2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Integrated Simulation Environments for Vehicular Communications in Cooperative Road Transportation Systems

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Abstract

Pervasive digital technologies and wireless communications are the key enablers for the "smart" evolution of transportation systems, where the current development trend is oriented to increase the level of safety and comfort in driving and traveling, to reduce CO_2 emissions and to finally support assisted and autonomous driving. With particular reference to vehicular traffic, the accurate localization, pervasive connectivity and cybersecurity are expected to play a key role for the development of cooperative and intelligent transportation systems (C-ITS). In this frame the present paper proposes an overview of on-going research activities at the University of L'Aquila: moving from specific investigations on radio channel congestion control and mobility management applications, we then focus on methodologies and facilities for validation and testing through the combined use of simulation tools, emulation setups and field trials. The research activity is fully connected to a large scale project that deals with city-wide deployment and experimentation of 5G technologies in the city of L'Aquila, wherein the connected car has been presented as a relevant use case.

1 Introduction

ITSs, as defined by the directive of the European Union 2010/40/EU, are evolving rapidly thanks to the introduction of new technologies: exchange of information among vehicles, infrastructures and pedestrians will be more reliable, safer and easier; likewise, the distribution of traffic flows will be improved in terms of safety, travel time and efficient management of resources. To achieve this goal, vehicles shall be equipped with on-board sensors to detect technical and environmental parameters from the car and the surrounding driving context, already embedded today in high-end cars. At the same time it is appropriate to study and formulate techniques and methodologies, and then develop platforms to manage mobility flows in an efficient, safe and eco-sustainable manner. The collection, processing and dissemination of an ever-increasing amount of information, originating from vehicles and road infrastructure, is necessary to support assisted driving applications. The main problem is gathering and processing huge amounts of heterogeneous data in aggregate form, taking into account time latency constraints typically imposed by safety applications. These informations, collected and elaborated directly by the vehicles or by the infrastructure, must be disseminated to road users to improve smart traffic management and driving operation. In the near future, vehicles will be able to interact with each other and the road infrastructure, through current and forthcoming wireless communication protocols. In C-ITSs, users and road managers coordinate their actions and take decisions based on information exchanged by vehicles, infrastructure, and pedestrians, i.e. through vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and vehicle to pedestrian communications (V2P). Vehicular networking applications are typically classified as: *road safety*; *efficiency and traffic management*; *infotainment*.

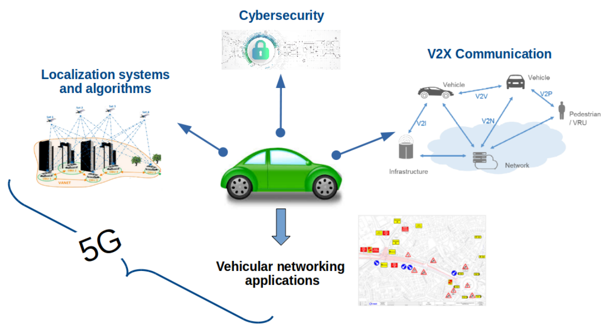

Figure 1. Enabling technologies for connected vehicles.

Our research activities concern Road Safety and Traffic Engineering applications, with a specific focus on the following areas of research (Figure 1).

Communication technologies and integrated data processing: short and long range communications techniques will be required, along with processing and dissemination of traffic information through dynamic maps that are updated on a local or centralized basis. Depending on the applications, several enabling technology families are considered, such as vehicular ad-hoc networks (VANETs), including IEEE 802.11p-based standard families, and cellular networks for infrastructured architectures, including long-term evolution (LTE) and the incoming 5G network paradigms [1].

Accurate localization: satellite-based localization is still the main reference for large scale spatial operations. Improved accuracy can be achieved through data fusion from different terrestrial surveillance and communication technologies, and also from upcoming satellite constellations, e.g. the European Galileo system. Assisted and autonomous driving will require an even tighter and timely precision, to be attained with more advanced techniques and wider data sets, that are still under definition. Location-awareness is an important research field: cooperative networks paradigms can be used to improve the accuracy of the ultimate on-board estimated location data. Relevant research assets have been developed in this frame by our colleagues of Radiolabs Consortium in the rail domain.

Cybersecurity: vehicles and related architecture elements will establish a network environment, thus exposed to a wide range of cyber-attacks. Requirements such as authenticity and confidentiality of exchanged information must be guaranteed and security of network elements must be ensured against intrusions. The contextualization of these topics to the vehicular environment is an open field of investigation and development of architectures, procedures, methodologies, and so on.

For validation and test of various technology components in the depicted scenario, a twofold approach can be envisaged: the deployment of a test-bed with real devices in a typically limited extension operating environment, or the abstraction of a larger scale scenario through hi-fidelity simulation tools that support the definition of high density and high mobility environments. Some test plants have been developed by car makers and also public institutions worldwide. They enable effective experimentation for several use cases foreseen by e.g. ETSI recommendations; however, existing test plants are not as large and complete as a city or a crowded highway and they are not yet a viable option for experimentation of traffic engineering/re-routing scenarios. The rest of the paper is organized as follows. Motivations and methods for experimentation and simulation are described in Section 2. Section 3 provides a description of the simulation environment and of three investigated use cases. Conclusions are drawn in Section 4.

2 Experimentation Tools and Simulation: Motivations and Methods

An experimental testbed has been developed and is currently available within our research facilities with the aim to provide a valid analysis tool for V2X communications devices based on the IEEE 802.11p standard. Specifically, a Software Defined Radio (SDR) USRP platform and Cohda Wireless devices have been chosen for testbed development. With regard to the first solution, we use Ettus USRP N210 platforms as front end of the SDR system, together with the GNU Radio real-time signal processing framework. The IEEE 802.11p GNU Radio receiver developed in [2] has been implemented with the aim of assessing compatibility between the SDR solution and the "Commercial Off-the-Shelf" Cohda devices. Because of USRP limitations as *(i)* inability to manage multiple access (no CSMA / CA) and *(ii)* problems to satisfy its power supply requirements on board of vehicles, the Cohda Wireless device has been used to implement a real vehicular network, with the aim to investigate and really validate some ITS use cases, partially listed in Section 3.

The above mentioned C-ITS applications require a massive broadcast dissemination of cooperative awareness messages to provide information about vehicle position and status to one-hop neighbours. To this end, Cooperative Awareness Messages (CAMs) in the ETSI ITS, as well as Basic Safety Messages (BSMs) in the American WAVE standard, are generated with a frequency typically ranging from 1 to 10 messages per second. Due to this massive dissemination of messages, without proper congestion control, the functionality of both safety and traffic-management C-ITS applications can not be adequately supported. In [3] we considered the ETSI Decentralized Congestion Control (DCC) method and proposed a cooperative awareness solution based on the dissemination of global road traffic information to cope with DCC oscillation and unfairness issues. A peculiar feature of our approach is the commitment of experimental validation for vehicular scenarios applying ETSI DCC techniques in a testbed consisting of the above mentioned COTS devices. To deepen the channel congestion issue, different stability techniques could be further investigated and implemented, such as the enhanced DCC algorithm, which uses additional DCC information from neighboring stations, e.g. the measured channel load. In this perspective, further effort will involve simulation techniques to implement our proposed strategy in a dense scenario with realistic mobility patterns. A simulation platform is being developed for performance evaluation and design of a vehicular network environment. The goal is to build a more manageable and less time consuming software platform compliant with existing vehicular standards and methods to support both safety and non-safety C-ITS applications. An example of use is represented by the implementation of the ACC (Adaptive Cruise Control) model developed in [4]. The proposed ACC algorithm could be tested through high-fidelity simulation techniques, with the aim to analyze and validate its functionalities.

3 High Fidelity Simulation for Vehicular Networks

The activities carried out by our research group concern the implementation of urban mobility scenarios in ordinary traffic conditions and in emergency situations. In these cases, communication technologies should allow rapid and safe dissemination of information in order to avoid collisions and re-route vehicles on alternative paths when a congestion occurs or to give priority to emergency vehicles. To overcome the current lack of scalability and reproducibility of the experimentations with real devices, we decided to develop a high-fidelity network simulation environment to be used in synergy with real world test-beds.

3.1 The Simulation Environment

Upon a survey on suitable alternatives, VEINS (a Simulation Framework for Vehicular Environments) turned out to well fit our needs: it is an open source Inter-Vehicular Communication simulation framework based on an event-based network simulator (OMNeT++) and a road traffic microsimulation model (SUMO) running in parallel [5].
A brief description of the three tools is provided below.

SUMO (Simulation in Urban Mobility): one of the most popular vehicle mobility simulation software, designed to simulate also the road network in a big city. The tool implements cars, public transportation systems, railway networks, motorcycles, pedestrians and so on.

OMNeT++ (Objective Modular Network Testbed): an extensible, modular, component-based C++ simulation environment. It provides a "simulation kernel" with the classes useful for the creation of the model components and with the features to realize their interconnections.

VEINS (Vehicles in Network Simulation): the framework that allows the coordination and the interaction via TCP between SUMO and OMNeT++. The basic mobility is handled by SUMO and is inherited as mobility patterns of network nodes in OMNeT++; vehicular communications among nodes are handled in OMNeT++ and their effect is transferred back to SUMO.

3.2 Simulation Scenarios

The analyzed scenarios have been referred to the urban road system of L'Aquila, which envisages the development of innovative solutions for the intelligent management of traffic flows. In particular, these activities will focus on the mobility of light commercial vehicles, that often operate in last mile delivery with constrained delivery times in their commercial version and as emergency vehicles in some circumstances: in the latter case priority on reserved lanes should be guaranteed to provide support to rescue operators, for example upon natural disasters or serious car accidents.
In the following we briefly describe three sample use cases. The first one highlights the channel congestion issue (see Section 2) in a highly crowded cross-road; the next two cases evidence the benefits of vehicular communications in the presence of a road accident. In the simulations, the WAVE protocol stack has been used, since VEINS includes a rather stable and widely accepted implementation; similar results can be obtained with the ETSI ITS-G5 standard.

1. *Channel congestion in highly crowded cross-roads.*
   Safety applications in a vehicular environment rely on a massive exchange of awareness messages that could lead to a congestion of the radio channel, as already stated in Section 2. When the network looses those messages, the system safety can not be guaranteed, hence it is crucial to avoid channel overloads. This use case aims at the investigation of the radio channel load on highly crowded roads; as an example, we performed the evaluation on a 300×300 meters intersection of two roads with an increasing number of approaching vehicles (up to 105 cars during 100 seconds). The scenario involves 4 flows of vehicles, each spawning from a different direction (north, south, east, west) and creating a traffic column; only cooperative awareness messages (i.e., BSMs) are exchanged (with a maximum size of 360 bytes, according to the standard) at a fixed bitrate of 12 Mbps. The Channel Busy Ratio (CBR) is investigated at four messages emission rates (1, 10, 20 and 50 messages per second) and is shown in Figure 2. As expected, the CBR value rapidly increases with the number of vehicles and with the emission rate, reaching not negligible values also in a quite small area.

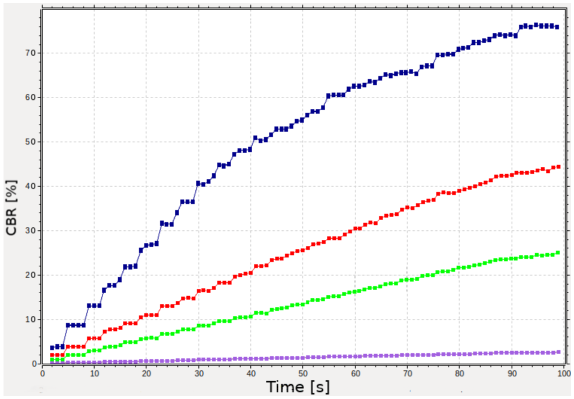

Figure 2. CBR for an increasing number of vehicles. The magenta, green, red and blue plots are obtained for 1, 10, 20, and 50 msgs/s, respectively.

2. *Management of traffic flows in the presence of car in failure or road accident.*
   This use case concerns the ordinary management of traffic flows through V2X communications, in the event of a road blocked due to an accident or a damaged car. Under these conditions, it is possible to disseminate informations towards approaching vehicles and force them to choose alternative routes, thus reducing the queues and avoiding risks of further accidents. A car failure is simulated at a junction with a major road, preventing the incoming vehicles to follow the desired direction (a left turn at the junction).

   Without vehicular communications capabilities, the incoming cars are unaware of the blocked road and do not change the chosen route. As a result, a long queue of vehicles is formed, congesting the road until a normal condition is restored; as a side effect, vehicles with a different route are also involved, since they cannot reach the junction to turn right (Figure 3a). The introduction of V2X communications completely changes the situation (Figure 3b): the vehicle in failure can now inform about the blocked junction all nearby road users with the dissemination of a warning message. Upon the reception of the message, a vehicle can compute a new route, excluding the unavailable road.

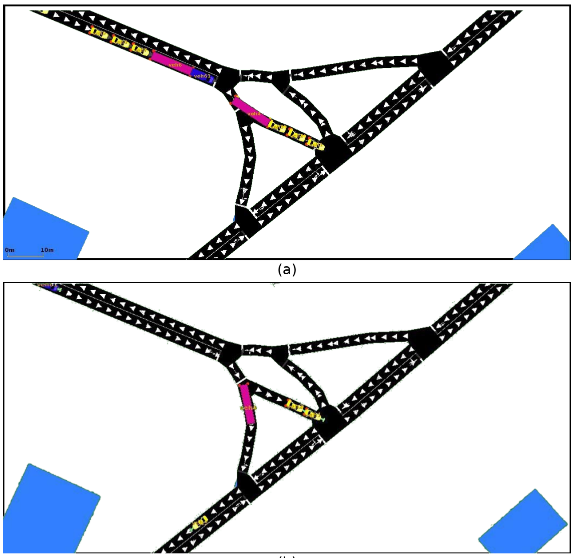

Figure 3. Traffic management upon a road accident (a) without vehicular communication, (b) with vehicular communication.

The simulation results show that the queue can be almost completely avoided; only the vehicles immediately following the failed one are not able to choose a new path, since they turn left before the warning message is issued.

3. *Assistance to emergency vehicles.*
Most emergency situations require urgent intervention to prevent worse consequences; therefore a crucial aspect is the time required for rescue vehicles to reach the operation site. In the vast majority of cases, both emergency and ordinary vehicles share the same roads and therefore are subject to slowdowns and traffic jams. Acoustic and visual signaling are traditionally used to warn nearby users in order to free up the road for an incoming rescue vehicle; even if a reduction of the travel time is obtained, an ongoing work for our research group concerns the investigation of the C-ITS paradigm applied to this scenario, since it can surely provide great improvements. First of all, the rescue vehicle could also rely on the dissemination of warning messages to advertise its presence and provide other useful informations (e.g., speed, destination, path); dedicated short range communications (i.e., 802.11p) provide a radio range up to 1000 m and relay capabilities allowing to timely alert vehicles on the road.

   Moreover the overall ITS infrastructure can also be involved by resorting to a centralized planning system: the route of the emergency vehicle could be computed using the information collected by the road side units deployed on the territory, thus considering also the actual road status. The road side units could also be used to inject in a selective way the advertisement of the incoming rescue vehicle.

4 Concluding Remarks

Research activities reported in this paper deal with simulation and emulation architectures for implementing vehicle communications in road traffic management processes. Specifically, high fidelity simulation environments have been setup with the ability to support accurate performance analysis and scalability while modeling complex real operating scenarios. Such simulation environments allow to overcome some limitations of pure experimental approaches in estimating the CBR and in overall assessment of traffic management applications. In the near future, enhanced solutions to reduce the congestion of the radio channel will be implemented, both in simulation environments and through experimental analysis on real devices, and other mobility management applications will be tested both for ordinary and emergency traffic conditions. The next step will be the deployment of a real testbed in the urban area of L'Aquila, to study and develop innovative solutions based on current and emerging communication technologies, such as 5G, and to validate architectures and applications for intelligent management of traffic flows.

5 Acknowledgements

The authors would like to acknowledge the support from EU ECSEL SAFECOP project and Ex-EMERGE project.

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