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A Hardware-in-the-Loop Framework for Urban Mobility Scenarios within the 5G Trial in L'Aquila

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Abstract

The revolution brought by the Fifth Generation (5G) mobile network in the telecommunications ecosystem opens the way to innovative applications, bringing out new opportunities to improve both the social and business contexts. There is a great effort worldwide to assess the capabilities of a 5G network and the city of L'Aquila is involved in the Italian initiative coordinated by the *Ministry of Economic Development* (MISE). One of the six use cases identified concerns connected vehicles and evolved mobility applications; two vehicles will be equipped with 5G terminals and used in the field trials. To obtain an environment closer to the real one while containing the monetary costs of the deployment, a hybrid solution that integrates a simulator of urban mobility with the Hardware-in-the-Loop (HIL) approach has been adopted. In this work a description of the mobility use case and of the trial setup will be provided along with an insight into the application of the HIL technique to the ITS environment; finally, an overview on the Artificial Intelligence methods that can be exploited to identify and predict road traffic critical situations is given.

1 Introduction

The city of L'Aquila is one of the five Italian cities selected by the Italian government to host the 5G experimentation [1]. This city has the specificity of being a "living lab", because it is currently passing through the reconstruction process after the earthquake of 2009, thus offering a *green field* scenario to the scientific community. The reconstruction process is designed according to the innovative paradigm of *Smart City* and the 5G technology is supporting it. The 5G Italian experience coordinated by *Ministry of Economic Development* has the target to create and enforce a 5G ecosystem development in Italy involving different public and private actors, industries, research centers and universities, like in the 5G PPP initiative.

5G will change the mobile communication business ecosystem by introducing location specific high-quality wireless networks that can be operated by different stakeholders. This development will change the traditional business models and ecosystem roles, as well as open the market for new local mobile network operators. One of the main objectives of 5G trials is to foster an ecosystem around the new 5G capabilities. Vertical industries are involved in the undergoing trial phase that will demonstrate key 5G functionalities and technical/technological enablers. According to 5G PAN European strategy, the selection of vertical pilots should take into account sectors including, but not limited to the media and entertainment, public safety, e-health, automotive, transport and logistic. Considering this the focus of the project "Città 5G" carried out in L'Aquila is to put citizens at the core of the new 5G ecosystem and to analyze how the new technology solutions will allow new opportunities to improve both the social and business contexts. Utilities, research centers and public administrations are involved as partners for the project[1] in L'Aquila. The expected result is a real ecosystem taking into account different contexts in which to deploy the new solutions that 5G makes feasible.

The different use cases selected for the 5G Italian MISE trial offer the possibility to test the technical capabilities of the 5G solutions and to explore more and more deeply new business models and revenue streams. The new 5G network will be able to operate in different application contexts (e.g., low power, high-reliability, low latency) providing multi-level network architectures. In this context, classic macro-cell structures coexist and integrate, in a functional manner, with different network types, such as small-cells, and they provide different communication modes (relay, device-to-device) to heterogeneous devices (e.g., smart objects, cyber physical systems, connected vehicles) related to different requirements in terms of Quality of Service.
More specifically, the following use cases have been identified: *(i)* Structural Health Monitoring, *(ii)* Building Automation & Energy Management, *(iii)* ICT for Cultural Heritage, *(iv)* Automotive and the connected vehicle, *(v)* Agricolture 2.0, *(vi)* E-Health/Medical Devices.

This paper describes the 5G related activities carried out by the University of L'Aquila within the Intelligent Transport Systems (ITSs) field. Currently, these activities consist of initial design of the infrastructure that will support the use case. The *Automotive and the Connected Vehicle* use case, as well as the reference architecture, are described in

[1] http://www.mise.gov.it/images/stories/documenti/Sintesi-progetto-5g-presentazione-13102017.pdf

Section 2. Section 3 describes the tools used for the creation of the simulation environment and its integration with the real world. Section 4 provides an overview of the considered Artificial Intelligence (AI) method for traffic efficiency. Conclusions and future works are drawn in Section 5.

2 Use Case: Automotive and the Connected Vehicle

The mobility scenario will change significantly in the near future: the new communication technologies, the demand trends and the need to reduce the environmental impact will require rethinking the mobility paradigm to enable a new driving experience for vehicles connected with transport systems and with the digital world of the future [2]. The ITS equipped vehicle will be aware of the traffic scenario, environmental conditions and driving context. These data will provide, in advance, all the information needed, for instance, to prevent accidents. To this aim, the ITS will supply the connected vehicles with the latest accurate and geo-localized positioning technologies in order to properly exploit all the benefits coming from advanced dynamic and safety navigation features Furthermore, for the sake of functionalities of services (especially safety–related ones), status of channels has to be monitored, to enforce congestion control when needed [3]. Advanced solutions for Cooperative ITSs (C-ITSs) are investigated within the *Automotive and the Connected Vehicle* use case. Specifically, Cellular-V2X (C-V2X) communications are exploited to manage fleets of vehicles with the aim to improve *(i)* road safety, *(ii)* comfort and driving experience, *(iii)* traffic management and *(iv)* pollution monitoring. In the considered use case, the vehicles periodically share information with a Central Unit (CU), which will be aware of the street-level status in a given area. The real-time information is then used to dynamically update an electronic road map and detect critical traffic conditions. Further, as explained in Section 4, this massive data collection may be exploited to develop advanced AI methods for centralized traffic control. However, since the limitation of the real-world experimentation in terms of both scalability and reproducibility, the test-bed platform has been integrated with a customized traffic simulator. Functionalities and performances of the implemented framework are described in detail in Section 3. Figure 1 shows the proposed network architecture: the CU with the backend server is located near the core network, in order to represent an expected Mobile Edge Computing (MEC) scenario. Thus, vehicles are equipped with a 5G Customer Premises Equipment (CPE) and communicate with the CU through a Next Generation NodeB (gNB). 5G CPEs and other network equipments are provided by ZTE Corporation and WindTre. Connected vehicles and OEM backend service are provided by FCA-CRF. Figure 1 also depicts the interaction with the traffic simulator, as described in Section 3. In the considered use case, vehicles periodically send Cooperative Awareness Messages (CAMs) to the CU with a fixed rate of 10 Hz, in order to

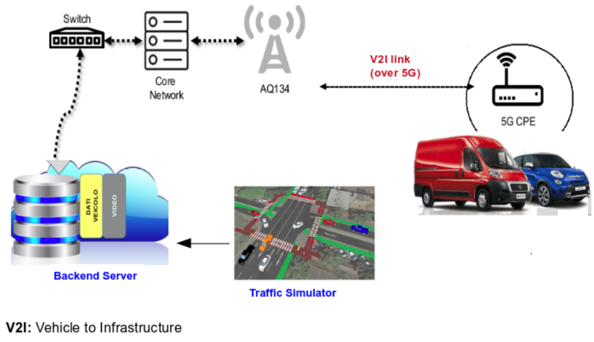

Figure 1. Network architecture

share their status and attribute information. CAM status information includes time, position, motion state, etc. CAM attribute information includes data about the vehicle dimensions and type. The CAM packet length (including security) ranges from 200 to 800 bytes, according to the considered mobility scenario (see ETSI EN302637-2 standard). For its part, the CU is allowed to send Decentralized Environmental Notification Messages (DENMs) back to the vehicles, in order to alert road users of any detected event. As specified in the ETSI EN302637-3 standard, DENMs are event-driven hazard warning messages and contain information related to a road hazard or an abnormal traffic conditions. Typically, a DENM is disseminated to vehicles that are located in a geographic area through direct vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications. In the presented work, only V2I communications are considered.

3 The Hardware-in-the-Loop Framework

In the ITS ecosystem it is a great challenge to perform realistic field tests and the situation is even worse when the we move towards the C-ITS model. The presence of Inter-Vehicle Communications (IVC) requires multiple equipped vehicles that should cooperate with a supporting infrastructure leading to a great expenditure also for small deployments. The simplest use-cases can be reproduced with a few number of devices: to assess the effect of IVCs in the envisaged ITS environment, big test sites with a lot of vehicles should be necessary, but it is difficult to reach numbers comparable to the ones of a modern city. To the best of our knowledge, the larges test sites under realizations are developed by the U.S. Department of Transportation (DOT) in three cities: New York (1190 vehicle of the 4000 foreseen), Tampa (794 on 1100) and in the state of Wyoming (52 on 405). However, they represent an exception: the majority of the field tests rely on one or two vehicles and only few attempts reach a few dozens (e.g. the Volvo Drive Me project); these numbers are evidently far away from a real urban environment. In order to reduce the costs and to overcome the field test limitations, mobility simulators are often used. This approach is the exact opposite of the real world experimentation and suffers from the simplifications introduced by the models and thus the validity of the results

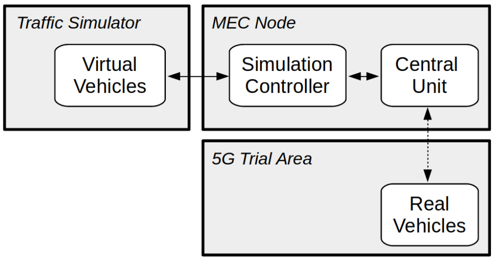

Figure 2. HIL architecture

is limited. Taking also in account the IVCs, even the best models cannot replicate the bit-by-bit message exchange. Moreover the radio channel has a strict dependency with the surrounding environment both by a physical point of view (e.g., multi-path) and by the electromagnetic one (e.g., interference); an accurate modeling of such characteristics is very complex and in some cases almost impossible. Lastly the simulation approach is not suitable to evaluate the contribution of all the devices involved in a C-ITS and much less to assess the effect of their multi-vendor nature.

A strategy to gain the benefits of both the above described solutions and whose popularity raised in the last years, is the Hardware-in-the-Loop (HIL) technique inherited form the embedded systems field. With the HIL, a physical entity can interact with a virtual counterpart through the support of a simulator. In the C-ITSs field, this approach allows the creation of a test environment much closer to the real one without involving exorbitant costs for the acquisition and management of large fleets of vehicles. Some examples of application of this approach are described in [4, 5, 6, 7].

The solution implemented for the field trial (as already shown in Figure 1) relies on the integration of the 5G infrastructure (provided by ZTE) and the CU (provided by CRF) with a traffic simulator in execution in the same MEC node. The coupling allows the augmentation of the surrounding environment perceived by the CU with the real-time simulation of virtual vehicles which will alter the road traffic conditions in the trial area where the real ones are moving. We have chosen the SUMO tool for the urban traffic simulation orchestrated in real-time by a *Simulation Controller* through its TraCI interface (see Figure 2). Every 100 ms, the controller drives the simulation a step forward, to keep the model aligned with the real time; the parameters that describe the kinematic of every virtual vehicle are extracted and sent to the CU in the same manner as a real vehicle sends its own data (resembling the exchange of CAM messages). From the CU point of view, there are no differences between data received from the two sources: the use of the traffic simulator is totally transparent to the other components. The basic role of the CU is to collect data from all the road users in its competence area (the one in charge to that MEC node) and warn them if a hazardous event is nearby; in a first stage the events are managed manually from an operator but in the future we foresee an automatic handling of the available information by an AI agent able to identify abnormal situations on the roads (see the next section). In this field trial, we have reproduced in the simulated environment the urban area near the test field taking into account multiple flows of virtual vehicles that follow a dynamic derived from real traffic data provided by the municipality (referred to 8 hours of observation). At a specified time instant, an accident is generated on the intersection that connects the test site with the public road; at this point the *Simulation Controller* (aware of what is happening) instructs the CU to create a new event at that specific position. When the real vehicles go towards the exit of the test area and move near the intersection, the CU detects that they are entering in the area of an event and informs them of the accident. With this first test case the performances of our HIL system were assessed proving that this approach suits well on such kind of experimentation. According with the ongoing research activity, an AI agent will be in charge of identifying such events observing the anomalies on the traffic flows using the approaches described in the following section.

4 AI Methods for Urban Traffic Efficiency

As widely studied in the last decades, C-ITSs represent an efficient strategy to improve performance, enhance security, and improve travelers' experience of transportation systems [8]. Control systems, and in particular system identification and predictive control techniques, are naturally related to this paradigm: given a mathematical model of an C-ITS system, it is possible to compute a predictive model of the system behavior and consequently compute optimal strategies to face critical situations, e.g. a bottleneck due to an increase of traffic flow. However, C-ITS systems are quite complex in general [9], thus derive a mathematical modeling that well captures systems' dynamics can be prohibitive. Some of the C-ITS problems are currently solved implementing rule-based transportation policies: e.g. during the 2008 Beijing Olympics, the city government imposed a restriction on car owners based on odd/even license plate numbers to keep 50% of private cars off the road [8]; it is clear that these methods do not aim at optimization, also they just work in case of special events. In the last years, the growing availability of a large amount of historical data, collected in several kind of systems from instruments like cameras, GPS, etc., made the so-called data-driven approaches a central topic in the research community of different scientific fields, from building automation to structural health monitoring [12, 13]. C-ITSs experienced this change of paradigm as well. For example, deep learning has been used to create nonlinear models for traffic flow predictions [10]. In [11] the authors proposed for automatic detection and characterization of cracks in roads using an unsupervised two-step pattern recognition system from images analysis. However, road images are not always available. It is clear from this analysis that, although a big potential is hidden in the data-driven approaches, a lot of effort still has to be pushed in this field. In this context, we propose an approach that leverages Regression Trees (RTs)-based algorithms to predict traffic jams that can occur due to an intensive flow of cars from different streets that converge into a single one. RTs are a Machine Learning methodology used to predict the value of a system output given some input variables called *features*. The algorithm creates a tree structure that partitions the dataset into hyper-rectangular regions, and assign to each region an estimate of the output given by the average of the values of the output samples in that region. limit production costsGiven historical traffic data, we can use RTs to create a structure able to identify different situations that can generate traffic jams. The data from each car, such as position, acceleration, etc., could be easily collected thanks to the new 5G technology, and a communication network that will connect all the cars. RTs perfectly fit this situation since the partitioning algorithm will create different regions referring to different traffic situations. The resulting model will be used to predict road traffic critical situations that could potentially occur, and generate optimal actions for the users to avoid them.

5 Conclusions

This paper presents our research activities within the 5G MISE Trial towards applications for C-ITSs. In a first phase, C-V2I communications have been implemented to make a real vehicle able to share information with a CU. In this way, the CU can be constantly aware of the street-level status in a given area and also it is allowed to send DENM messages back to the vehicles, in order to alert road users of any detected event. Then, with the aim to reduce the costs and to overcome the field test limitations, the mobility simulator SUMO has been exploited to build a hardware-in-the-loop framework. In the proposed architecture the CU is able to receive CAM messages from both real and simulated vehicles and viceversa, information coming from the real scenario (i.e., from the CU) can be exploited to update the simulation environment. Last, we propose an RTs-based approach to predict critical congestion scenarios. Our future work will focus on simulation techniques to implement dense scenario with realistic mobility patterns, in order to develop and validate the proposed RTs-based strategy.

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