Assessing the Impact of Inter-Vehicle Communication Protocols on Road Traffic Safety

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ABSTRACT

Intelligent Transportation Systems (ITS) will change the experience of driving in the near future. Most applications will use wireless communication (cellular or ad-hoc) for being able to provide the required services. Usually performance evaluations of communication protocols are conducted with typical network metrics like delay, jitter, or goodput for example. However, in the context of ITS it has been shown that network metrics are not sufficient to evaluate vehicular safety applications. Therefore, we extended our existing simulation framework Veins with a model that allows to simulate dangerous road traffic safety situations, i.e., we implemented a driver behavior model for intersection approaches. Furthermore, we implemented an autonomous controller which tries to avoid crashes at intersections. We showcase the impact of different Inter-Vehicle Communication (IVC) protocols, although the intersection approach model and autonomous controller could be also employed to carry out safety evaluations of other communication technologies.

1. INTRODUCTION

In near future Intelligent Transportation Systems (ITS) will enable diverse applications for vehicles ranging from entertainment to vehicular safety applications. Most of these applications will rely on Inter-Vehicle Communication (IVC) protocols (e.g., IEEE 802.11p and cellular networks) to enhance future driving experience. Currently the IVC research community investigates beacon-based solutions, because typical routing mechanisms have been proven to be unsuitable due to the highly dynamic nature of vehicular networks [4]. To avoid ineffective high channel load, congestion control mechanisms have been developed [6, 12].

The evaluation of developed communication protocols usually is carried out with typical network metrics, for example goodput, latency, jitter, and in case of wireless networks the channel load and occurred collisions. However, when

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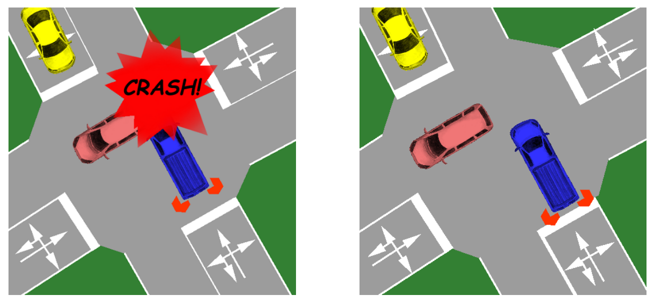

(a) Crash Situation (b) No Crash Situation

Figure 1: Detailed view of intersection area.

communication is needed to enable life-saving applications, this metrics are not meaningful enough to judge whether communication is sufficient in particular situations. Instead the use of safety metrics has been proposed [4]. Currently research on vehicular safety applications is studying the effects of communication with extensive simulations to investigate their applicability [1, 7, 9]. In [10] we addressed the lack of safety metrics for one particularly challenging safety application – intersection assistance application – and proposed the *intersection collision probability* as a first safety metric.

Intersection assistance applications try to warn endangered drivers or let cars react even autonomously. Initial studies of the transportation science community have shown the feasibility of intersection assistance applications (e.g. [2, 3]). However, most of these studies considered wireless communication to be fully reliable within the needed short range. Hence important effects caused by the environment on radio propagation (like concurrent usage of the channel of by numerous vehicles and different applications) have been neglected. Therefore, we extended our existing simulation framework Veins to support the investigation of vehicular safety applications by:

- Development of an intersection approach model that simulates arbitrary driver behavior which lead to Crash situations at intersections (Section 2.2, cf. Figure 1).
- Implementation of a simple autonomous reaction controller which tries to avoid crashes (Section 2.3).
- Impact of IVC communication strategies, namely ETSI Transmit Rate Control (TRC) and Dynamic Beaconing (DynB), on road traffic safety (Section 3).

	Parameter	Value
PHY & MAC	Path loss model	Free space ($\alpha = 2.0$)
	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
DynB	I_{des}	0.04 s
	b_{des}	0.25

Table 1: Simulation parameters for communication.

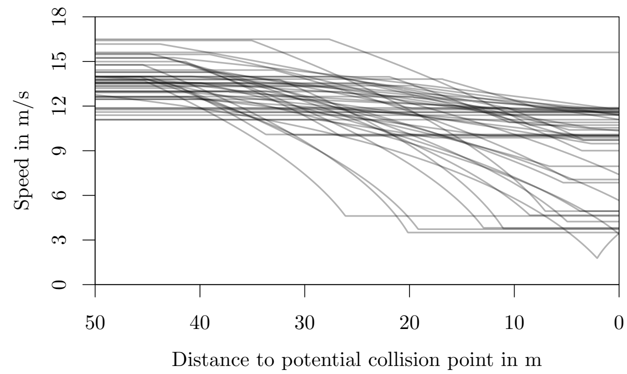

Figure 2: Vehicle dynamics of 24 exemplary intersection approaches of two vehicles.

2. SIMULATION MODELS

We use the Veins simulation framework[1] which bidirectionally couples the road traffic simulator SUMO and the network simulator OMNeT++. This framework has been extended to simulate random intersection collision scenarios, to detect crashes, and to simulate a simplified autonomous controller that resembles reactions of endangered vehicles. In the following we describe first briefly the used communication models and then outline in detail how CRASH situations are simulated and how the autonomous reaction controller tries to avoid CRASH situations.

2.1 Communication

Different communication strategies can be simulated with OMNeT++ where Veins provides already detailed models for radio propagation, physical layer, and Medium Access Control (MAC). To study the effect of current communication strategies on road traffic safety, we employed two state-of-the-art congestion control mechanisms for IVC, namely ETSI TRC [6] and DynB [12]. Basically, both protocols TRC and DynB try to keep the channel load at an acceptable level, however, they differ in their reactions and hence aggressiveness. A detailed description of both protocols can be found in [12]. The list of the employed simulation models and their parameters can be found in Table 1.

2.2 Simulating Crashes at Intersections

In [5] the authors propose a driver model that is parameterized by the *aggressiveness* and *discipline*. The aggressiveness resembles different usage of the brake pedal whereas the discipline models the fact that drivers do not always brake in time. For simulating different kinds of dangerous intersection approaches, we implemented this model and chose parameters which lead mainly to CRASH situations.

The simulation model always creates and executes only one `CollisionScenario` at a time to ensure that there are not multiple vehicles involved in a CRASH. This allows us to study the effects of two endangered vehicles.

First a targeted time delta $t_{\delta\,\text{target}}$ is chosen according to the specified time delta distribution. Then aggressiveness and discipline (D_{agg} and D_{dis}, respectively) as well as a crossing speed (v_{cross}) are selected according to their parameters for both vehicles. Using the chosen parameters the crossing times (t_{c1} and t_{c2}) can be calculated for both vehicles. By calculating $t_\delta = |t_{\text{c1}} - t_{\text{c2}}|$ the time delta can be determined. If the calculated t_δ is not matching the afore chosen $t_{\delta\,\text{target}}$, new driver behavior is selected by choosing new values for D_{agg}, D_{dis}, and v_{cross}. With the parameter $t_{\delta\,\text{target}}$ the outcome of a `CollisionScenario`, i.e., CRASH, NEAR CRASH or NO CRASH, can be influenced. Very small deltas (approximately less than 1 s) usually result in a CRASH (cf. Figure 1a). Depending on the speed and the outlines of the vehicles, larger deltas cause either a NEAR CRASH or NO CRASH (cf. Figure 1b).

For being able to distinguish the different outcomes at the intersection, we implemented a collision detection algorithm which is checking if the outlines of two vehicles are overlapping. By adding a safety boundary of 0.4 m around the outlines of vehicles, the algorithm can also differentiate between NO CRASH and NEAR CRASH situations. The parameters for the collision detection are listed in the lower part of Table 2.

2.2.1 *Evaluation of Intersection Approach Model*

In Figure 2 the vehicle dynamics of 24 independent intersection approaches are depicted. It can be seen that according to the chosen parameters listed in Table 2, the vehicles start to decelerate earliest 50 m and latest 10 m before the potential collision point. Moreover, it demonstrates, that with the chosen parameter set, arbitrary crash situations can be simulated, i.e., with different speed, acceleration/deceleration behaviors.

	Parameter	Value
Vehicle dynamics	Max. speed [3, Tab. IV]	$\sim \mathcal{N}(13.89, 2.92)$ m/s
	Max. acceleration	2.1 m/s^2
	Max. deceleration [11]	9.55 m/s^2
	Driver aggression D_{agg}	$\sim \mathcal{U}(10, 90)$ %
	Driver discipline D_{dis}	$\sim \mathcal{U}(10, 50)$ m
	Crossing speed v_{cross}	$\sim \mathcal{U}(3, 12)$ m/s
	Time delta distribution	$\sim \mathcal{E}(1)$ s
	Simulation time step	10 ms
	Vehicle length	5.0 m
	Vehicle width	1.75 m
	NEAR CRASH boundary	0.4 m

Table 2: Simulation parameters for the road traffic simulation and the intersection approach model.

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

2.3 Crash Avoidance

Whenever a vehicle receives a Cooperative Awareness Message (CAM) it calculates the intersection collision probability as proposed in [10]. If the calculated intersection collision probability exceeds the threshold of 50 %, the vehicle is choosing one of the following reactions:

1. If it is the vehicle which is closer to the potential collision point it will continue with the same speed.
2. Otherwise it will perform a full stop immediately with the maximum deceleration rate.

As we will see in the next Section, this does not allow us to avoid 100 % of all CRASH situations. Therefore, more effort is needed to develop advanced reaction controllers which might even negotiate the reaction with other vehicles.

3. IMPACT OF COMMUNICATION

We simulated 250 different dangerous situations at an X-intersection out of which 175 resulted in CRASH when no autonomous reactions have been triggered. When enabling the autonomous reaction controller, the number of avoided crashes depends on the communication protocol or strategy. Since the controller is not able to avoid all crashes even with perfect knowledge, we first performed simulations with perfect knowledge and it turned out that the controller is able to prevent crashes in 157 cases or 89.7 % of CRASH intersection approaches.

To make the scenario interesting from a communications point of view, we placed 30 vehicles within the communication range to cause background communication by exchanging CAMs with the same communication protocol as the two dangerously approaching vehicles. With TRC as communication primitive, the controller was able to prevent 132 crashes which translates to 84.0 % of avoidable CRASH situations. When employing DynB, the controller was able to prevent 139 crashes which corresponds to a crash prevention rate of 88.5 %. So even for this relatively simple scenario, the difference of 7 crashes is non-marginal.

4. CONCLUSION AND FUTURE WORK

In this paper we presented a model for simulating CRASH situations as well as a simple autonomous controller to showcase the impact of communication protocols on road traffic safety. We compared the impact of two state of the art communication protocols for IVC. A more detailed simulation study regarding the impact of road traffic safety as well as a solution to the fairness dilemma of current congestion control mechanisms has been published in [8]. However, in that work we used the *unsafe time* that a vehicle experienced during the last three seconds before a crash, as a safety metric.

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. For the future evaluations we suggest 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.

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