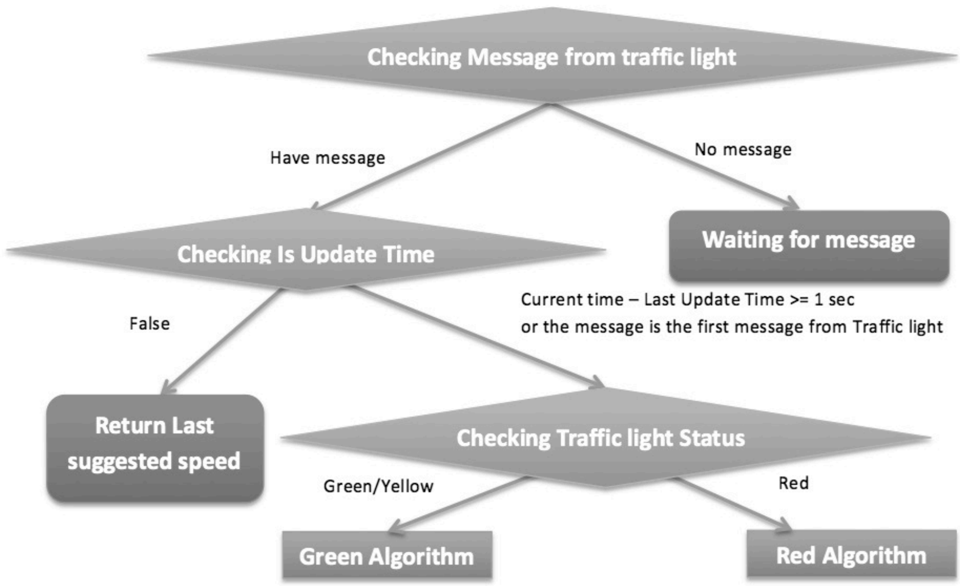
Among the V2X applications shown in **Figure 2**, only the Green Light Optimized Speed Advisor (GLOSA) application is implemented and will be discussed later in detail.

When combined, OpenTraffic and OpenV2X represent a highly modular framework for V2X application simulation, with the possibility of adding a multi-user driving simulator. With the 'Frame' and 'Message' object for information exchange, the two systems can be synchronised and do not necessarily follow the same update frequency. However, if a driving simulation is included, the overall time keeping needs to be within the driving simulator, as it is a real-time application.

4.2 V2X Application Simulator

For this paper, a Green Light Optimized Speed Advisory (GLOSA) application has been chosen to demonstrate the usability of OpenV2X middleware. A GLOSA is a vehicle to infrastructure communication application between vehicles and traffic light controllers. After vehicle's onboard device receives the green light timing, it will calculate suitable speed for passing the next traffic light and advice the driver accordingly (Katsaros, et al., 2011).

Figure 3: Green Light Optimized Speed Advisory (GLOSA) algorithm

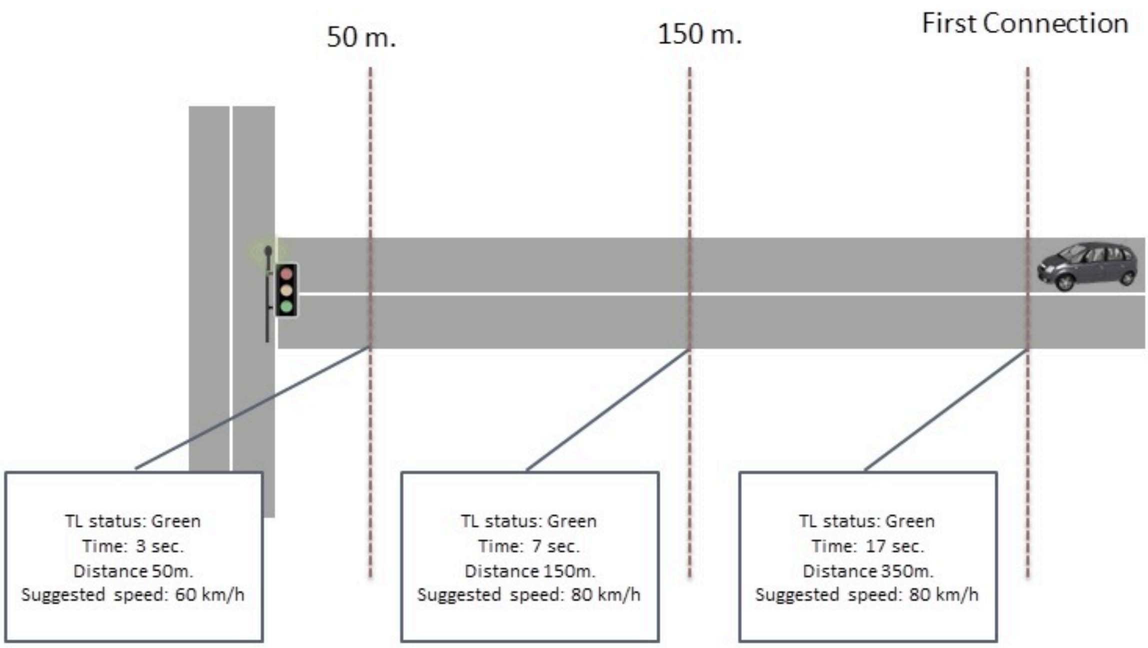


To implement the GLOSA as a V2X application in OpenV2X middleware, that should generate advice for computer vehicles as well as driving simulator vehicles controlled by human drivers, we propose the following approach. For computer vehicles, we implement the GLOSA algorithm shown in **Figure 3**, as part of OpenV2X middleware (see **Figure 2**), which would compute the advisory speed for them. Figure 3 shows how the speed advisory is processed by OpenV2X and OpenTraffic to control the computer vehicles.

For driving simulator vehicles controlled by human drivers, we implement the GLOSA algorithm as a part of the "On Board Device" in each driving simulator client as shown in Figure 6(b). For this to work, OpenV2X middleware would make sure that the information (status, green light remaining time, which vehicles are connected) about traffic lights located in the driving simulator vehicle's path, is available as part of the "Frame "which is sent (process 17 in Figure 3) to the Functional Control. Then the Functional Control would broadcast that information across DiVE framework so that all "On Board Devices" of driving simulator clients receive it.

Unlike the GLOSA speed advisory which is feedback to the computer vehicles in each time-step, we need to devise an appropriate method to decide how frequently speed advisory should be instructed to the human drivers. For that, we use the distance from the driving simulator vehicle to the next traffic light as a model to control updating of speed advisory for human drivers as shown in **Figure 4**.

Figure 4: Distance Model to control updating of suggested speed for human drivers



Further, we define seven types of advisory message that can be used to instruct the human drivers:

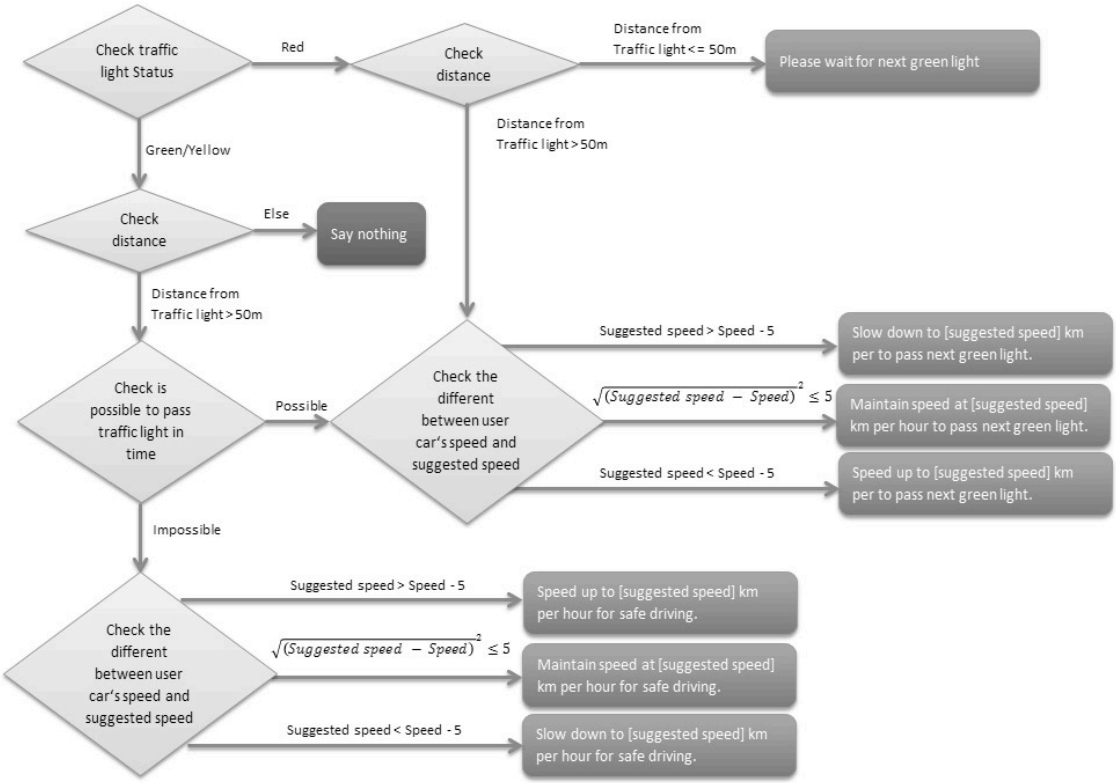
1. Please with for next green light
2. Maintain speed at [suggested speed] km per hour to pass next green light.
3. Speed up to [suggested speed] km per hour to pass next green light.
4. Slow down to [suggested speed] km per hour for safe driving.
5. Maintain speed at [suggested speed] km per hour for safe driving.
6. Speed up to [suggested speed] km per hour for safe driving.
7. Slow down to [suggested speed] km per hour for safe driving.

The above messages are chosen according to the decision tree in **Figure 5**. The algorithms to choose the message as well as to control the frequency of updates of suggested speed are implemented as part of the "On Board Device" in each driving simulator client.

4.3 Driver Assistance in Multi-User Driving Simulator

In driving simulator client, we implemented a driver assistance system based on simple text to speech system which converts the chosen advisory text message to human voice, instead of displaying it visually. In this way, we expect the voice based driver assistance system to reduce the distracted attention from driving because the human user does not have to read the suggested speed message from the device.

Figure 5: Decision tree to determine the message generated to advice the human driver on his or her speed decision based on the traffic light status



5. Experiments and Results

Two experiments have been designed to test the implementation of the system. A first scenario is using the computer vehicles (from traffic simulation) only to allow checking on the interaction of the traffic simulator and communication network simulator without the interference of human drivers. Afterwards, a human driver was introduced to test the full system.

5.1 Experiment Setup

We use the virtual 3D city, a 3D model of an urban road environment resembling a neighborhood of Tokyo, Japan, as the virtual experiment space to test the implementation of OpenV2X middleware and GLOSA as V2X application.

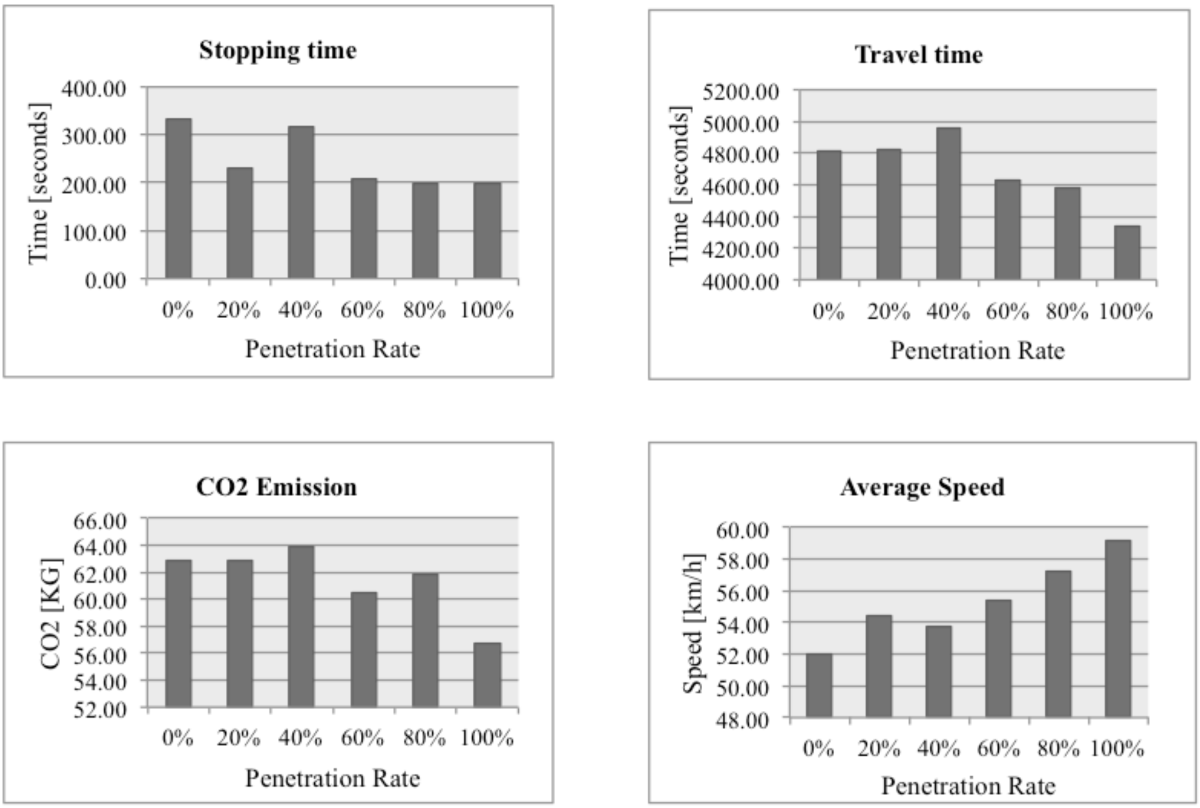
The 3D model has a stretch of roads connected by three intersections which are regulated by traffic lights. The total length of road distance is about 2.8 km, from the source to destination. The traffic lights would function as sensors, in OpenV2X and OpenTraffic context, to detect the nearby C-ITS enabled vehicles which can connect to it.

5.2 Computer simulated vehicles and GLOSA algorithm

To study the effect of GLOSA on average stopping time, travel time, CO_2 emission, and average speed, computer vehicles were simulated in the 3D virtual environment. Simulations were performed considering penetration rates of V2X enabled computer vehicles from 0% to 100% in 20% increments. The traffic demand for the three lane arterial road was set to 2400 computer vehicles per hour at source. In this experiment, no distance model was used to control the update frequency of the speed advisory.

Figure 6 shows typical results for testing onboard units. A 20% penetration rate already cuts the stopping time by 30%. However, travel time and CO2 emission are nearly the same, though there is an improvement in average speed. With a penetration rate of 40%, the situation is worse than without the cooperative ITS devices, an effect similar to the introduction of routing equipment to vehicles. Though after passing the threshold of 60%, stopping time in at equilibrium of 35% below the baseline, travel time and average speed are improving, and CO2 emissions are doing better than the base case. While these results are promising, it is unrealistic to assume that all vehicles will follow given advice, and the frequency of advice given has to be limited to avoid distraction of the driver. Therefore, these results are considered to be the 'best' achievable after utilizing the cooperative ITS device.

Figure 6: Results from Experiment 1, illustrating the changes in stopping time, travel time, CO2 emission and average speed for different penetration rates of V2X enabled vehicles



5.3 User & Computer simulated vehicles with/without GLOSA algorithm

The general setup of this experiment is the same as before with the addition of having human drivers participating. Out of a group of 10 candidates, everyone was asked to drive a driving simulator vehicle (one driver at a time) in one of the following scenarios:

1. User vehicle and Computer vehicles without Cooperative ITS system
2. User vehicle with V2X device and Computer vehicles without V2X device
3. User vehicle with V2X device and 10% Computer vehicles with V2X device
4. User vehicle with V2X device and 100% Computer vehicles with V2X device

To identify the impact of human behavior, in this experiment a driving simulator has been used to study the drivers' response on the advice given by the C-ITS device. **Figure 7** shows the drive cycle of two different drivers, indicating that the response of a driver is lacking several seconds, depending on the speed difference. Further, it indicates that driving conditions do not always allow adapting to the advice speed.

Figure 7: Drive cycle of a human driver with the recommendation of speed given by the cooperative ITS device in an environment of equipped vehicles. A recommendation of 0 km/h equals to no advice

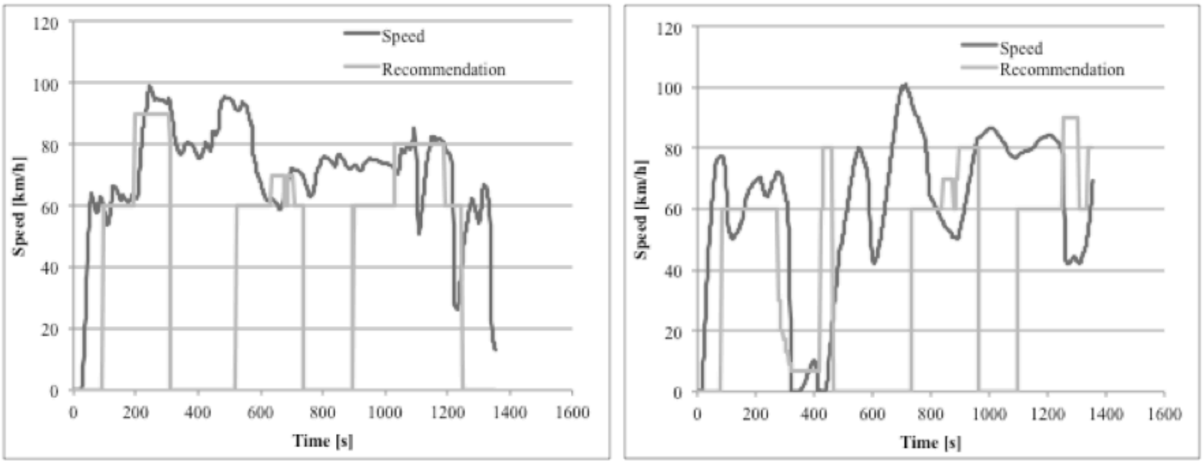
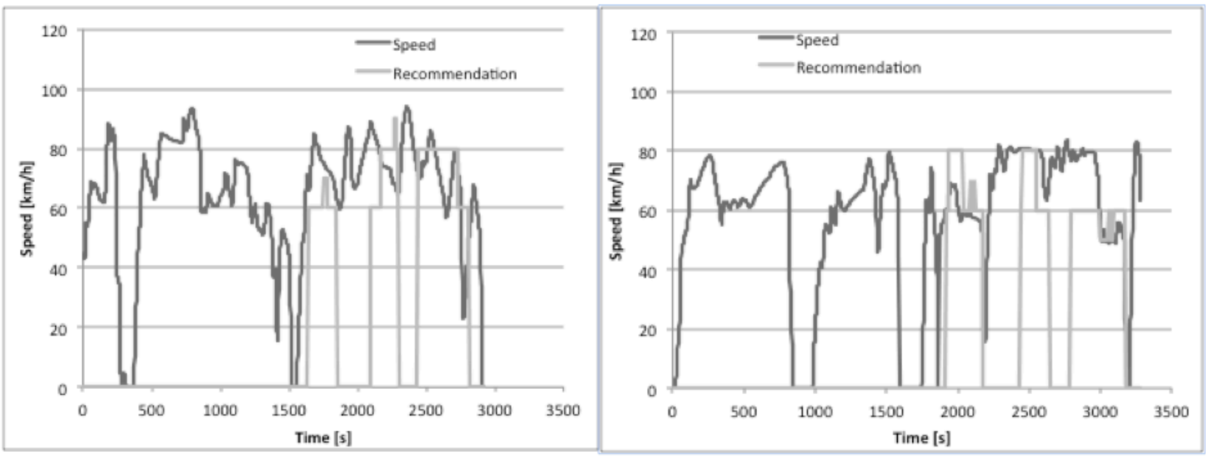


Figure 8 shows the drive cycle in an environment in which only 10% of the vehicles are

equipped with a C-ITS device. Due to the less controlled traffic stream, the advice given to the driver seems to be counterproductive. When comparing the first half of the graphs, which are without advice, to the second half, the drive cycle seems less smooth and the CO2 emissions of the equipped vehicle are increasing.

Figure 8: Drive cycle of a human driver with the recommendation of speed given by the cooperative ITS device in an environment where 10% of vehicles are equipped with ITS devices. A recommendation of 0 km/h equals to no advice



While perfectly controlled vehicles, as in Experiment 1, can improve the situation with a low penetration rate, the human behavior, and ability to follow the advice is reducing the impact of the speed advice. However, with an increase of equipped vehicles this effect is getting less and a better performance of the traffic stream is possible.

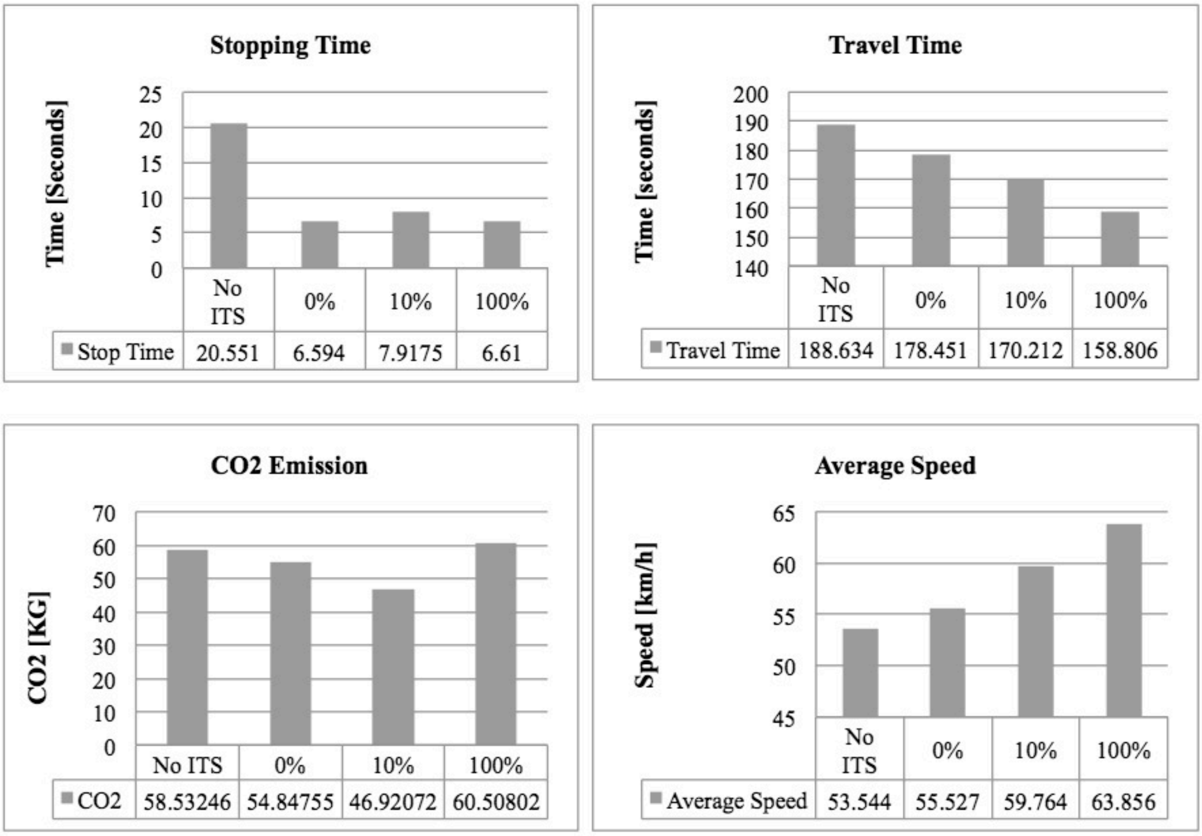


Figure 9: Results from the experiment 2, illustrating then changes in stopping time, travel time, CO_2 emissions and average speed of user vehicle for different penetration rates of cooperative ITS device, ranging from 0, 10% and 100%

Figure 9 shows the result of GLOSA with human driver. Stopping time when the user's vehicles are equipped with a C-ITS device is reduced by 67.63 percent. The higher of the GLOSA penetration rate is the more benefits with 15.7 percent of reduction travel time, 19.83 percent CO_2 emission and 16.06 percent of increase average speed.

6. Discussion & Future Work

In this paper, we have presented the OpenV2X middleware framework which integrates a traffic and communication (wireless) network simulators with a multi-user driving simulation for the purpose of simulating a C-ITS system and capturing human response to it. To demonstrate the usability of the OpenV2X middleware, we developed a V2X application implementing the algorithm of Green Light Optimized Speed Advisory (GLOSA). The OpenV2X middleware framework in together with a V2X application allowed us to study a) the performance of a C-ITS device on computer simulated vehicles, and b) the human response on the advice given by the C-ITS device. The study shows promising results.

The result from the computer vehicles only, with GLOSA experiment suggests that the GLOSA application has a positive effect to computer vehicles. The higher of the GLOSA penetration rate is the more benefits with 40.36 percent of reduction stop time, 10.18 percent in travel time and up to 8 percent reduction in CO2 emission.

The result from user and computer vehicles with/without GLOSA experiment suggests that the GLOSA application has a positive effect to human drivers even the response of drivers is lacking several seconds, depending on the speed difference. Stopping time when the user's vehicles are equipped with a cooperative ITS device is reduced by 67.63 percent. The higher of the GLOSA penetration rate is the more benefits with 15.7 percent of reduction travel time, 19.83 percent CO2 emission and 16.06 percent of increase average speed.

The results show that the OpenV2X middleware framework is able to reproduce the findings of similar simulation studies, and to extend them with additional findings such as compliance rate based on the information provision, and driving behaviour changes based on penetration rate. An analysis of intersection performance and pollution has been performed to compare the situation with and without the usage of a C-ITS device. Key here is that all results are obtained through a single system, rather then a compilation of various applications.

As an initial step to evaluate our system, we conducted the experiment involving one human driver at a time, even though our simulation framework can handle multiple human driven vehicles simultaneously. In future, we plan to conduct extensive studies that would focus human-to-human interaction during the driving task in the context of a C-ITS application.

The middleware framework presented in this paper offers researchers and policy makers a low-cost, virtual experiment station, that allows studying the effect of C-ITS in a safe and controlled multi-user environment. Researchers are enabled to test new communication methods, and control algorithms, while policy makers can analyse the impacts of those prior to application and real-life trials. Additionally, every experiment with the system provides feedback data to the simulation component for calibration, so to provide an even more realistic environment.

With vehicular communications to be considered the next step in increasing transportation safety and comfort, future work will include further developments of V2X applications, such as cooperative collision avoidance and adaptive route change. Further, the implementation of additional simulators, or connection to existing ones, has priority as it relates to the fact that every study should chose the appropriate simulator based on its requirements.

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