Impact of NS-2 as FOSS Simulation Tool for Research in Vehicular Ad-hoc Networks

Osama M. Hussain Rehman[1], Hadj Bourdoucen[2], Mohamed Ould-Khaoua[3]

Abstract— **Vehicular Ad-hoc NETworks (VANETs) is considered a state-of-the-art area of research in communication networks. A number of simulation tools have been used and recommended for various research works in VANETs. The Network Simulator 2 (NS-2) is a free and open source software (FOSS), used for performing simulations in communication networks. It is well established that NS-2 is the most widely used simulation platform in communication networks. While relying on records gathered from the online IEEE publication database, this paper quantitatively highlight the impact NS-2 has on VANETs research community. This novel work shows that among a list of used network simulators, NS-2 stands out as the most favorable and widely used simulation tool for research in VANETs to this date. Analysis shows that approximately 877 research papers, working in VANETs while using NS-2, where published in different conferences and journals & magazines in the last ten years. Alongside the quantitative analysis, this paper backs-up NS-2's popularity for research in VANETs by the impact of free & open source regime in making NS-2 a potential candidate for VANETs simulations.**

Index Terms— **Free and open source software (FOSS), IEEE, network simulator 2 (NS-2), vehicular ad-hoc networks (VANETs).**

I. INTRODUCTION

SINCE the last thirteen years or more, Vehicular Ad-hoc NETworks (VANETs), also known as Inter-Vehicle Communication (IVC), is a constantly active area of research in wireless communication networks. Considerable attention is diverted from world governments, industries and academic institutions, towards the application of VANETs for improving road safety and providing on-road infotainment facilities [1-5]. At research, design and development stages, on-road application of VANETs based services is a difficult task to carry out due to financial limitations and physical constraints in large scale deployments. Therefore, a pre-deployment stage is required in order to evaluate the performance quality provided by the underlying VANETs services. Hence, simulation tools are effective means for evaluating performance of any proposed VANETs communication protocols and on-road vehicular communication scenarios.

A number of FOSS and closed source (proprietary) network simulators dealing with VANETs have been used and reviewed by the scientific and research community [6-10]. Some of the popular ones include Network Simulator 2 (NS-2), Network Simulator 3 (NS-3), QualNet, Opnet, GloMoSim, OMNeT++, NCTUns, JiST/SWANS, GrooveNet, MobiREAL, NetSim, GTNetS, Veins and J-Sim. In general, VANETs simulators are either considered as standalone network simulators or an integration between a network simulator and a mobility pattern generator [6].

In general, NS-2 is considered as the most widely used simulation tool among all FOSS and closed source simulators used in communication networks [11]. NS-2, developed in 1989, is a discrete event simulator designed for research in communication networks, written in C++ and OTcl languages and targeted to run on Linux based operating systems but can also be used on Windows platforms through Cygwin emulator. NS-2 is licensed under the GNU General Public License version 2. Various version of NS-2 were released, where the latest version was NS-2.35 that was released a year ago on 4th of November 2011, along with its complete documentation [12].

In this work, quantitative analysis of NS-2's popularity for VANETs research is provided based on records available in IEEE publication database, retrieved through IEEEXplore portal. Only IEEE publication records were taken into account, where IEEE is considered as the most widely used platform for publishing scientific research works related to communication networks. We show that from quite a lengthy list of available network simulators suitable for simulating VANETs scenarios, NS-2 stands out as the most popular and widely used simulator for simulating VANETs related works. Impact of NS-2 being a FOSS simulation tool is highlighted while providing comparative analysis with other simulation tools. Additionally, we briefly investigate NS-2 with respect to its capabilities in fulfilling the necessary requirements a VANETs simulation scenario would usually contain. This paper concisely discusses the sufficiency level of NS-2 as a FOSS simulation platform for performing research works in VANETs, while considering its flexibility, diversity and limitations. Few available VANETs supporting NS-2 modules are highlighted while considering both built-in modules and the ones available externally as FOSS modules

[1] Department of Electrical & Computer Engineering, College of Engineering, Sultan Qaboos University, P.O. 33, Al-Khodh, Muscat-123, Sultanate of Oman (phone: 968-24143775; fax: 968-24413454; e-mail: p091608@ squ.edu.om)

[2] Communication and Information Research center, Sultan Qaboos University, P.O. 17, Al-Khodh, Muscat-123, Sultanate of Oman (phone: 968-24143696; fax: 968-24144336; e-mail: hadj@squ.edu.om)

[3] Department of Electrical & Computer Engineering, College of Engineering, Sultan Qaboos University, P.O. 33, Al-Khodh, Muscat-123, Sultanate of Oman (phone: 968-24141363; fax: 968-24413454; e-mail: mok@ squ.edu.om)

on the internet. This paper shows that NS-2 has a wide range of reusable built-in modules usable in VANETs, augmented by a large number of freely available modules.

The remainder of this paper is organized as follows. Section II provides statistical-based approximate quantitative analysis of NS-2 popularity in VANETs research, along with comparative analysis with other network simulators. Section III briefly discusses major usable NS-2 modules that can be utilized with or without modifications for VANETs. In addition, another source of strength is discussed that permits NS-2 to accept vehicular mobility patterns as trace files from other free and open source mobility patter generators. Section IV gives concluding remarks on NS-2 popularity, sufficiency for performing VANETs related simulations and how it could be improved towards a much desired VANETs simulator.

II. NS-2 Popularity Among VANET Simulators

NS-2 is a highly used simulation tool for simulating various VANETs protocols working at different layers of the communication networks model. To quantitatively highlight its popularity, a statistical analysis is presented in this section based on IEEE publication database as the most widely used research publications portal in the field of communication networks. Advance command based search queries are used in the IEEEXplore portal in order to analyze how many research papers have worked on VANETs while using NS-2 or any other network simulation platform. For case of this work, only conference proceedings and journals & magazines are taken into consideration. It is important to note that in IEEE search results, journals & magazines records are returned as a single group.

A. Advance Command Search Query

A direct link to the advance command based search option at IEEEXplore digital library is provided in [13], whereas an advance search query which is among a set of all used queries, is presented in Fig. 1. All used search queries have taken into account all the possibly used technical keywords having interchangeable meanings in VANETs research papers. For VANETs, these words include VANET, intervehicle and intervehicular. In addition, both NS-2 and NS2 keywords are also used in all queries for referring to the underlying NS-2 simulator. It is to be noted that the ".PLS." seen in the queries, is an IEEEXplore customized command that denotes the plus sign "+".

Surely the query in Fig. 1 can be easily modified and utilized for searching in any discipline of research other than communication networks that fall within IEEE's publication database. Hence, through this paper we also provide this query as an advance command based search query that can meet the demands of researchers from various disciplines.

```
((((((((((((((((( vanet OR vanets OR intervehicle OR intervehicular )
AND ( ns-2 OR ns2 ) ) NOT ns-3 ) NOT qualnet ) NOT opnet )
NOT glomosim ) NOT nctuns ) NOT omnet.PLS..PLS. )
NOT jist/swans ) NOT groovenet ) NOT mobireal )
NOT netsim ) NOT gtnets ) NOT veins )
NOT j-Sim ) NOT swans.PLS..PLS. )
```

Fig. 1 Advance command search query.

For sake of synchronization, all search process where executed on the 26th/Dec/2012, where an increase in number of records returned by the search queries will occur with passage of time. A total of fifteen known network or VANETs simulators were included in each search query as listed in Table 1, but only the results of nine simulators, given in Table 2, are included in this work. The remaining simulators were left since their returned records were very trivial, if not none.

In Table 1, simulators' licensing policies are highlighted as well which are either closed source (Proprietary), free & open source or open source but with some constraints. Due to lack of available information, few simulators are left without identifying their licensing policies. In addition, some further comments were included in Table 1 for any further clarifications seen necessary for some simulators.

S#	Simulator	Licensing Status	Comments
01	NS-2	FOSS	▪ License under GNU General Public License version 2.
02	NS-3	FOSS	▪ License under GNU General Public License version 2.
03	QualNet	Closed Source (Proprietary)	▪ Closed source version of GloMoSim.
04	Opnet	Closed Source (Proprietary)	-
05	GloMoSim	Copyrighted	▪ Permission is provided to use, copy, and modify GloMoSim and its documentation for education and non-commercial research purposes only.
06	OmNet++	Academic Public License (for academic and non-profit use)	▪ Academic Public License rights are similar to GNU General Public License. ▪ Retains possibility to financially support development by selling commercial licenses for commercial users.
07	NCTUns	Closed Source (Proprietary)	▪ Closed source in Feb. 2011. Sold by commercial name EstiNet.
08	JiST/SWANS	Copyrighted	▪ Copyrighted under Cornell Research Foundation. ▪ Licensee is granted permission to download, compile, execute, copy, and modify Software for non-commercial academic purposes.
09	SWANS++	Copyrighted	▪ An extension to JiST/SWANS.
10	GrooveNet	-	▪ It is free for academic use.
11	MobiREAL	-	▪ Can be used for research purpose and non-commercial usage.
12	NetSim	Closed Source (Proprietary)	-
13	GTNetS	-	-
14	Veins	FOSS	▪ License under GNU General Public License version 2.
15	J-Sim	Open Source	▪ Released under The Academic Free Licence v 2.1, certified by the Open Source Initiative (OSI).

Table 1 Network simulators included in search queries.

S#	01	02	03	04	05	06	07	08	09
Simulator	NS-2	NS-3	QualNet	Opnet	GloMoSim	OmNet++	NCTuns	Jist/SWANS	GrooveNet

Table 2 Network simulators analyzed for popularity in VANETs research.

Nine search queries were executed, where all contained a common search settings of selecting "Full Text & Metadata" option. Hence, the search queries do not limit themselves to the content available in Title, Abstract, etc, but it includes the whole content of documents. On the other hand, the search queries have the following two main features included automatically:

1. Publication years include all available years.
2. Publishers source does not only include IEEE database, but all the following: IEEE, AIP, IET, AVS, MITP, IBM, VDE, BIAI and TUP.

B. Quantitative Analysis of NS-2 Popularity in VANETs

Detailed statistical results returned from nine different queries, corresponding to the nine most popular simulators used in VANETs, are presented in Table 3. It is important to understand that these results are approximate results rather than absolute, since it was near to impossible to open up each document and check the content manually. For the sake of partial verification, it is worth mentioning that in each occasion of search, one to ten documents were randomly opened and checked manually. This proved to be successful in all search process while excluding very few records.

As shown in Table 3, NS-2 clearly surpasses all other simulators with respect to its usage in both conferences and journals & magazines. QualNet usage for VANETs research has recorded noticeable usage as well, placing it in the second place in the list. But based on the achieved results, NS-2 usage surpassed that of QualNet by around seven and twelve times more for conferences and journals & magazines publications, respectively. More interestingly, NS-2 alongside GloMoSim and Opnet, are one of the first used simulators in research areas of VANETs, identified by "Publication year" column in Table 3.

NS-2 standing out firmly with a total scored publications of 877, including 751 conference and 126 journals & magazines, shows a significant impact on the research area of VANETs in the last ten years, i.e. from 2003 to 2012. Naturally speaking, conference publications exceed a lot compared to that of journals & magazines publications, but a record of 126 journals & magazines publications for NS-2 further cements the significant impact NS-2 had throughout the years in VANETs research.

A bar chart graphical representation of the achieved statistical results is given in Fig. 2, where it shows the significant usage difference among NS-2 and all other highlighted network simulators. It's like a putting skyscraper alongside few story buildings! As it can be seen from Fig. 2 and Table 3 that while using NS-2, the number of journals & magazines published papers alone exceeds the total publications of that for the runner-up QualNet. These statistics, charts and their corresponding analysis show that NS-2 has a major impact on the research field of VANETs, not just recently but since the birth of VANETs research, despite NS-2 being a FOSS simulation tool with still ongoing modifications and bugs removal process.

Another worth highlighting point is the rapid popularity and acceptance that NS-2's successor, Network Simulator 3 (NS-3) is gaining. NS-3 also possesses the quality of being FOSS simulation platform. Only in the span of three years, 2009 to 2012, forty eight publications were recorded in IEEE publication database which obviously contained a higher weight for conference papers publications. But again, with these figures, the impact of a simulation tool being a successor of NS-2 and FOSS in nature can be felt and is expected to excel its presence along upcoming years.

For readers' curiosity, the famous MATLAB simulation tool has not been including in the search queries. Whereas, MATLAB based VANETs research works returned significant number of publication records, with a total of more than 200 publications. But, it also has been observed that a significant portion of the returned records were related to research works at the physical layers of VANETs communication systems, control theory within VANETs and VANETs communication modeling. Whereas, the scope of this paper is only limited to research works related to communication network layers of VANETs.

Simulator	Conference	Journal & Magazine	Total Publication	Publication Year
NS-2	751	126	877	2003 - 2012
QualNet	101	10	111	2006 - 2012
Opnet	65	6	71	2000 - 2012
OmNet++	64	4	68	2007 - 2012
NCTUns	52	2	54	2005 - 2012
NS-3	40	8	48	2009 - 2012
GloMoSim	39	3	42	2003 - 2012
JiST/SWANS	33	6	39	2007 - 2012
GrooveNet	9	3	12	2007 - 2012

Table 3 Approximate total number of conference and journals & magazines papers published while using underlying simulation tools.

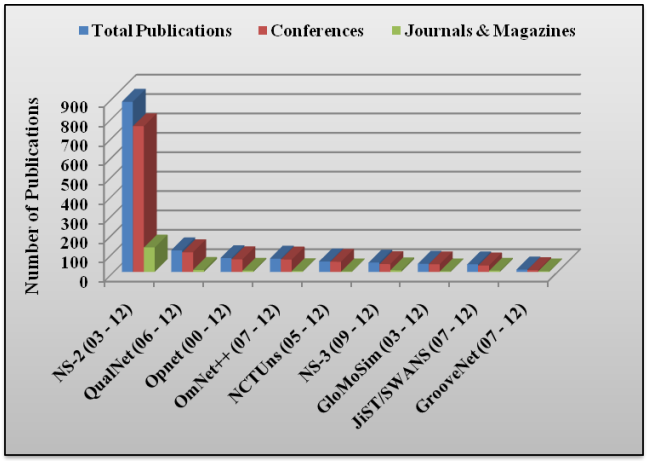

Fig. 2 Approximate usage of network simulators in VANETs research published in IEEE conferences and journals & magazines

III. NS-2: MODULES SUPPORT FOR VANET RESEARCH, COMPATIBILITY WITH MOBILITY GENERATORS & DEFICIENCIES

A. NS-2 Supportive Modules for Research in VANETs

NS-2 supports wireless networking modules alongside wired networking modules. For the case of VANETs, proper wireless connectivity and nodes mobility are the main concerns that a simulator should be investigated, and NS-2 has the capability to provide both facilities for VANETs protocol developers, either as built-in modules or as an extension. Besides that a number of communication protocols, related to transport, network and data-link layers are supported as built-in modules that augments NS-2 capability as a simulator for VANETs. Protocols in NS-2 are usually referred to as "Agents" capable of performing a certain task. Some of the built-in protocols that can be used for VANETs include constant bit rate (CBR), transmission control protocol (TCP), user datagram protocol (UDP) and internet protocol (IP). In addition, a number of Mobil Ad Hoc Networks (MANETs) supportive routing protocols are included as a built-in components in NS-2, including Ad hoc On-demand Distance Vector (AODV), Ad hoc On-demand Multiple Distance Vector (AOMDV), Dynamic Source Routing (DSR) and Destination-Sequenced Distance Vector (DSDV). Unfortunately, direct usage of the underlying MANETs routing protocols is not possible due to the occurrence of principle characteristic differences between MANETs and VANETs [14]. On the other hand, modified versions of the available MANETs protocols may be employed in VANETs simulation scenarios, hence saving time in building up protocols from scratch.

NS-2 implements both time division multiple access (TDMA) and IEEE 802.11 medium access control (MAC) protocols. NS-2, with its latest version, i.e. NS-2.35, has two built-in IEEE 802.11 MAC modules, the Mac802_11 and its extension Mac802_11Ext classes. The availability of these two module is another plus point for NS-2 to be supportive for VANETs related simulation works, where both modules can be configured through OTcl scripts to its various standards including IEEE 802.11(a,b,g,n and p). Conversely, NS-2 has built-in modules for wireless personal area networks (SPAN), identified as IEEE 802.15 standard. But, it is worth mentioning the most of the research works consider IEEE 802.11 as the wireless access mechanism in VANETs, as compared to other wireless medium access mechanism, such as WPAN technologies including Bluetooth and ZigBee. Amazingly, NS-2 also provides an OTcl script file with configurations of the IEEE 802.11p standard that was specially designed for vehicle to vehicle (V2V) or vehicle to road side units communication. The OTcl script location in NS-2.35 is provided in the following path: //˜ns/tcl/ex/802.11/ IEEE802-11p.tcl, where ˜ns refers to the home directory of NS-2 installation.

NS-2 also support the physical wireless layer modeling by providing built-in modules of transmitting antenna type, wireless network interface and a number of wireless channel propagation models. NS-2 has an omni-directional antenna module which is usable off the shelve and can be easily integrated in any developed VANETs scenario. Conversely, NS-2 directional antenna modules can be found as a free and open source module on the internet. Additionally, NS-2 built-in propagation channels models include FreeSpace, TwoRayGround reflection, Shadowing and Nakagami fading channel models. These models are considered as basic radio channel models, where the TwoRayGround reflection is the mostly used model in various research works.

Basic nodes' mobility patterns are supported with built-in NS-2 modules that include deterministic and random mobility patterns. The deterministic mobility is achieved by defining the destination (x, y) coordinates that falls within a pre-define topology area. Whereas the random model is defining by just enabling or disabling a random motion command.

Alongside NS-2 built-in modules, a large number of ready to use modules are developed and uploaded on the internet by diversified NS-2 users. A non-exhaustive list of NS-2 contributed codes that has not yet been integrated with NS-2 releases can be found in [15]. These codes are available as a free and open source modules, where most of them are associated with the instructions on how to add them into the underlying NS-2 simulator.

In general, most recent research works including VAENTs, require NS-2 simulation modules that are not built-in, whereas incorporating new modules require profound understanding of NS-2 architecture [11]. The FOSS regime of NS-2 allows researchers to traverse inside available built-in MANETs, IEEE 802.11, IEEE 802.15, propagation channels and nodes mobility pattern modules and carry on with the changes as necessary for their VANETs scenarios. This shows how the free and open source regime makes NS-2 easily disseminated among a large number of contributors, customizable to different scenarios' need and ease of addition and integration of new modules, which in turn are the source of NS-2 flexibility, diversity and expandability.

B. NS-2 Compatibility with Mobility Pattern Generators

NS-2 has a wider spectrum of integration capability with external traffic mobility model generating tools, as compared to other network simulation tools [6]. The diversity in NS-2 compatibility with mobility patter generators provide researchers with a sense of higher confidence in using NS-2 as a free & open source tool. This gives NS-2 the leverage in becoming more desired to work with. Some of the mobility model generating tools compatible with NS-2 include CanuMobiSim, VanetMobiSim, SUMO, MOVE and CityMob. The NS-2 open source policy can help developers in tightly integrating a mobility generator to that with NS-2, such as it is done in integrating SUMO with NS-2, that produced a VANETs simulation tools known as Traffic and Network Simulation Environment (TraNS).

C. NS-2 Deficiencies in VANETs Research

A number of deficiencies are observed in NS-2 as a VANETs simulator, that can be removed with the inclusion of a number of well desired modules. These desired modules could be worked on and integrated as future free and open source NS-2 modules. For VANETs researcher, many limitations exists in current built-in NS-2 modules, but we will limit our discussion for few main ones that can be

summarized as follows. NS-2 requires more diversity in the set of mobile radio channel models, especially the ones known as multipath Rayleigh and Rician fading channels. Along the mobile radio channels, no proper radio mobility model has been specially developed for vehicular communication scenarios in NS-2. Radio obstacle models for modeling terrain obstacles, such as on road cars, buildings, trees, are not present. The number of simultaneous nodes existing at a simulation scenario is limited to a total of approximately 400 nodes, hence system's scalability is bound to a relatively small limit.

IV. CONCLUSION

This work presents a quantitative analysis of NS-2 popularity as a VANETs simulation platform. IEEE publication database has been utilized for this matter as the most widely used publication platform in communication networks. The impact of NS-2's free and open source regime on VANETs research community is highlighted through the achieved quantitative results. In this quantitative analysis, fifteen popular network simulators are compared with each other, where NS-2 topped the list with a large margin having a total conference and journals & magazines publication records of approximately 877. Due to NS-2's FOSS policy, many rapid updates took place since its first release. With that, it is shown that NS-2 facilitates a large collection of VANETs supportive modules that are either built-in or available on the internet. In addition, these modules are modifiable to the requirements of the designed VANETs scenario. A number of NS-2 deficiencies for research in VANETs are indicated as well, where future suggested works would be to fill-up the gaps identified in these deficiencies. Basing on the achieved quantitative analysis, till this date, NS-2 is a much preferred VAENTs simulation platform over all other compared simulation tools, including its successor NS-3.

ACKNOWLEDGEMENT

This paper is based upon research work supported by The Research Council (TRC) Oman, under Grant No: ORG/ICT/12/002, (www.trc.gov.om).

REFERENCES

[1] World Health Organization, "Saving Millions Of Lives," United Nations, Geneva, 2011.

[2] World Health Organization, "Global plan for the decade of action for road safety 2011-2020," United Nations, Geneva, 2011.

[3] H. T. Cheng, H. Shan, and W. Zhuang, "Infotainment and road safety service support in vehicular networking: From a communication perspective," *Mechanical Systems and Signal Processing*, vol. 25, no. 6, pp. 2020-2038, 2011.

[4] R. Chen, W. L. Jin, and A. Regan, "Broadcasting safety information in vehicular networks: issues and approaches," *IEEE Network*, vol. 24, no. 1, pp. 20-25, 2010.

[5] C. E. Palazzi, M. Roccetti, and S. Ferretti, "An Intervehicular Communication Architecture for Safety and Entertainment," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 1, pp. 90-99, 2010.

[6] F. J. Martinez, C. K. Toh, J. C. Cano, C. T. Calafate, and P. Manzoni, "A survey and comparative study of simulators for vehicular ad hoc networks (VANETs)," *Wireless Communications and Mobile Computing*, vol. 11, no. 7, pp. 813-828, 2011.

[7] E. Alba, *et al.*, "Accuracy and Efficiency in Simulating VANETs," in *Modelling, Computation and Optimization in Information Systems and Management Sciences*. vol. 14, H. Le Thi, *et al.*, Springer Berlin Heidelberg, 2008, pp. 568-578.

[8] G. Grilli, "Data dissemination in vehicular networks," Ph.D. Thesis, Department of Computer Science, Systems and Production, University of Rome "Tor Vergata", 2010.

[9] V. Cristea, *et al.*, "Simulation of VANET Applications," in *Automotive Informatics and Communicative Systems: Principles in Vehicular Networks and Data Exchange*, ed: IGI Global, 2009, pp. 264-282.

[10] A. Hassan, "VANET Simulation," Masters Thesis, School of Information Science, Computer and Electrical Engineering, Halmstad University, 2009.

[11] T. Issariyakul, and E. Hossain, *Introduction to network simulator NS2*, Second ed. New York: Springer, 2011.

[12] K. Fall, and K. Varadhan, *The ns Manual*, 2011.

[13] IEEEXplore Digital Library: [Online]. Available: http://ieeexplore.ieee.org/search/advsearch.jsp?expression-builder

[14] J. J. Blum, A. Eskandarian, and L. J. Hoffman, "Challenges of intervehicle ad hoc networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 5, no. 4, pp. 347-351, 2004.

[15] NS-2 Contributed Code [Online]. Available: http://nsnam.isi.edu/nsnam/index.php/Contributed_Code.