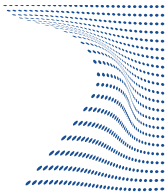
ScuDo
Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE, TAKES YOU FAR



Doctoral Dissertation
Doctoral Program in Electric, Electronic and
Communication Engineering (XXXIII cycle)

Safety Applications and Measurement Tools for Connected Vehicles

Marco Malinverno
* * * * * *

Supervisors
Prof. Claudio Ettore Casetti, Supervisor
Prof. Carla Fabiana Chiasserini Co-supervisor
Prof. Nicola Amati Co-supervisor

Doctoral Examination Committee:
Prof. Claudia Campolo, Università Mediterranea di Reggio Calabria
Prof. Michele Segata, Libera Univesità di Bolzano
Prof. Pietro Manzoni, Universitat Politècnica de València
Prof. Raphael Frank, Université du Luxembourg
Prof. Paolo Giaccone, Politecnico di Torino

Politecnico di Torino
February, 2021

I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

. . . . . .

Marco Malinverno
Turin, February, 2021

Summary

The automotive industry is in the middle of a technological revolution, which in the coming years will see every vehicle connected through Vehicle-to-Everything (V2X) technologies. The most important standardization bodies have done their part to usher in this slow but inexorable transition: IEEE, with the WAVE stack (Wireless Access in Vehicular Environment) and ETSI, with the ITS-G5 stack, have contributed to defining the foundations of the ITS (Intelligent Transportation System) scenario for US and Europe. The network access technology to be adopted to enable such communications is at the center of a major debate in the scientific community: IEEE proposed a protocol coming from the 802.11 wireless-LAN family, while 3GPP proposed a solution derived from the cellular networks (C-V2X).

All these technologies will enable an incredible number of applications, which will overturn the mobility experience in all of its forms. The main topics of this thesis are V2X communications, and after an initial analysis on the main solutions already developed, it presents and discusses original contributions ranging from the world of network simulation to that of V2X embedded devices.

Simulations tools plays a pivotal role in the automotive industry: because of the complexity and the high deployment costs of vehicular applications, it is usually convenient to extensively test them by simulation. This thesis introduces MS-VAN3T, an open source ETSI ITS-G5 model for the ns-3 simulator that, coupled with SUMO (Simulation of Urban Mobility), allows the reproduction of complex vehicular scenarios. MS-VAN3T can be used to develop any kind of application and comes with the possibility of transparently changing the underlying access technology.

Day-0 applications will leverage V2X technologies to improve road safety. For this reason, MS-VAN3T is used in this thesis to develop a collision avoidance system that, leveraging Cooperative Awareness Messages (CAMs) and Decentralized Environmental Notification Messages (DENMs) can warn vehicles and vulnerable users about possible future collisions. The information generated by the system is then used to build an automatic strategy, which allows vehicles to autonomously assess the collision risk and take appropriate reactions to avert the collisions.

In response to the growing demand for V2X solutions enabling the aforementioned applications, this thesis proposes an open source testing platform that can be used to assess the performance of V2X Wireless Network Interface Cards (WNICs), and that

enables a fully working 802.11p communication. The proposed platform is composed of a patched modified version of OpenWrt, an OS that is widely used for embedded devices, and it is used to test the throughput, the radio range and other important KPIs of off-the-shelf low-cost WNICs.

One of the key parameters for vehicular networks, which must be constantly measured to guarantee a reliable service, is latency. Being capable of measuring such a parameter can be very important in providing applications with acceptable performances. Although several solutions exist in literature, such as `ping` or other measurement platforms, they are typically bound to a specific protocol, such as ICMP, or require additional hardware or software capabilities other than the testing application. In this thesis, a novel lightweight, flexible, and custom latency measurement protocol is presented. The protocol, named LaMP (Latency Measurement Protocol), is completely agnostic of lower-layer protocols and enables micro-second precise latency measurements. The first open source tool leveraging LaMP, called LaTe (Latency Tester), is presented as well. LaMP and LaTe, which are constantly updated and added with new features, are used to validate and test the above-mentioned V2X platform. This thesis presents the most important results of such an analysis, and highlights the importance of open source solutions for the performance assessment of technologies for connected vehicles.

This Ph.D. thesis has been typeset by means of the TEX-system facilities. The typesetting engine was LuaLATEX. The document class was `toptesi`, by Claudio Beccari, with option `tipotesi=scudo`. This class is available in every up-to-date and complete TEX-system installation.