

Co-Simulation of Cooperative Vehicle Safety Applications and Communication Networks

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ABSTRACT

Cooperative collision warning (CCW) systems use communication networks as a main component for creating situational awareness and eventually hazard detection. Simulation and analysis of such systems are generally more complicated due to the system being composed of components from very different domains of communication and vehicle safety. These components are inherently developed and modeled in different domains, as their basic operations are usually defined and engineered by researchers from different disciplines. Creating a simulation tool for CCW systems requires combining simulation models that are developed using different methodologies. As a result, a unified tool for study of such systems is not readily available. In this paper, we describe a co-simulation tool that models both components of communication and hazard prediction in one framework. The tool uses several different levels of abstraction for the communication model, while modeling the application in a precise manner. We show that communication component can indeed be abstracted to some level without loss of accuracy. We also investigate the impact of using different communication strategies on the performance of CCW systems, and demonstrate the possibilities that the co-simulation tool offers.

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INTRODUCTION

Automated crash avoidance is one of the important objectives of research in automotive safety. While fully automated systems that can operate under all situations may still be years away, many flavors of collision avoidance systems are being gradually offered by the industry. Collision avoidance systems rely on situational awareness (real-time mapping of their surrounding) to make decisions to either warn the driver or automatically take action to prevent a crash. The source of information for situational awareness could be local sensors, or information received over a network from other cars (or a combination of both). Cooperative systems that rely on information exchange between cars have been identified as an early and low cost method of creating the situational awareness needed for hazard detection. In particular, Cooperative Collision Warning (CCW) systems, also called cooperative vehicle (CVS) safety systems, are actively under study and development [7], [8], [9], [10], [11], [12]. These systems rely on exchange of vehicle state information (GPS coordinates, speed, heading, etc.) over a wireless channel [9], [10], [11], [12]. The wireless network used in these systems use Dedicated Short Range Communication (DSRC) technology. The vehicle to vehicle (V2V) communication in these systems is the key enabling factor, which is why CCW systems are sometimes referred to as V2V based active safety systems.

Analysis and development of CCW applications require study of two distinct components of the system: the vehicle safety application (hazard detection and warning) and the communication network. Since these components are not traditionally studied together, there are currently no tools that allow their simulation and analysis in a unified framework. As a result, the mutual effects of these components are rarely studied, and cannot be directly modeled using existing tools.

To fill this gap, a co-simulator is proposed to study the interaction between CCW applications and V2V networking component. This allows for rapid analysis of vehicle safety applications under different communication network constraints. The proposed tool allows for simultaneous simulation of the behavior of safety applications and communication networks in a single framework and allows direct modeling of their mutual effects. We elaborate on the challenges of the design of such a unified framework in this paper and present some preliminary results that are obtained.

In order to generate collision warnings, several functionalities must be integrated including real-time mapping or situation-awareness service; this service generates a real-time map of all cars in the proximity of a vehicle.

In this paper, we first identify the main components that need to be simulated and specific platforms which could be studied for each. We then elaborate on how these platforms may be used to create the unified framework.

TOOL PLATFORMS AND COMPONENTS TO SIMULATE

The simulation platforms that we consider in our work are network simulator 3 (ns-3) and MATLAB. ns-3 is an open source discrete event simulator, natively designed for simulation of networks. We have also extensively modified and enhanced ns-3 for simulation of DSRC networks. Safety applications can be implemented in any environment, including ns-3; however, MATLAB provides a more powerful environment for study of vehicle trajectories, and algorithm performance. Network simulation in MATLAB is also possible, but not scalable (especially for wireless networks).

ns-3 has many useful features specifically geared towards wireless networks. Scalability of ns-3 allows integration of new models such as new propagation or PHY models and relatively precise simulation of DSRC networks with thousands of nodes. Tracing is another useful feature that allows reporting various events across the protocol layers. All these features along with a very rich set of stable models for the protocol stack make ns-3 a sufficiently realistic network simulator for most of the real-world network scenarios. However, the elaborate simulation of wireless networks makes most of the simulation time spent on the details of wireless networks, which may not be necessary for all analyses of CCW.

Table 1. Comparison between MATLAB based and ns-3 based co-simulation

	Communication component	Safety Application	Analysis tools
Native MATLAB Co-Simulator	Limited	High fidelity Flexible	Flexible
Native ns-3 Co-Simulator	High fidelity	High fidelity Non-flexible	Limited

Depending on what the emphasis of a study is, different platforms may be chosen for co-simulator development. Basically, MATLAB simulator is more flexible when different safety applications are investigated, but it has to use network models with lower fidelity. On the other hand, ns-3 provides a precise implementation of V2V communication and safety application, at the cost of being non-flexible for implementation of safety applications (table 1) and dedication of much of simulation time to wireless network behavior. In the next subsections we describe specific considerations for each of the safety application and communication network components.

SIMULATION OF SAFETY APPLICATIONS

Safety applications that we consider here are the warning applications such as Forward Collision Warning (FCW) [1], [2], [3], [4], [5], [6]; these applications are designed to warn the driver in situations that

are identified as a collision threat condition. The major problem in designing these applications is to provide enough time for the driver to react based on situation and warning signals.

One of the well-known algorithms for generating FCW is proposed in [3]. While this algorithm is already replaced by much more elaborate recent algorithms (such as CAMP Linear [1]), we discuss it here only as an example. The co-simulation tool implements several algorithms including CAMP Linear and a proprietary algorithm designed by Hyundai; however, we do not discuss the details of those algorithms, as it is not central to the design of the simulation framework.

The algorithm in [3] is designed such that a warning is generated before it becomes necessary for the driver to take a sudden action to a situation. Alerts are generated based on warning distance at each timestamp (which changes as the speed, acceleration of vehicles change). If the distance between a Remote Vehicle (RV) and a Host Vehicle (HV) becomes less than the warning distance, a collision warning should be issued to the HV. The work in [3] categorizes the warning generation problem into two different scenarios. The first one deals with situations where RV (front vehicle) is realized to be stationary (speed equals zero). Warning distance (D_w) for stationary RV is derived from the following equation:

$$D_w = \frac{v_H}{2a_H} + T_D v_H \quad (1)$$

where, v_H and a_H are velocity and deceleration of host vehicle respectively. T_D is total time delay before the driver of the HV initiates a full response (2.05 seconds).

The second scenario models situations where RV is decelerating. Warning distance for decelerating RV is derived from the following equation:

$$D_w = \frac{v_H}{2a_H} + T_D V_H - \frac{v_R}{2a_R} \quad (2)$$

where, v_R and a_R are velocity and deceleration of the remote vehicle respectively. In CCW system the HV always gets its current safety information (position, speed, acceleration) from GPS, and estimates safety information about RV through real-time tracking over DSRC network. This means that all values describing state of the RV have to be replaced by network estimates.

It should be noted that we may need input (positions, velocities, accelerations) from field tests, or trajectories derived from other simulators like VISSIM, and SUMO [21]. Therefore, implementation of safety application in the co-simulator should consider different data formats. In general, the implementation complexity of the safety algorithms is not significant as these algorithms are expected to run in embedded computers inside cars. Therefore, MATLAB or event driven simulators such as ns-3, could be directly used for implementing precise models of the safety applications.