Demo: Simulating the Impact of Communication Performance on Road Traffic Safety at Intersections

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ABSTRACT

Performance evaluation of communication protocols is usually carried out using typical network metrics as delay, jitter, or goodput. However, recent studies in the context of Inter-Vehicle Communication (IVC) have shown that using these metrics is not sufficient for evaluating vehicular safety applications. To highlight the importance of safety metrics and their applicability, we extended our existing simulation framework Veins to visualize these metrics live while the road traffic and network simulation are running in parallel. In particular, we demonstrate the impact of communication on intersection assistance applications. To simulate different intersection approaches, we implemented a simulation model that resembles different kinds of driver behavior and enables crashes at intersections. The resulting situations are displayed in the road traffic simulator and give the visitor insights on the current state of endangered vehicles. Furthermore, an autonomous controller has been implemented which tries to avoid accidents and hence shows the real-world impact, i.e., accidents can be avoided using advanced beaconing techniques. To increase interactivity of the demo, visitors will have the possibility to interact with and take control over endangered vehicles.

1. INTRODUCTION

Inter-Vehicle Communications (IVCs) will enable future vehicles to run diverse applications ranging from entertainment to vehicular safety applications. Current research is focusing on vehicular safety applications, since they are regarded as the main driver to deploy Dedicated Short-Range Communication (DSRC) radios [4]. Envisioned safety applications are manifold. One particularly challenging application regarding the communications point of view are so-called intersection assistance applications, as they require reliable real-time communication mostly under demanding Non Line of Sight (NLOS) conditions.

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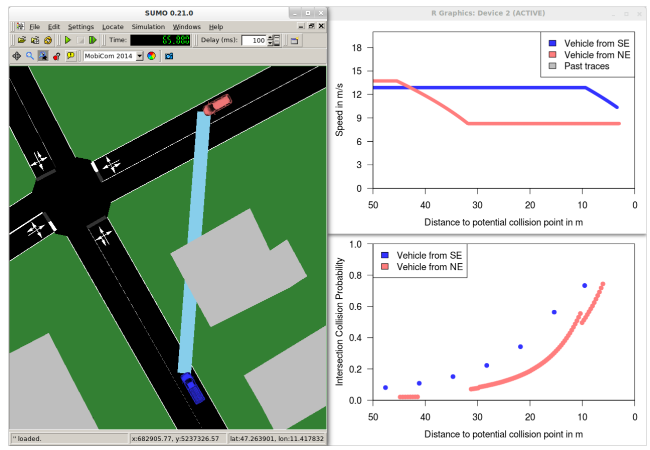


Figure 1: Overview of the demo GUI.

In the past decade, several standards for IVC have been developed (e.g., [7]). Although first Field Operational Tests (FOTs) have been conducted it is still unclear to which extent IVC will be able to support safety applications. Moreover, FOTs are not the primary method to develop and investigate new communication protocols or strategies. Therefore, current research on vehicular safety applications is relying on extensive simulation studies to investigate the effects of communication on vehicular safety applications [1, 8].

Usually communication protocols are evaluated with typical network metrics as goodput, latency, jitter, and in case of wireless networks, channel load and collisions. However, these metrics are not adequate to assess the impact of communication on life saving applications, i.e., a high throughput might not be an indicator that a lot of accidents can be avoided. Thus more adequate safety metrics for IVC have been proposed [5]. We made a first step towards safety metrics by introducing the *intersection collision probability*, which is a measure for crash likelihood at intersections [9]. The evolution of the intersection collision probability is depicted in the lower right part in Figure 1.

Our work follows a line of research that was started earlier. In 2005 a complete simulation architecture for IVC based intersection assistance applications has been presented in [2]. Interestingly, the authors showed the impact of their Time Division Multiple Access (TDMA) based communication strategy already by proofing the reduction of crashes and by showing the average speed of colliding vehicles. Meanwhile the IEEE 802.11p standard using CSMA/CA has been released and beacon-based solutions with congestion control mechanisms [7] are proposed instead of TDMA approaches. Therefore, an up-to-date simulation environment for intersection assistance applications will help to study and design communication strategies.

This demo highlights how *Communication Performance* and safety metrics have an impact on *Road Traffic Safety*. To demonstrate the impact of different communication strategies this demo is based on the following contributions:

- We integrated the calculation of the intersection collision probability into the Veins simulation framework.
- We developed an intersection approach model that allows to simulate arbitrary driver behaviors which lead to CRASH situations (Section 2.1).
- We implemented a simple autonomous reaction controller as well as an interaction interface which both allow to omit crashes (Section 2.2).

More specifically, this demo points out that, in certain situations, current standards (e.g., ETSI Transmit Rate Control (TRC)) are not able to provide sufficient communication opportunities. Furthermore, we show how this limitation can be overcome with the help of so called *situation-based rate adaptation* proposed in [8].

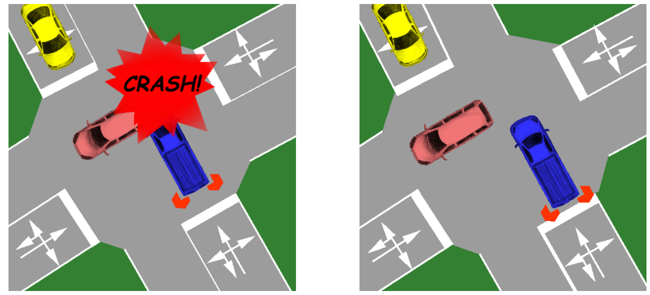
2. INTEGRATION WITH VEINS

As a basis we use the Veins simulation framework[1] which couples the road traffic simulator SUMO and the network simulator OMNeT++ bidirectionally. We extended this framework to simulate arbitrary collision situations at intersections, to detect crash situations, and to perform autonomously reactions of endangered vehicles when the communication-based intersection assistance application triggers them.

Our simulation includes several vehicles in vicinity of the intersection. For being able to demonstrate the effect of communication, we consider always only two dangerously approaching vehicles at a time. As depicted in Figure 1 the monitored vehicles are coloured blue and red as long as they have not been communicating with each other. When the monitored vehicles receive a Cooperative Awareness Message (CAM), they can calculate their intersection collision probability as defined in [9] and change their color according to the estimated crash likelihood (starting from green over yellow to red). In addition the evolution of the intersection collision probability is plotted live for both monitored vehicles (cf. Figure 1 lower plot on the right) dependent on the distance whenever they receive a CAM. Moreover, the upper plot in Figure 1 depicts the vehicle dynamics of both vehicles, i.e., the driven speed at distances of less than 50 m to the intersection.

Other vehicles are yellow for visibility reasons and do not influence the colliding vehicles from a road traffic point of view. Nevertheless, all vehicles are exchanging CAMs and hence, the communication of the two potential collision vehicles is influenced by all present vehicles in the simulation. Communication is simulated in OMNeT++ using detailed models for radio propagation, physical layer, Medium Access Control (MAC), and the ETSI TRC. The simulation models and parameters are listed in Table 1.

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



(a) CRASH Situation (b) NO CRASH Situation

Figure 2: Detailed view of intersection area.

2.1 Simulating Crashes at Intersections

For being able to simulate and analyse arbitrary intersection approaches we implemented a simulation model which is parameterized by the *aggressiveness* and *discipline* of the driver as proposed in [6]. The aggressiveness parameter accounts for the fact that not all drivers are pushing the brake pedal equally. The second parameter simulates driver's braking reaction (i.e., drivers do no always brake in time) and hence called discipline. In particular this allows to simulate crashes with different speeds, acceleration/deceleration behaviors; where right-of-way rules or traffic lights are ignored by the drivers. More precisely, the vehicles in the road traffic simulator SUMO ignore traffic rules and their speed as well as acceleration or deceleration are completely controlled via a so-called `CollisionScenario` implemented in OMNeT++. To ensure that the demo is easy to follow the simulation model always executes only one `CollisionScenario` at a time.

Basically, the `CollisionScenario` determines the simulated driver behavior by randomly choosing aggressiveness and discipline (D_{agg} and D_{dis}, respectively) as well as a crossing speed (v_{cross}). Based on this information, the crossing times (t_{c1} and t_{c2}) of both vehicles to the potential collision position can be computed. Moreover, the time delta t_δ can be calculated by $t_\delta = |t_{\text{c1}} - t_{\text{c2}}|$. The value of this time delta t_δ is used by the intersection approach model and affects the outcome of the corresponding `CollisionScenario`, i.e., CRASH or NO CRASH. Depending on the speed and outline of the vehicles very small deltas (less than 1 s) typically result in CRASH (cf. Figure 2a). Whereas, larger deltas (more than 1.0 s) usually still imitate dangerous driving behavior, but result in NO CRASH (cf. Figure 2b). The parameters used for the intersection approach model are listed in Table 1.

Even though the autonomous controller or the people interacting with the demo try to avoid crashes, they can still occur. Therefore, a collision detection algorithm is executed every simulation time step, which checks whether the outlines of any two vehicles at the intersection are overlapping. The collision detection is parameterized with the values listed in the lower part of Table 1.

2.2 Crash Avoidance

Our demo has two modes that can be executed: One makes use of a simple autonomous reaction controller to demonstrate the real-world impact of different communication strategies. The other one allows visitors of the demo trying to avoid a crash by taking control over one of the two endangered vehicles.

	Parameter	Value
PHY & MAC	Path loss model	Free space ($\alpha = 2.0$)
	Shadowing model	Building Shadowing [11]
	Attenuation per wall [11]	$\beta = 9.0$ dB
	Attenuation per m [11]	$\gamma = 0.4$ dB
	PHY model	IEEE 802.11p
	MAC model	IEEE 1609.4
	Frequency	5.89 GHz
	Bitrate	6 Mbit/s
	Access category	AC_VO
	MSDU size	193 B
	Transmit power	30 dBm
TRC	$I_{\min}$, I_{def}, $I_{\max}$	0.04 s, 0.5 s, 1 s
	$b_{\min}$, $b_{\max}$	0.15, 0.40
	T_{M}, T_{DCC}, T_{up}, T_{down}	1 s, 1 s, 1 s, 5 s
Road traffic simulation	Max. speed [3, Tab. IV]	$\sim \mathcal{N}(13.89, 2.92)$ m/s
	Max. acceleration	2.1 m/s^2
	Max. deceleration [10]	9.55 m/s^2
	Driver aggression D_{agg}	$\sim \mathcal{U}(10, 90)$ %
	Driver discipline D_{dis}	$\sim \mathcal{U}(10, 90)$ %
	Crossing speed v_{cross}	$\sim \mathcal{U}(3, 12)$ m/s
	Time Delta t_δ	$\sim \mathcal{U}(0.1, 1.0)$ s
	Simulation time step	10 ms
	Vehicle length	5.0 m
	Vehicle width	1.75 m

Table 1: Simulation parameters for the demo.

The autonomous reaction controller monitors the intersection collision probability for both endangered vehicles individually. When the collision probability exceeds a threshold of 50 %, the vehicles are reacting as follows:

1. The vehicle closer to the potential collision point is continuing with the same speed.

2. The vehicle further away is going to perform a full stop immediately with the maximum deceleration rate.

Obviously, this is not sufficient for all possible crash situations and thus more effort is needed to develop more advanced reactions controllers, but by using this approach we can already observe a major impact of communication on road traffic safety.

3. POSSIBLE FUTURE SAFETY METRICS

In [8] we have used *intersection approach model* described in Section 2.1 to investigate the impact of communication fairness on road traffic safety. One safety metric in that paper was the *unsafe time* that a vehicle experienced during the last three seconds before a crash.

In future the presented simulation framework can be used in conjunction with any realistic autonomous controller or a driver reaction model to evaluate communication protocols and strategies for intersection assistance applications. We suggest future simulation the use of the following more comprehensive safety metrics:

- *Percentage of avoided crashes*

- The *reduced collision speed* and the *reduced maximum percentage of possible overlap*, might serve together as impact reduction metric, for the remaining crashes.

4. ACKNOWLEDGMENTS AND VIDEO

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A one minute video clip that shows the demo is available at `www.youtube.com/watch?v=FwQxbcOmfB8&hd=1`.

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