

# Towards a comparable evaluation for VANET protocols: NS-2 experiments builder assistant and extensible test bed

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## Abstract

In order to validate an Intelligent Transportation System (ITS) application or service, simulation techniques are usually employed. Nowadays, there are two problems associated to this kind of validation: the relative complexity of existing simulators and the lack of common criteria in the creation of simulation experiments. The first one makes it hard for users not familiar with a simulation tool to create and execute comprehensive experiments. The second one leads to a situation in which different proposals are validated in different scenarios, thus making it difficult to compare their performance. This work contributes on addressing both problems by proposing VanSimFM, an open-source assistant tool for creating NS-2 simulation experiments, and by defining an extensible test bed which contains a set of simulation scenarios. The test bed is intended to represent the different situations that may be found in a real vehicular environment.

**Keywords:** VANET; simulation; VanSimFM; test bed.

## 1. Introduction

In the last decades we have witnessed a great evolution in the development of wireless communications. The past years have brought these advances to the car industry. Particularly, a new family of services and applications, collectively called Intelligent Transportation Systems (ITSs), are currently being developed. ITSs usually rely on a new, specific kind of communications network called Vehicular Ad-hoc Network (VANET). VANETs are a subtype of Mobile Ad-hoc Networks (MANET) in which its nodes are mainly vehicles, equipped with a communication unit called On-Board Unit (OBU). Besides them, it is usually assumed that there will be some static nodes called Road-Side Units (RSUs), which are placed aside the roads.

Validating ITS-related proposals must ensure that the designed service is suitable for a realistic vehicular environment. However, achieving a holistic validation framework poses a challenge to researchers. Since the required technology (i.e. OBUs, RSUs, embedded systems) is currently being developed and the cost to perform real world experiments is usually unaffordable, simulation is the preferred experimental validation technique, as a complement to the theoretical analysis.

Designing a simulation experiment requires six steps to be performed (see Figure 1). At the first step the map on which the simulation will take place is defined. Afterwards, the mobility patterns of nodes is defined (step 2), thus enabling the creation of mobility traces in the third step. With the output of the mobility simulation and the network parameters, the network simulation is configured in the fourth step and then run in the fifth phase. Finally, the achieved output is analysed in order to assess some performance aspects of the proposal.



Figure 1 - Steps to perform a VANET simulation

There are two main problems related to the validation based on simulation. The first one is the relative complexity of existing simulation tools. There are dozens of simulators, each one covering a different set of steps (and at a different extent) within those identified on Figure 1. Therefore, creating VANET experiments can be very difficult, especially for users not familiar with certain network or mobility simulators. The second problem is the lack of common criteria to define simulation experiments. Thus, each of the aforementioned parameters may have different values. For example, the number of involved vehicles may vary from 2 (e.g. [3]) to 3500 (e.g. [45]). As a result, the comparison between different proposals can be hard to perform or almost impossible. This situation is especially undesirable for the designers of the underlying hardware, as their goal should be to support as much services as possible. Without a unified validation framework, it is difficult to obtain a set of performance requirements to design the hardware.

The goal of this work is to address both problems. For the first one, an extensible open-source tool<sup>1</sup> (called VanSimFM) that assists on the creation of simulation experiments is proposed. On its current version, it allows to create simulation scenarios for the NS-2 tool [5], which is often used for evaluating VANET-based protocols and services. It must be noted that VanSimFM is not a simulator itself, but an assistant tool that simplifies the use of existing simulation tools. For the second problem, a benchmark or test bed composed by a set of simulation experiments has been defined. Their parameters have been established taking into account current simulation practices. For this purpose, a set of more than 30 VANET-related papers have been surveyed.

**Paper organization.** The reminder of the paper is as follows. Section 2 briefly introduces the state of the art in VANET simulation tools. Section 3 presents a survey of several recent scientific contributions and analyses the different settings used in their simulation experiments. Section 4 describes the features and user interface of VanSimFM. Section 5 describes the proposed test bed, which has been built using the mentioned tool. Section 6 presents the conclusions and the future work.

## 2. Overview of existing VANET simulation tools

There is a plethora of simulation tools that may be used to perform an experimental validation of an ITS-related proposal. As a result of a survey of more than 30 papers published in the last three years, it may be seen that there have been several different combinations of tools in the evaluation of different proposals (see Table 1). It is important to note that not every tool provides with the same functionality at the same extent. In this Section, the most relevant simulation tools that are currently used are presented. Afterwards, their main drawbacks are identified. For the purpose of this work, only the most prominent features of these tools are presented. Interested readers may refer to [6, 7, 8] to get further information.

### 2.1. Description

There are three types of simulation tools according to their focus [1]. Thus, there are *mobility* simulators (i.e. they focus on generating mobility traces), *network* simulators (i.e. they perform the data

<sup>1</sup> VanSimFM and the proposed test bed are available at <http://www.seg.inf.uc3m.es>

interchanges of the network nodes) and *integrated* ones that offer the features of the previous two types (see Figure 2). Within this last group, such integration may be done in a single tool or by incorporating other existing mobility and network tools.

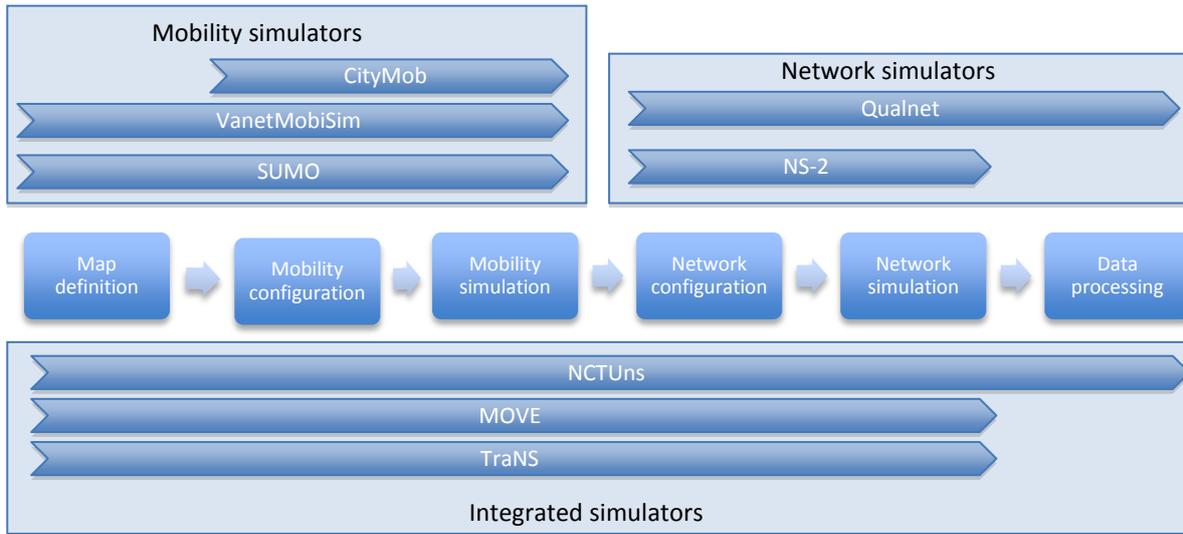


Figure 2 - Scope of the surveyed simulators

SUMO [9], VanetMobiSim [10] and CityMob [49] are *mobility* simulators. All of them are open-source and are able to build output files that may be used in the NS-2 network simulator. They receive map information in different formats, such as OpenStreetMaps [11] (in SUMO) or TIGER [12] (in VanetMobiSim). On the other hand, CityMob generates vehicular movements for urban scenarios, following three mobility models called simple, Manhattan and downtown [49].

Regarding the *network* simulators, NS-2 [5] and Qualnet [13] are two well-known alternatives. Both are prepared to simulate any kind of communication network, so a specific configuration for the vehicular environment is then required. As a difference, Qualnet provides tools for processing the obtained results, whereas NS-2 does not offer this feature.

With respect to the *integrated* tools, there are three prominent options, namely NCTUns [14], TraNS [15] and MOVE [16]. The first one is a commercial single tool that performs all the steps including the processing of the obtained results. Its simulations may be done in a handcrafted map or using an existing one from TIGER. The other two tools are federated options in which SUMO (for mobility) and NS-2 (for network) are employed. The main difference between them is that in TraNS both tools may interact during the simulation, which is not possible in MOVE.

## 2.2. Discussion

Considering the ease of use, integrated tools offer the simplest approach to the simulation of ITS-related proposals. These tools provide the user with a unified entry point to interact with the underlying network and mobility simulators.

The preparation of the simulation experiment has to be as simple as possible. Its starting point should be a graphical interface that allows users to easily define the required parameters. However, most existing tools require a considerable level of expertise in order to use them appropriately. As an example, MOVE offers the user a great range of configuration options, especially for the mobility simulation, making this operation complex for users not familiar with the tool.

### 3. Survey on simulation practices in recent scientific contributions

The election of the simulation settings has a direct impact on the evaluation results. Thus, a very heavyweight, bandwidth-consuming data exchange protocol may be successfully validated in a rural, sparse scenario, although it could have been found unsuitable in a crowded downtown.

A remarkable amount of recent contributions have defined a personalized simulation scenario. Table 1 summarizes the simulation tools used in the surveyed papers along with the main simulation parameters, namely the time, the number of nodes and the scenario type and size. The analysis of other context-specific settings, such as traffic regulations, cryptographic capabilities of the nodes or the assumed communication channel reliability is left to future work.

	Type of simulation tool		Simulation parameters			
	Mobility Simulator	Network Simulator	Simulation Time (sec)	Number of nodes	Scenario type	Scenario size (km)
[18]	VanetMobiSim	Qualnet	250	100-350	Road	2.5x2.5
[19]	VanetMobiSim	Not specified	200	12, 144	Random	1x1
[20]	VanetMobiSim	Not specified	Not specified	50-250	Highway	4
[21], [22]	TraNS (SUMO)	NS-2	100	576	Urban	13.4x12.3
[4]	TraNS (SUMO)	NS-2	200	916	Urban	Not specified
[2]	TraNS (SUMO)	NS-2	78	20-80	Urban	Not specified
[23]	SUMO	NS-2	300	150,250,350	Urban	1.5x1.5
[24]	STRAW (Urban), FleeNet (Highway)	Jist/SWANS	60	10 urban, 100 highway	Urban, Highway	3x3, 12
[25]	None (Random waypt.)	NS-2	600	50x9	Not specified	5x5
[26]	None (Random waypt.)	MATLAB	600	35	Random	1x1
[3]	None (Random waypt.)	Qualnet	900	2-100	Random	3x3
[27]	R	R	Not specified	25, 100	Not specified	Not specified
[28]	Bai et al [51]	NS-2	Not specified	150	Manhattan	2.4x2.4
[29]	Not specified	Qualnet	60	15-25	Road	1x1
[30]	Not specified	NS-2	Not specified	50	Urban	5x5
[31]	Not specified	NS-2	600	75	Highway	Not specified
[32]	Not specified	MATLAB & NS-2	Not specified	Not specified	Highway	Not specified
[33]	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
[34]	Not specified	Not specified	Not specified	Up to 1560	Road	30
[35]	Not specified	MATLAB	1200	Variable	Highway	8046
[36]	Not specified	MATLAB & NS-2	90	50 per second	Urban	7.4x7.4
[37]	NGSim	NS-2	15	18 every 100m	Highway	0.64
[38]	NCTUns	NCTUns	80-100	Variable	Road	0.6x0.4
[39]	Custom	NS-2	700	100	Urban	1.2x1.2
[40]	Custom	Not specified	Not specified	Not specified	Not specified	Not specified
[41]	Custom	Not specified	Not specified	31.7 / minute	Highway	Not specified
[42]	Saha et al [50]	NS-2	Not specified	300	Urban	2.4x2.4
[43]	Pre-created traces	NS-2	200	150	Urban	2.4x2.4
[44]	Pre-created traces	NS-2	Not specified	50-100	Road	3x3
[45]	Saha et al [50]	NS-2	200	Aprox. 3500	Urban	6.7x2.7

Table 1 - Simulation tools and parameters in recent research papers

**Simulation tools.** NS-2 is the preferred network simulation among the surveyed papers, used in 16 of them. The other papers use different network simulators, but a significant number of them (6) have no network simulator specified. Regarding the mobility simulation, there is no preferred choice, and it is remarkable that 8 papers do not specify this issue.

**Simulation time.** There is an important difference in the simulation times even when using the same type of map. As an example, two contributions that use a highway map consider 15 seconds [37]

and 600 seconds [31]. The most common values (chosen in 11 papers) are between 100 and 600 seconds. Moreover, near one third of the papers do not specify this issue.

**Number of nodes.** There is a tendency towards values between 50 and 250 nodes, as more than one third of the papers use values within this range. This parameter is also the most documented, as only 3 papers do not specify it.

**Scenario (type and size).** There are three types of scenarios, namely urban, highways and secondary roads. Among them, urban scenarios (12 papers) and highways (7 papers) are preferred. Interestingly, 7 papers either do not specify the type of scenario or do not use any type of map. With respect to their size, it ranges from 0.6x0.4 kilometres to 13.4 x 12.3 kilometres, but most of the maps are between 1x1 km and 5x5 km size.

These results show that the task to compare ITS-related proposals can be almost impossible since there may be irreconcilable differences between the simulation configurations used. In this situation, it is not possible to discover whether two or more protocols may execute at the same time in a given context. It must be noted that the *purpose* of the simulation scenario for each of the surveyed papers has not been studied. Thus, one author may present the worst case situation, while other may show the best or average performance of her contribution. However, we claim that having a unified simulation benchmark (or test bed) that integrates all these individual scenarios could improve the current situation. With such a benchmark, the evaluation for each contribution would not consist on the results for a single scenario, but for the whole set of scenarios within the benchmark. Thus, the analysis currently shown on papers could still be possible, while their comparability would be improved.

#### **4. VanSimFM: An assistant tool for creating NS-2 simulation experiments**

Current simulation tools require some sort of expertise to use them, as discussed in Section 2.2. In order to simplify their use, an open-source assistant tool called VanSimFM (**VANET Simulation Framework Modeller**) is proposed in this work. A description of its features is given in Section 4.1. In order to illustrate its design and use, its graphical user interface is briefly introduced in Section 4.2.

##### **4.1. Feature analysis. Comparison with other tools**

VanSimFM aims to assist the user along the six steps to perform a VANET simulation (see Figure 1). For this purpose, it provides the user with a graphical user interface that is intended to simplify the use of other existing mobility and network simulators. In its first version, VanSimFM uses SUMO and CityMob as mobility simulators, and NS-2 as network simulator. It must be noted that the election of a given simulator may have a significant impact over the evaluation reliability. Particularly, previous works have highlighted the relevance of the mobility simulator (i.e. its trace generation algorithm) in order to build a realistic vehicular scenario [47]. On the other hand, it is also important to use well-scaling network simulators. Although NS-2 has a limited scalability [48] it is still used in recent contributions (as shown in Section 3). For these reasons, the software design of VanSimFM is intended to provide with enough extensibility to integrate other simulators.

In order to minimize the impact of a given movement trace on the achieved results, different traces should be applied to the same map. VanSimFM provides with this option, thus resulting in a simulation workflow (see Figure 3) which is slightly different from that on Figure 1. As opposed to existing alternatives, VanSimFM enables the automatic generation of several NS-2 scenarios, each one using a different trace (i.e. the result of the *mobility simulation* step), using a single mobility configuration (see Figure 3). Moreover, it can execute sequentially all these simulation scenarios. For the *data processing* step for each simulation, the tool allows to execute user-defined AWK scripts [17]. It must be noted that this option is not present in other integrated tools like MOVE or TraNS.

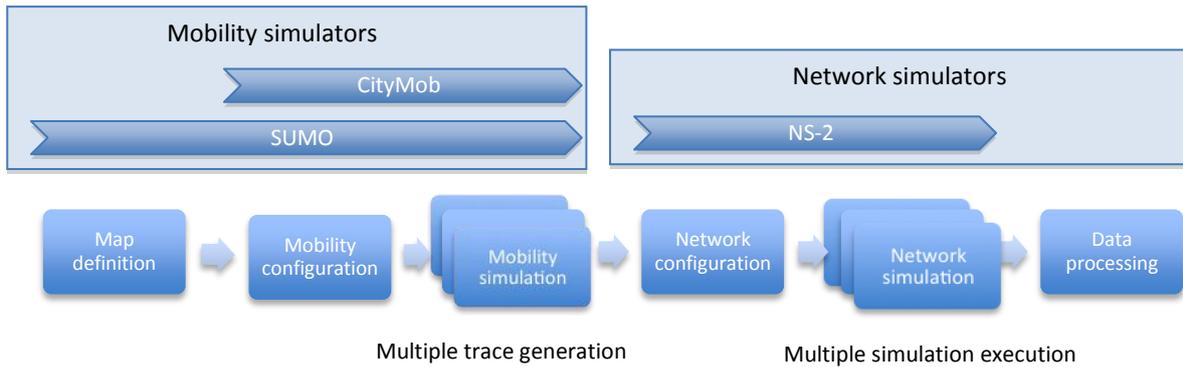


Figure 3 - Execution workflow of VanSimFM

Although the proposed tool has the same purpose as MOVE, it offers three features that are currently not present in the aforementioned tool. First, it allows introducing Road-Side Units (RSUs) nodes in the scenario, which may have a different behaviour (i.e. role in the VANET protocol) than that of vehicles. Second, a *penetration ratio* (i.e. the proportion of vehicles that are equipped with an OBU) may also be defined. This issue increases the realism of simulations as not all vehicles will be equipped at the beginning of the deployment of ITSs. Moreover, the mere existence of vehicles in the road may become a physical obstacle for vehicular communications, thus affecting their performance. Third, user-defined code sections (e.g. variables, functions, etc.) may be automatically integrated in the resulting NS-2 scripts. For example, specific statistical functions may be easily retrieved during the execution of the simulation, providing the researcher with an additional source of information.

#### 4.2. User interface

The simplicity of use for inexperienced researchers is the main design directive of VanSimFM. This concern has to be combined with ensuring the completeness of the tool. This trade-off implies that, in the end, it should offer (at least) the same simulation features than those offered by existing alternatives, but making them more accessible for non-expert users.

A major decision has been to design the user interaction according to the steps shown in Figure 1. This sequential definition of settings is implemented through the use of tabbed panels. To illustrate this decision, Figure 4 shows the *map & mobility settings* window. This window addresses the three first phases of the definition of a new simulation. Thus, it contains a *map settings* panel (phase 1) and a *mobility settings* panel (phase 2). The generation of mobility traces (phase 3) is performed when the button *Generate Mobility and proceed with network settings* is pressed. It must be noted that the *number of route files* field defines the amount of traces that will be created for this experiment. This window also contains an *experiment* tab, which allows giving a name for the current simulation that will be further used to store all the resulting files.

Once the mobility settings have been defined, the network parameters (phase 4) must be established. Particularly, it has been divided into three major sets of decisions – network settings, application settings and trace options (see Figure 5). *Network settings* focuses on low-level issues such as the communication range. As defining these parameters requires some background, a default configuration which is usually employed in these scenarios is given. Moreover, a guide to understand these choices is available through this interface. *Application settings* are related to the VANET service that is evaluated. They define the behaviour of participating OBUs/RSUs, the specific additional code to obtain measures and indicators during the execution and the specific positions of RSUs, if any. Finally, *trace options* (not shown in Figure 5) are intended to configure the network simulator regarding the level of traces required (e.g. agent trace, mobility trace, etc.).

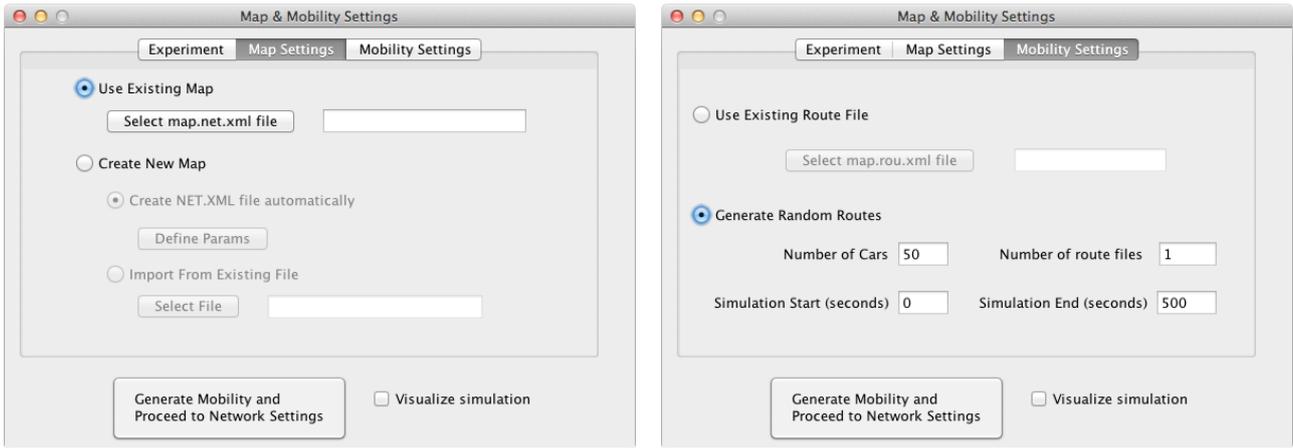


Figure 4 – VanSimFM map definition (left) and mobility definition (right)

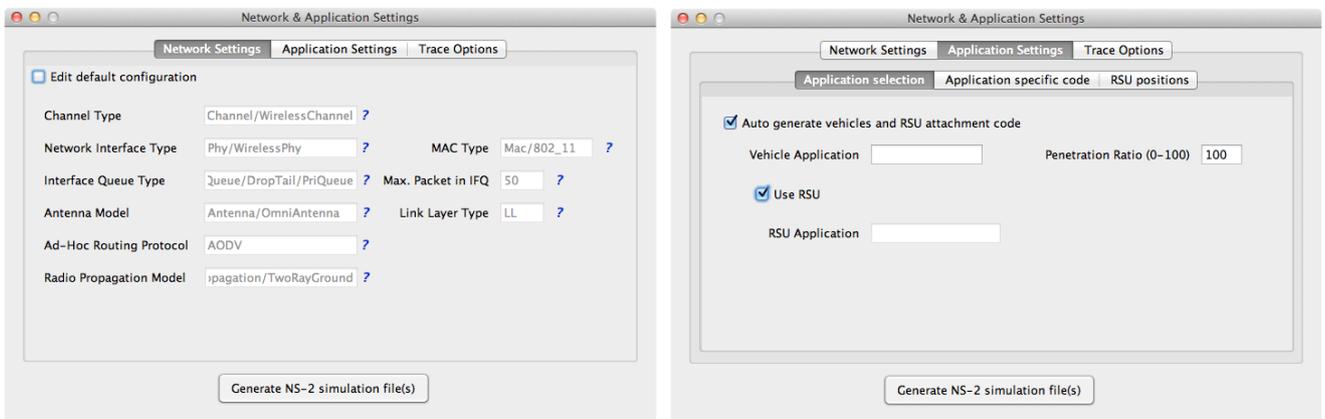


Figure 5 - VanSimFM network parameters (left) and application settings (right)

## 5. Proposed test bed for VANET protocol evaluation

In order to address the lack of comparability problem discussed in Section 3, in this work a test bed for VANET protocol evaluation is proposed. It is composed by a set of simulation scenarios that represent the different situations that may be found in a real vehicular environment. As these situations may vary, this test bed is open to be extended by the research community.

In its current version, the simulation scenarios have been created with VanSimFM. Therefore, they are only suitable for the NS-2 simulator. Specifically, the set of scenarios that form the test bed are intended to summarize the situations that have been considered in the surveyed literature (Table 1). Moreover, some additional well-known settings have also been added. The resulting scenarios that are currently part of the test bed are described in Table 2 and explained below. Table 2 must be interpreted as follows: there is a 5x5 kms Manhattan map where 50 nodes are running during 100 seconds, 250 nodes are running during 600 seconds and 750 nodes are running during 1000 seconds. This leads to a total amount of 15 different settings. It must be noted that five instances have been created for each setting. This decision aims to avoid the influence of the mobility trace on the evaluation results.

	Number of nodes	Simulation time	Size
Urban (Manhattan)	50, 250, 750	100,600,1000	5x5 km
Urban (Eichstätt, Germany)	50, 250, 750	100,600,1000	4.5x3 km
Highway	50, 250, 750	100,600,1000	4.5x5.5 km
Cloverleaf Interchange	50, 250, 750	100,600,1000	3.8x3 km
Secondary roads	50, 250, 750	100,600,1000	12.5x9.5 km

Table 2 – Summary of the simulation scenarios contained in the test bed

**Simulation scenarios (type and size).** Five different types of maps are currently considered. Two of them are *urban* scenarios – a Manhattan-like map and a section of the German city of Eichstätt (taken from [46]). There are two *highway* maps, one having 2 lanes with 3 kilometres length and the other one being a cloverleaf intersection of 3 lanes per direction. Finally there is a *rural* map containing secondary roads. With respect to their sizes, they are on average bigger than those surveyed. This decision is based on the fact that having bigger maps may enable gathering a greater amount of real-life vehicular situations (e.g. bottlenecks, movement trends, etc.) than in a smaller one.

**Amount of nodes.** The number of nodes for each simulation experiment ranges from a minimum set of 50 nodes to a maximum of 750. Due to the significant variation between both limits, an intermediate value of 250 has been selected. To come up with these choices, the highest and lowest surveyed number of nodes (i.e. 2 and 3500) have been discarded. The intermediate value has been set taking into account the average of nodes considered in the studied simulations. Thus, with these values it is expected to enable simulations in high, regular and low traffic density. However, it must be noted that this setting should also consider the computational capabilities of the evaluation platform, as it usually has a direct impact on the performance of simulators. Therefore, the addition of smaller (or even greater) values is foreseen as future work.

**Simulation time.** The values of 100, 600 and 1000 seconds have been defined in order to reflect most of the values found in the studied papers. Although longer simulations may lead to more valuable conclusions, they may cause the experimentation phase to extend dramatically. Thus, the minimum is intended to avoid this fact while remaining useful to evaluate a protocol performance.

## 6. Conclusions. Future work

In this work, we have presented VanSimFM, an open-source tool that assists on the creation of simulation scenarios for the NS-2 network simulator using SUMO and CityMob as mobility simulators. Now in its first version, this tool offers several unique features such as allowing the user to introduce specific code segments in the resulting script or automatically creating several scenarios based on a single configuration. Moreover, its user interface has been designed with the aim of simplifying the whole process.

On the other hand, a test bed composed by a set of simulation experiments has been proposed. Such experiments have been configured taking into account the most common simulation practices found in recent papers. This test bed, currently in its initial version, aims to provide with a common evaluation framework that ensures the comparability of the results of different proposals.

Future work will be focused on validating the suitability of the proposed tool and test bed. Such validation will be based on the feedback given by researchers. Moreover, some extensions of both contributions have already been identified. Regarding VanSimFM, new mobility simulators will be introduced to improve the realism of the created scenarios. Other network simulators will be considered as well. Moreover, other security-related parameters (e.g. cryptographic computation cost for each node) should be added to the tool to capture the growing relevance of security in vehicular networks. The visual definition of vehicular routes and flows and the introduction of obstacles that block the node

signal will also be considered. With respect to the test bed, additional variables may be considered to complete its scope. For example, introducing speed limits, traffic regulations or channel reliability constraints (e.g. effective communication range and bandwidth, packet loss, etc.) would make the test bed be more comprehensive.

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