# A Platform for Realistic Online Vehicular Network Management

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***Abstract*—This paper introduces a platform for realistic and computationally efficient online vehicular networks simulation. It permits decentralized traffic management applications simulation as nodes mobility is modifiable at runtime thanks to the integration of two state-of-the-art network and traffic simulators. The platform embeds a tool that generates vehicular traces based on traffic counting data and ensures performance through a geographical decomposition of the network. Evidence of its performance is given on a Luxembougian traffic management scenario, using real road network and traffic data.**

## I. Introduction

Traffic management has become increasingly attractive these last few years, allowing more safety and efficiency in public transportation. Initially based on a fixed, centralized and costly infrastructure (cameras, magnetic loops, etc.), traffic flow estimation had a coverage typically limited to highways and a low reactivity that in the end leaded to poor efficiency in alternative route planning. More recently, with the emergence of Vehicular Ad Hoc Networks (VANETs), governments, industry and academia have been more and more interested in enhancing traffic management coverage and accuracy by using vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I) communication technologies, such as 2G/3G/4G, Mobile WiMAX, LTE or dedicated new standards (i.e. IEEE 802.11p).

Current commercial efforts (e.g. TomTom HD Traffic service) are put on the V2I communication by using Floating Car Data (FCD) consisting of GPS and/or GSM based probes collected by traffic processing centers that bring dynamic route planning capabilities to GPS devices. Such solutions present several critical issues, as recently outlined by the Joint Research Center (JRC) of the European Commission [1] among which communication load and cost are central.

V2V based communications may help to tackle the technological bottlenecks and increasing costs of infrastructure-based solutions thanks to decentralized and costless information dissemination. As an independent or complementary approach, novel information dissemination and gathering algorithms targeted to such highly dynamic networks have to be developed, like distributed data aggregation [2], [3] or georouting algorithms [4], [5].

Yet such algorithms have to be analyzed, tested and validated either using real testbeds like [6] or more likely simulations thanks to their lower cost and complexity. However, ensuring realistic vehicular network simulation implies accuracy in both network and vehicles mobility models while keeping acceptable computing needs.

More precisely, the simulated network model has to take into account signal propagation issues (e.g. path loss, shadowing) that are computationally expensive. Vehicles mobility, defined by physical (e.g. acceleration/braking capacity) and environmental (e.g. speed limit, number of lanes, density of cars, traffic lights) parameters, is also decisive to the resulting communication network. Indeed, in [7] the authors showed that given the observed density of vehicles on some given roads, algorithms dedicated to mobile and wireless routing like AODV [8] and DSR [9], are simply unsuitable. Therefore, to be useful, vehicular network simulations have also to consider real traffic schemes which are already widely studied in the field of Intelligent Transportation Systems (ITS) with traffic micro-simulations. Finally, simulating traffic management applications, such as traffic congestion avoidance, requires to modify vehicles mobility at runtime, e.g. changing the predefined route of a vehicle if a congestion appears. On the one hand the traffic simulator provides the mobility of the vehicles (position, direction and speed) while the network simulator computes the corresponding wireless network according to the given position and mobility. On the other hand, the network application may decide a change in the route of a vehicle and ask the traffic simulation to modify this vehicle mobility. In the remaining of this paper, this feedback loop between the network and traffic simulators will be referred to as "online" simulation.

The development of such vehicular network simulation platforms has already driven many research projects [10][11] and is still a very active domain, putting emphasis on simulation realism and performance. Therefore in this paper we introduce a realistic vehicular network simulation platform allowing traffic management by interconnecting the SUMO [12] traffic simulator, and the ns-3 [13] network simulator. In addition, this platform provides a tool that generates vehicular traces based on real traffic data (e.g. from induction loops) and a geographical decomposition of the simulated network improving computational performance and scalability. Demonstration of the platform's usage and performance is achieved on a traffic

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management application using real data (maps and traffic data) from the city of Luxembourg.

The remainder of this paper is organized as follows. In the next section, a state-of-the-art on realistic VANET simulations is provided. In Section III our vehicular network simulation platform is presented. Section IV introduces an example of use of this platform in the context of our defined Luxembourgian testbed. Finally section V presents our conclusions and perspectives.

## II. State Of The Art

Network simulation is a vast field of research and application. Many tools have been proposed among which some are able to achieve wireless networking with more or less accuracy. The most popular are QualNet [14], ns-2 [15], ns-3 [13], GloMoSim [16], OMNET++ [17], JiST/SWANS [18], or OpNet Modeler [19]. None of them is however purely dedicated to VANET simulation. ns-2 is probably the most used and validated in academia. ns-3 is intended as an eventual replacement for ns-2 and tries to enhance the flaws observed in ns-2 with a centralized approach for integrating code and new features.

Traffic simulation can be considered on different levels, from macroscopic level, dealing with flows of vehicles on wide areas and wide time windows, to microscopic level, taking into account speedups and slowdowns of cars, lane changes, or traffic lights. We focus here on micro-simulation where proposed solutions rely on largely studied car-following models [20], [21] that define how vehicles accelerate or anticipate traffic slowdowns. Many softwares, commercial and open-source, are popular: MATSim [22], Paramics [23], SimTraffic [24], VISSIM [25], CORSIM [26], or SUMO [12]. VanetMobiSim [28] or [27] also have some traffic simulation capabilities but are limited to static vehicular traces generation.

Existing VANET simulation solutions either use an integrated approach, embedding network and traffic simulation, or an interacting approach that focuses on linking existing network and traffic simulators.

Among integrated solutions, [29] tackles the production of realistic testbeds for both a traffic network and a communication network. In the proposed simulation model the traffic information, the communication between stations and applications are mixed together in a single platform, and thus in a single network. The aim is to reduce the overhead of classical models where the traffic is computed in one model, the communication is also computed on its own, while applications make use of the two previous networks. Integrated Simulation Platform (ISP) [30] includes a traffic simulator, an application simulator, a network simulator and a propagation prediction engine. Highway Traffic Simulator (HiTSim) [31] is another VANET-dedicated, all-in-one simulation tool that allows the simulation of vehicles on highways, using the DSRC protocol. Its main aim is to evaluate the probability of accidents provided that warning systems based on DSRC communication tend to increase the time the driver has to react to an event. The main drawback of such integrated solutions is that they are bounded to the technologies they implement and are hardly maintainable or extendable.

For this reason a number of projects aim at linking existing traffic and wireless simulators. This gives a good reactivity in several communities and more opportunities for new features (protocols, data formats [32], or technologies). Integration facilities like the TraCI [33] client/server approach are definitely a plus in the construction of efficient feedback loop between simulators.

An efficient feedback loop between the two simulators is important to allow efficient online simulation, as stated above in Sect. I. In [10] the distributed simulation of a transportation simulator CORSIM and the communication network simulator QualNet is proposed. Tra-NS [11] connects ns-2 and SUMO through the TraCI client/server API. TraCI is also used by Veins to connect SUMO with OMNET++ or JiST/SWANS. Finally, the recent ongoing FP7 project iTETRIS [34] intends into integrate SUMO with ns-3 for real-time road traffic management solutions but does not yet provide an implementation of their model. The platform proposed in this paper and described in details in the next section integrates the same components, as the SUMO traffic simulator answers many requirements enumerated hereinbefore (reactive, actively developed, able to be driven from a third party application) and the ns-3 network simulator intends to replace the current open-source leader, ns-2.

## III. Platform Architecture

As emphasized in the state of the art, accurate VANET simulation has to benefit from advances in both traffic simulation and network simulation. Our platform uses SUMO for traffic management, as it gives access to a complete client/server API (TraCI) that allows its handling by third party applications. It is open source, actively developed and compatible with several maps and data formats. To manage the network, ns-3 is considered due to its accurate implementation of physical layers, wireless standards, and its active development community. In the following subsections a detailed description of the platform's architecture and capacity of simulating large environments is given.

### A. An Online Simulation platform

The key feature of the proposed platform is to allow the simulation and analysis of vehicular networks protocols and applications, including traffic management. The real interaction between the traffic simulator and the network simulator needs to be automated as much as possible, so as to let the user level models untouched. Figure 1 illustrates the general overview of the model.

The leftmost box represents the traffic simulator part which is composed of two items:

- ”vehicular traces” that represent the static data obtained from realistic maps and traffic data to create mobility scenarios;
- ”online mobility” that represents the computation of the above models in the environment, with the resulting

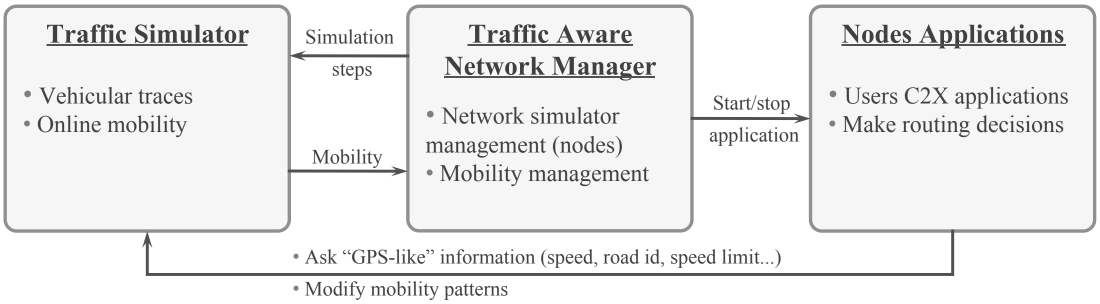


Fig. 1. Platform General Architecture.

interactions (speed limitations, lane changes, traffic jams, collisions...).

This online computed mobility is given to the network simulation part when a simulation step is demanded.

The middle box in Fig. 1 is the heart of the platform that allows both simulators to work together. It performs the following actions:

- Starts, initializes and manages the network simulator.
- Starts the traffic simulator as an independent server and initializes it with a user given mobility scenario.
- Provides the network applications (at nodes level) with an interface allowing queries to the traffic simulator as if that one was an on-board GPS. Respectively, its is possible to know the current speed, position, road is, speed limit, or lane number of every node.
- Iteratively asks the traffic simulator for simulation steps.
- Manages the set of nodes in the network so as it reflects the number of cars in the traffic simulator.
- Manages the mobility of the nodes according to the mobility information given by the traffic simulator.
- Starts and stops user defined vehicles applications.

The rightmost box in Fig. 1 represents the user part of the platform: the implementation of the user's designed algorithm/protocol. This part is given an interface to communicate with the traffic simulator. It can ask for GPS-like information about its represented vehicle. It can also modify the vehicles behavior by asking for the traffic simulator to change their route.

### *B. Simulation of Large Environments*

Traffic simulators are, by nature designed to simulate large environments whereas network simulators are not. As stated in section II, ns-3 and the other wide spread simulators are not designed for VANET applications. The simulation of large environments has a strong impact on the performances of the simulator. Indeed the design of the physical layer implies that any transmission emitted by a device can theoretically reach any receiver listening to the same channel. In practice this is impossible since the natural attenuation of the signal limits the reachable area. Depending on the technology, the maximum range varies from meters to hundreds of kilometers. For Wifi or 802.11p WAVE technology ranges are at most a few hundreds meters and one kilometer respectively. In ns-3 the implementation of 802.11 standards is based on a list of devices that are all polled for every transmission no matter the distance between devices. The time complexity for the transmission computation is of the order of $O(n^2)$, with $n$ the number of devices. We propose here a subdivision of the space based on the theoretical maximum range for the considered technology. For every device, the space is divided into cells with a width of this given range according to its geographical position. When transmitting, a device only checks devices located in its cell and in the surrounding ones, which means at most 9 cells. Given a range $r$, the maximum distance between two devices is between $r$ and $2\sqrt{2r^2}$.

Figure 2 illustrates the impact of subdividing the environment into cells when simulating a Wifi-based vehicular application. Results using four different cell sizes, ranging from 200 to 2000 meters are presented. However, this range must not be set below the maximum reachable distance for the considered devices so as not to bias the experimentation. We also have to consider signal strengths below the reception threshold because it is considered as noise and also has a consequence on the resulting communication network. The smaller the range, the faster the computation. For instance

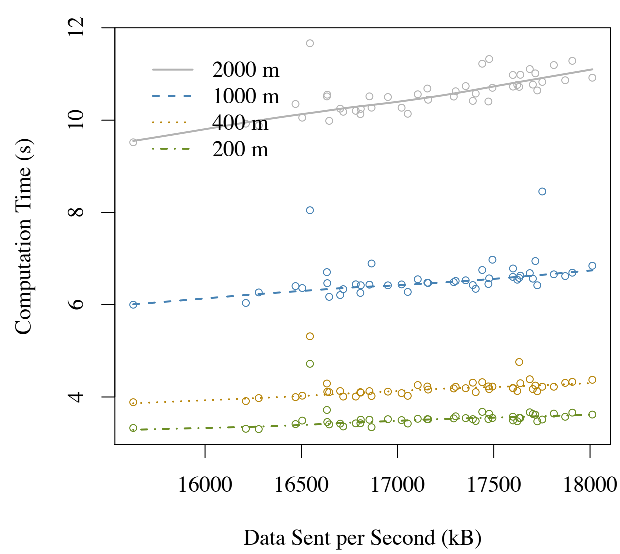


Fig. 2. Performance analysis of the subdivision of the environment.

the computation of one second of simulation (around 1000 devices) during which 18 MB are sent takes less that 3 s with a 200 m range and more that 11 s with a 2000 m range. This range can automatically be adjusted during the simulation, depending on the characteristics of the devices involved.

To be realistic, the number of vehicles in a traffic-based simulation is not meant to be constant. For instance, on a day-long simulation, is less vehicles will drive at night than during the morning rush hours. In ns-3, the number of nodes and their network interfaces are to be predefined for the whole simulation duration. For simulation realism needs, some modifications in the way nodes and interfaces are handled have been introduced in ns-3. The platform currently supports the anytime introduction or removal of nodes and corresponding interfaces.

## IV. An Example Realistic Traffic Management Application

In order to validate the developed platform, the simulation of traffic management on Luxembourg's road network has been considered for three main reasons. Firstly, despite its small size, Luxembourg faces important road congestion issues due to more than 150.000 persons commuting everyday from its three neighboring countries (i.e. France, Belgium and Germany). Efficient distributed ITS for Luxembourg is therefore of high economical, environmental and user safety interest. Secondly, the OpenStreetMap project provides accurate and fine grain information on Luxembourgian roads, with precise information about speed limits, number of lanes, or traffic light logic. This information is used by SUMO, which permits accurate simulation or Luxembourg's environment. Finally, real traffic counting data collected on all types of roads across the whole Luxembourg and made available by the Ministry of Transport [35] is converted by the tool into realistic vehicular traces.

In the following, our platform was used to accurately simulate the usage of a simple V2V-based traffic management application on a Luxembourgian scenario exploiting real infrastructural and traffic data.

### A. Description of the Model

The hypothesis is that vehicles are equipped with wireless network interfaces and also GPS-based navigators. Every vehicle follows its own planned route and knows at anytime its geographical position, current speed, road id, and the road speed limitation. While evolving in the environment, it may be forced to stop because of the traffic in front of it. Above a given time threshold, it will emit a signal to warn about this congested road in its surrounding neighborhood. Vehicles that receive the signal and whom route leads to that problematic road will then be able change their route. Warning signals may also be forwarded so as to reach a wider area. Different threshold and parameters are defined and may need tuning. The following algorithm presents the basic iterative behavior of a vehicle:

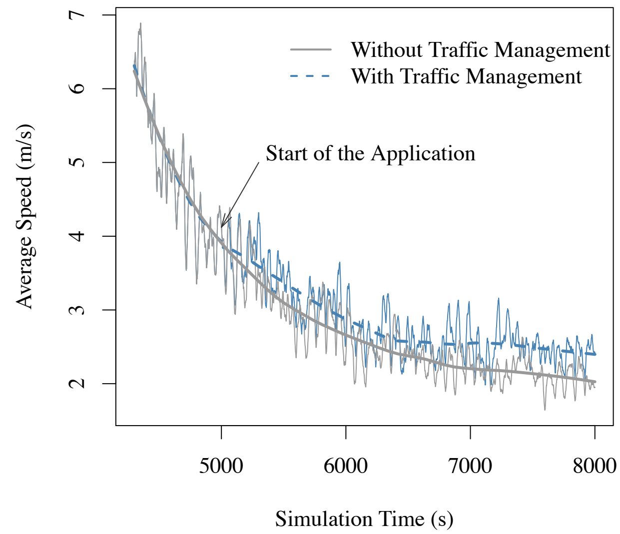


Fig. 3. Evolution of the average vehicles speed in the simulation.

**if** Stop condition **then**
    StopApplication()
**end if**
current_speed ← GetCurrentSpeed()
current_road ← GetCurrentRoad()
**if** current_speed $<$ SPEED_THRESHOLD **then**
    SendWarningPacket(current_road)
**end if**

Upon reception of a warning packet, a vehicle verifies if the road indicated in the packet is part of its future road list. If positive, it can choose an alternative route. In any case the vehicle may forward the packet so as to give it a wider visibility.

### B. Results

The simulated environment is one part of the city of Luxembourg, namely Kirchberg (22 $km^2$), Luxembourg's financial district that has a particularly high vehicular traffic. Simulation starts in the morning, during commuting hours. Figure 3 shows the average speed of vehicles in the simulated area with and without using the traffic management application. In the observed period, the volume of vehicles increases from around 900 to 1500. For both curves, the traffic degrades and the overall average speed is decreases. At simulation time 5000 the traffic management application is started for each vehicle, and cars start communicating and managing their route. The blue-dotted curve shows the slow enhancement of the average speed, reaching 2.3 m/s after 3000 s with traffic management compared to 2.0 m/s without. The SPEED_THRESHOLD is set to 20 % of the authorized speed; the minimum interval between two packets sent by a vehicle is 1.5 s. Packets time-to-live is 30 hops. This enhancement can also be observed in Fig. 4 showing the ratio between the two average speed values (with and without the application), i.e. a 15 % improvement at the end of the simulation.

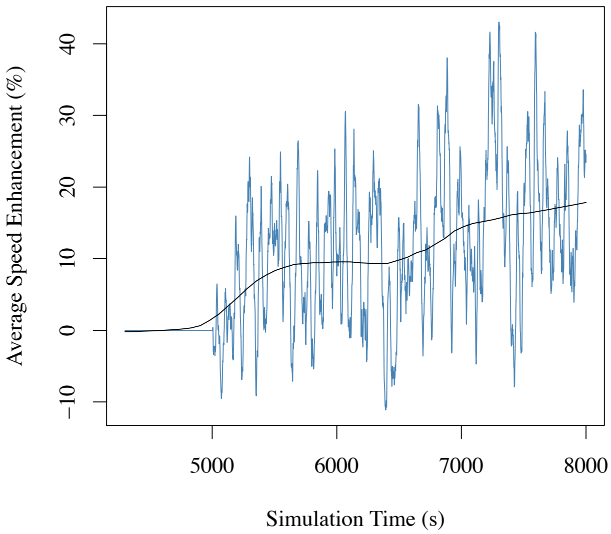


Fig. 4. Average vehicle speed Enhancement ration (with and without traffic application).

This platform and all the traffic data are freely available at http://ovnis.gforge.uni.lu.

## V. Conclusion

In this paper we introduced a novel platform for realistic online vehicular network management. Relying on SUMO for traffic simulation, it provides a tool that permits the generation of vehicular traces based on real traffic counted data. Based on ns-3 for realistic network modeling, its computational efficiency and scalability is ensured by a geographical decomposition of the simulation space. Finally, the modification at runtime of the precomputed vehicular traces, necessary for traffic management applications simulation, is ensured by a two-way interaction between both embedded simulators. Demonstration of the platform's performance and usage for simulating a simple V2V-based traffic management application was achieved on a Luxembourgian testbed based on real-data.

Future works will focus on improving the platform and to using it for the development and testing of new traffic management algorithms and applications.

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