A Comparative Analysis of VANETS Simulator

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Abstract – Simulation is performed by taking description of experiments and running episodes and executing models so that the behavior of the objects is reflected in the real time basis, without exposing any danger or risk to experimenter. The high cost and extensive labor along with high danger is involved while deploying and testing the real time experiments of Vehicular ad-hoc Networks (VANETs). In other words, simulation is one of the most useful alternatives to test an approach on the machine to avoid potential dangers, realize the experiments results and the behavior in the real world, prior to actual implementation. In order to simulate a VANET, simulation environment consisted of both a network and traffic simulator for smooth functioning. This chapter discusses challenges faced by VANET simulation, Vehicular Mobility Models, the vehicular traffic generator, the network simulator and the use of these tools in VANET simulation. In particular, in this article various software characteristics, graphical user interface (GUI), popularity, ease of use, input requirements, output visualization capability, accuracy of simulation, etc. is discussed and compared. In this manuscript it has been concluded that a good simulation environment for VANETs, refinements and further contributions are needed before they can be widely used by the research community.

Index Terms – Vehicular Ad Hoc Networks, Simulators, Challenges.

1. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs) are a special type of MANET where vehicles act as a node and primarily designed to provide safety on roads, traffic management and on-board entertainment. VANETs have distinct characteristics like: 1) Highly mobile nodes with independent or correlated speeds. 2) Nodes with ample energy and computation power. 3) Different communication environment, mostly highway and city scenarios. 4) Support applications with different QoS requirements. 5) Nodes use global positioning system to synchronize with communicating vehicles. There is no transport protocol developed for vehicular networks and it is difficult to adapt existing protocols or design new complex protocols. It becomes very difficult to convince the early adopters to buy VANET equipment for their vehicles, the potential of VANET may not be realized by customer so proper awareness and advertisement must be spread. Other challenges include, it must work properly in a wide range of conditions such as dense and sparse vehicular traffic, designing the MAC protocol is the key issue, making use of more than one channel results in multi-channel synchronization problem particularly in vehicles with single transceiver and also co-channels interference problems. In addition, providing security and privacy in VANET is also a challenging task. As VANET applications are mostly based on providing safety and traffic management, its simulation applies to various large scale scenarios and it must consider the distinct characteristics of vehicular environment. Testing and deploying the vehicular network scenario requires ample amount of money, large workforce and intensive labor. To test the applications and advancements computer simulation is used before actual deployment. It is quite feasible, requires less cost, time, effort, possesses no danger and generates reports of different aspects of the application. VANET simulation is different from MANET because it has unique requirements and challenges; it considers factors like road topology, traffic light, traffic congestion, varying the speed and mobility of the vehicle. VANET simulation faces a lot of challenges which are explained in the next section.

1.1. Challenges Faced by VANET Simulation

Simulation of VANET requires a large number of nodes. Nodes are highly mobile with speed ranges from 0 to 40m/s, whereas in MANET nodes speed ranges from 0 to 5m/s. Vehicle movement are not independent of each other, but restricted by vehicular traffic models.

Obstacles- Obstacles disrupt the communication process and vehicular movement. Example- When a wireless signal passes through obstacles like building, mountain, etc. signals may disrupt.

Trip motion- Trip means path from source to destination. There are different paths available from source to destination. It is according to the driver which path he will choose. So, VANET simulation must take driver interest in consideration.

Path motion- Path means set of road segments taken by the vehicle on its trip from source to destination. Drivers choose path according to various constraints like road congestion, distance, time of the day, etc.

Time patterns- Traffic density is different during different time of the day. Simulation must consider the difference between rush hour and normal hour. This time greatly influences the path selection of a vehicle.

External Influence- Simulation must take into account external influences like road accidents, temporary road works.

Human driving patterns- Drivers consider both the static as well as dynamic obstacles like neighboring cars and pedestrians. Therefore, selecting a good and efficient simulation environment is a crucial task as it helps in generating different communication environment like city, highway and town scenarios with ease and less danger and safety issues. This motivates us to proceed with the survey of existing VANET simulators. In the next section, an overview of existing VANET simulators is presented.

2. OVERVIEW OF SIMULATION IN VANET

In this section, various VANET simulators used by the research community are discussed. The paper presents only freely available and open source software which allows free access to the simulator source code. VANET simulation is done in 3 phases and three different simulators are used. They are a) VANET simulators. b) Network simulators. c) Vehicular mobility generators. Figure 1 presents the taxonomy of VANET simulation software.

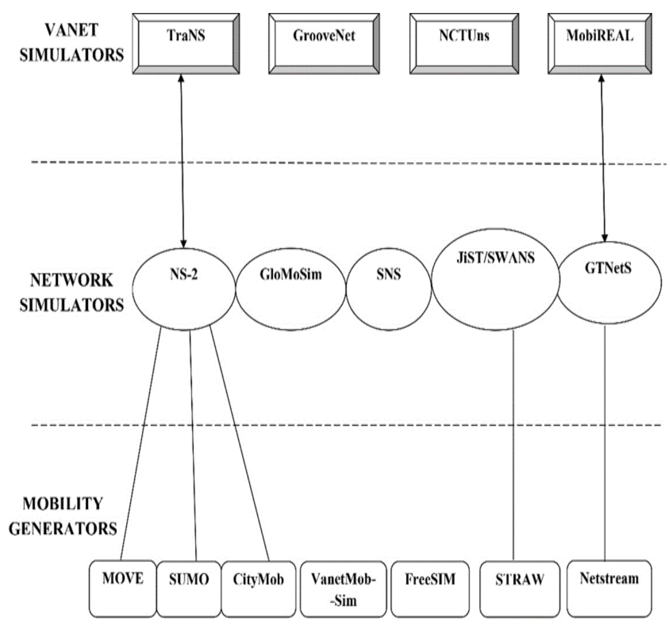

Fig. 1. Taxonomy of VANET simulation software.

Vehicular Mobility Generators are used to provide realism in VANET simulations. The output of the mobility generator includes traces of realistic vehicular mobility which act as an input to the network simulator. Inputs to the mobility generator include the road model, scenario parameters like rates of vehicle arrivals and departures, maximum vehicle speed, etc. From the trace details, it is easier to identify the location of each vehicle at each time instant for the entire duration of the simulation and their mobility profiles. Examples are SUMO, MOVE, Free SIM, STRAW, Netstream, etc. After traffic simulation, next phase is network simulation. Network simulator model computer network configuration, perform detailed packet level simulation of source, destination, background load, route, links and channels. With the help of network simulator, we can differentiate various network setups, identify the limitations and resolve it before deploying and conducting expensive tests in the real world. Network simulators used for MANET require VANET extensions to be able to be used in VANET simulation. Examples are NS-2, SNS, J-SIM, OMNET++, GloMoSim, etc. Lastly, VANET simulators provides both network simulation and traffic flow simulation. Examples are GrooveNet, TraNS, MobiREAL, etc. In the further section, characteristics, limitations, and comparison of various vehicular mobility generator, network simulator and VANET simulator are discussed in great depth.

3. VANET MOBILITY GENERATORS

Vehicular mobility generators add realism to the VANET simulation. Inputs include road models and scenario parameters and output consists of traces of detailed vehicular movement. The simulator must be compatible with the network simulator as it cannot be used directly for the simulation, must be combined with network simulator.

Mobility models are generally classified as either macroscopic or microscopic. The microscopic models consider each vehicle as a distinct entity, focuses on its movement and behavior with respect to others, whereas macroscopic models considers quantity of interest such as traffic density, velocity of cars, traffic lights, roads and streets. It consists of two functional blocks: Motion constraints and traffic generator. Motion constraints; consider the relative degree of freedom of each vehicle. Microscopically, motion constraints are streets or buildings, whereas microscopically, constraints are modeled by pedestrians and neighboring cars. Traffic generator deals with different cars and their interaction with the environment under study. Macroscopically, it models traffic flows or densities and microscopically, deals with acceleration, inter- distances between cars and braking.

The realistic mobility model must possess the following features:

a) **Smooth acceleration and deceleration-** Acceleration and deceleration models must be considered as the vehicles don’t abruptly break and move.

b) **Vehicle characteristics-** The traffic parameters of any network are directly affected by the characteristics by the vehicle which includes the speed, height, weight etc. As an example, some part of the national highways are blocked for heavy vehicles during some timings in a day and also the traffic generator can be altered by the different speeds of different types of vehicles.

c) **Pattern of driving-** The pattern of driving is affected by the different types of obstacles. The obstacles can be static or dynamic in the form of different types of vehicles, pedestrians, trees etc. Therefore, mobility model should control mutual interaction of vehicles.

d) **Time patterns-** The density of the pattern is dependent on the timings of the day. It is not homogeneous as during the peak hours or office timings the density of the traffic is very high.

e) **Topological maps**- The heterogeneous density of the traffic on the roads is managed by the maps. The maps contain the topology of the roads, including all the lanes and streets.

f) **Points of Attraction or Repulsion -**The source and the destination chosen by the vehicles are not random. Mostly, drivers are driving towards a similar destination or to same attraction point (e.g. Office) or coming from a similar initial point, creating bottlenecks in the attraction and repulsion point.

g) **Management of different intersections -** All different types of intersections is controlled by the mobility models. The intersections can be of any different types as it can be of static, conditional or time-dependent. The constraints of the motion are directly affected by all these intersections or obstacles as the models need to differentiate between stoppages due to red lights and due to heavy traffic.

h) **Trip motion-** A trip is defined as the set of initial and destination point in the urban scenario. Different drivers use different paths to reach the same destination according to their own interest.

i) **External influence-** Some of the mobility patterns are externally influenced, so they are not configured by vehicular mobility models. Communication system provides primary sources of information about these external influences. Development of modern mobility generator is classified into four different classes: 1) Synthetic models. 2) Traffic Simulators-based models. 3) Survey-based models. 4) Trace- based models. Synthetic models help to develop mathematical models reflecting a realistic physical effect, but lacks to provide realism towards human behavior. To validate a mathematical model it is compared with real mobility. Traffic Simulator-based models are realistic traffic simulators, used to model urban scenario traffic, energy consumption and monitoring of noise level. Survey based-models are used to develop models based on surveys from a number of research areas. Trace-based models save the time to validate the mobility models by directly extracting generic mobility patterns from movement traces.

3.1. Existing Mobility Generators

Various simulation software exists and are considered as a pillar for evaluation and validation of various applications. Some of them are explained below:-

a) VanetMobiSim It is open source and freely distributed and based on CANU vehicular mobility generator (CanuMobiSim). VanetMobiSim produces detailed traces of vehicular movement and realistic models of automotive motion at both macroscopic and microscopic levels. It is designed such that it can be integrated with network simulators and through customizable scenario simulates different traffic conditions. The mobility patterns are validated by recreating distinctive vehicular mobility effects. The limitation of CanuMobiSim is reduced by VanetMobiSim by providing a higher degree of realism. It has all features which are necessary to provide realistic vehicular mobility modeling such as integration of Voronoi topologies and TIGER maps, intersection modeling, overtaking capabilities, traffic light management, a complete road topology characterization and MOBIL mobility models. It is a discrete event simulator based on JAVA, supporting various simulations and emulation tools like GloMoSim, NS-2, QualNet, etc.

b) SUMO (Simulation of Urban Mobility) It was developed by the Institute of Transportation Systems at the German Aerospace Center. It is also open source, portable traffic simulator and handle large network. It uses a microscopic traffic simulation package. Each vehicle is uniquely defined with unique path and identification number. Its features include multi-lane streets with lane changing, hierarchy of junction types, an open graphical user interface, collision free vehicle movement and dynamic routing. SUMO requires network file for simulation. Combining SUMO with openstreetmap.org help to simulate traffic of different locations of the globe. SUMO generates traces that cannot be directly used by the network simulator as it is a pure traffic generator, which is the biggest limitation of SUMO.

c) MOVE (Mobility model generator for Vehicular networks) It generates mobility patterns for VANET simulation more rapidly than SUMO. It generates realistic mobility trace file as output, which can be directly used by the network simulator such as NS-2. It also provides user with GUI to generate realistic simulation scenarios without any difficulty of learning about internal details and writing simulation scripts.

d) FreeSim: It is a traffic simulator by which the freeway systems are represented. They are implemented with the help of graphs and the weights of the edges of graphs are initialized with the speed of the vehicles in the network. Entire network are executed by the traffic or graph algorithms created by the simulator. It uses traffic data which are either given by the users of the network or by the organizations that are monitoring the network. It effectively helps the vehicles in communicating with the vehicles as well as with the infrastructure after monitoring the traffic.

e) STRAW (STreet RAndom Waypoint) provides accurate simulation results using the vehicular mobility model for US cities. Its implementation is written for JiST/SWANS event simulator and part of the Car-to-Car Cooperation Project. It limits its mobility, according to vehicular congestion and simplified traffic control mechanisms.

f) City Mob The simulator, which is particularly designed to investigate different mobility models present in VANETs and their impact on inter-vehicle communication performance. It is compatible with a NS-2 network simulator to simulate VANETs. CityMob prevents accidents or traffic jams in urban areas by simulating damaged cars to send information across the network to other neighboring vehicles. It implements 3 different mobility models. They are:- a) Simple Model (SM) b) Manhattan Model (MM) c) realistic Downtown Model (DM). In SM model, vertical and horizontal mobility patterns are created. In MM model, city is represented as a Manhattan style grid, with uniform block across simulation area. The DM model adds traffic density to Manhattan model. In town, traffic is not uniformly distributed everywhere there are various areas with higher traffic density and these areas are in the downtown, the vehicles move slowly in the outskirts. Both Simple and Manhattan are similar in behavior, but propagation of packet is faster in Manhattan. The downtown model provides more realistic mobility pattern than simple and Manhattan.

3.2. Qualitative Comparison of Mobility Generators

In this article we have compared the simulators according to five different categories: a) software characteristics, b) maps types, c) mobility models supported, e) traffic models implemented, and e) trace formats supported. As given in table, none of the simulator satisfied all the capabilities as desired by the researchers. FreeSIM provides good software characteristics, but City Mob is good in both software features and traffic model supported. Only, VanetMobiSim provides excellent trace support.

4. NETWORK SIMULATORS

Network Simulators are used to model the real world network. Users fulfilled their analysis need by customizing the simulator. The system can be modeled; its features can be changed easily in the simulator. The cost of model modification is relatively cheaper than real implementation, a wide variety of scenarios are easily deployed. They are also used to measure performance parameters like delay, bandwidth, throughput, packet loss ratio and speed. Network simulators are either commercial or open source and simple or complex. Example of commercial are: OPNET, QualNet, etc. Open source are: NS-2, NS3, OMNeT++, etc. Complex network simulator allow users to specify the protocols which process the network traffic, whereas simple ones define network topology, nodes present on the network, links between them and the traffic between the nodes.

4.1. Existing Network Simulators

a) NS-2 (Network Simulator) It is based on a REAL network simulator. It is event driven open source network simulator originally developed at the University of California-Berkely. NS-2 is programmed in C++ and OTcl (a Tcl script language with object-oriented extensions developed at MIT). NS-2 has a special feature of separating control path implementation from the data path. Both C++ and OTcl has its own advantages to be used in NS-2. C++ helps in implementing routing protocol in the network and OTcl helps user to control the simulation scenario and customize it according to the analysis needs. OTcl script schedules the event, set up the network topology and tells the traffic from the source when to start and stop through event scheduler. NS-2 scales well for only few numbers of nodesand its quality of simulation degrades in physical layer due to the dynamic nature of VANET. NS-2 has come with its newest version as NS3. NS3 is also open source event driven simulator used for educational and research purpose. Its main features are:- C++ programs and python scripting, software integration, support virtualization and testbed integration, alignment with real systems and attention to realism. NS3 is still in the development process with limitations which needs to be solved.

b) GloMoSim (Global Mobile Information System Simulator) This simulator is used to simulate large wired and wireless network. It uses parallel discrete event simulation capabilities provided by Parsec [C based simulation language]. GloMoSim has features like: Supports protocols used in wireless networks, built according to OSI layered approach, supports parallelization, GUI can be customized and used for real-time simulation. It supports two models of node mobility, nodes move according to model random way point model and random drunken model.

c) SNS (Staged Network Simulator) Traditional network simulator performs various redundant computations within a single simulation run which makes them slower and they repeatedly recompute node positions every time node change their position. To eliminate this limitation and improve the performance of wireless network simulators,a technique called stage simulation was proposed. Stage simulation removes the redundant computation through function caching and reuse.

The basic function of staging is to store the results of expensive operations and reuse whenever required. A staged simulator is built based on NS-2 called as SNS, it is 50 times faster than NS-2. Due to its level of performance, it is used to simulate large network with more than 10,000 nodes in an hour. It depends on function caching along with three processes, namely currying, auxiliary result computation and time-shifting to restructured events in simulator and simulator and allow function caching to work effectively.

	TraNS	GrooveNet	NCTUns	MobiReal
Mobility generator	SUMO	GrooveNet	NCTUns	MobiReal
Network Simulator	Ns-2	----	----	------
Mobility Model	Random and manual	Random Waypoint, Expicit origin-destination	Random Waypoint	probabilistic rule-based
Simulation Type	Macroscopic	Microscopic	Microscopic	Macroscopic
Lane Model	Multi-lane	Multi-lane	Multi-lane	Multi-lane
Speed Model	Street Speed	Uniform, Street Speed Markov Model, Load based	Random	Street Speed
Traffic Flow Model	Car following	Car following	Car following	Car following
Road Topology	Any	Any	User Defined	Any
Traffic Lights	Manually Defined	Manually Defined	Automatically Generated on Intersections	Manually Defined
Intersection Model	Junction-based Right-of-way rules	Managed by traffic lights	Managed by traffic lights	right-of-way rules and managed by traffic lights
Trip Model	Random, Manually defined	Djikstra, sightseeing	Manuallly defined	Manuallly defined
VANET built-in Application Support	Dymanic re-route and road danger warning	Adaptive re-broadcast and vehicle warning	-----	-----
Ease of Setup	Moderate	Moderate	Hard	Easy
Ease of Use	Moderate	Hard	Hard	Hard
Comments	Integrates both traffic and network simulator	Supports hybrid Simulations	Supports Seamless integration of emulation and simulation.	Simulates realistic Mobility of human cars

Table 1. VANET simulators Comparison

d) JiST/SWANS JiST is event driven, high performance simulation engine running over JAVA virtual machine. JiST converts virtual machine to simulation platform. SWANS (Scalable Wireless Ad Hoc Network Simulator) built atop the JiST platform. It is similar to NS-2 and GloMoSim. It consists of various components capable of implementing different types of applications like networking, routing, radio transmission and reception. It is highly efficient than other existing and traditional tools. It provides high simulation throughput, saves memory and run standard JAVA applications.

4.2. Comparison of Network Simulators

In Table 2, we present the characteristics of the studied network simulators for VANETs. Among all, NS-2 is the most popular and readily used, but not suitable for simulating large networks unlike SNS or JiST/SWANS. All the simulators are freely available over the internet. JiST/SWAN is difficult to install. These simulators lack in considering vehicular traffic flow models, 802.11p MAC, road topologies and obstacles.

5. VANET SIMULATORS

Both Traffic and Network simulator work independently and none of them provide a complete environment to simulate VANET. VANET simulators allow these two simulators to interact with each other. Traffic and Network simulator cannot interoperate due to mismatch in formats. For example- NS-2 cannot interpret trace files from traffic simulator.

5.1. Existing VANET Simulators

a) Trainees' (Traffic and Network Simulation Environment) It is a simulation environment written in JAVA and C++ and works under Linux and Windows. It uses visualization tool to support SUMO and NS-2 to simulate VANET. SUMO translates the traffic file so that it can be used by network simulator NS-2 to some dump file. TranNS Lite is a stepped down version of TraNS used for generating a mobility model without the support of integrating with network simulator. TraNS Lite is a scalable software supporting simulation of up to 3,000 nodes and extracts mobility traces using Shapefile. TraNS is unable to send the output from NS-2 back to SUMO which makes the two loosely coupled simulators to produce results as that of real life examples. Main features of TraNS are: a) provides mobility trace generation to NS-2 from Shapefile maps. b) Generation of random and flow-based vehicle routes. c) provides simulation on large scale basis upto 10,000 nodes. d) Framework for developing new VANET applications. e) Helps to simulate road traffic events e.g.- accidents. f) TraCI interface provides SUMO and NS-2 coupling. g) It provides two ready-to-use VANET applications:

a)Road Danger Warning (safety) and b) Dynamic Reroute (traffic efficiency). It influences the vehicle behavior in the mobility model using the information exchanged in VANET.

b) GrooveNet It is an open source hybrid VANET simulator capable of integrating traffic as well as network simulator. It allows communication between simulated and real vehicles. It supports correctness, rapid development, testing of vehicular network protocols, and prototyping of test-beds for multi-hop communication on the road. It also supports simulations of multiple-channels and standards-based DSRC (Dedicated Short Range Communication). It has following features: a) GrooveNet is event based simulator with model interfaces, making it easy to add new models without concerning about the conflicts with existing models as dependencies areresolved automatically. b) It supports three different types of simulated nodes: vehicles capable of multi-hoping data over more than one DSRC channels, fixed infrastructure nodes and mobile gateways capable of inter vehicle and vehicle-infrastructure communication. c) Provides multiple network interfaces for inter vehicle and vehicle-infrastructure communication such as IEEE 802.11a/b/g, EVDO cellular interfaces, etc. d) It support hybrid simulation where vehicle position, its direction is broadcast over the cellular interface from one or more infrastructure nodes. e) It is able to connect to vehicle's on- board computer. f) GrooveNet supports emergency, warning messages and GPS messages which are periodically broadcasted to inform vehicles about accidents, vehicle current position and emergency situation. It is implemented in C++ and Qt graphics. GrooveNet is composed of Model life cycle, Network abstraction layer, Network visualization and Modular architecture.

c) NCTUns (National Chiao Tung University Network Simulator) It is Linux based simulator used to execute real world applications without any modifications. It is open source software with highly integrated Graphical User Interface and event based simulator. It is implemented using C++ and runs in Fedora Linux. It acts as both simulator and emulator. To support remote and concurrent simulation, NCTUns uses a distributed architecture divided into seven components mainly,

1)GUI operating environment- GUI allows user to edit the network topology, specify mobile node paths, etc. The user can schedule between multiple simulation jobs. 2) Simulation Engine- It functions like small operating system. The simulation engine is combined with various protocol modules to form a single user-level program called as simulationserver. Only one simulation server run at a time on a single machine as it consumes a lot of kernel resources. 3) Protocol Module and Job Dispatcher- Protocol module helps to implement layers of the protocol stack. It consists of set of functions which is compiled by the simulation engine to create a simulation server. Inside the simulation server, multiple protocol modules form a protocol stack. Job Dispatcher is a user level program to control concurrent simulation on multiple simulation machines. If all machines are busy then jobs are queued which are managed by dispatcher as a background job. 4) Coordinator – User level program presents in a machine where the simulation server exists. It informs job dispatcher whether the machine is working or not. When the coordinator receives jobs from dispatcher it executes simulation server to simulate the specified network and protocols. 5) Kernel Modification- As the name suggests modifies the kernel so that the simulation server can correctly run in the machine. It automatically performs UDP/TCP port mappings between port number specified in simulation user and port number used in the kernel.

6) User-Level Daemon and Real-World Application Program – User-Level daemons executes simulation jobs at user level, whereas Real-World application program generates, configure and monitor network traffic. 7) Parallel, Concurrent and Remote Simulations- To increase total simulation throughput, multiple machines serve multiple simulation jobs.

d) MobiREAL It is primarily designed to provide realistic mobility models of nodes. It depicts real movement and behavior of nodes in mobile ad-hoc network simulation. To represent the movement or behavior of nodes, MobiREAL uses rule-based model. Each node is assigned into a group, and each group is specified by the dynamic and realistic behavior of its nodes. It is composed of two components called MobiREAL behavior simulator simulating behavior of nodes and the MobiREAL network simulator simulating data exchanged between mobile nodes. The network simulator and behavior simulator are two different programs periodically exchanging information through TCP channel.

5.2. Comparison of VANET Simulators

VANET simulators that join scalable vehicular mobility models descriptions and the network stack protocols, modeling in a single tool. Table III describes the comparison between studying VANET simulators. All VANET simulators provide different result, while simulating similar scenarios because all were developed with different focus. TraNS and GrooveNet were designed primarily for VANET simulation, but MobiREAL was designed for simulating MANETs, recently enhanced to support VANET simulation. TraNS and NCTUns supports 802.11p implementation and GrooveNet and TraNS provide built-in VANET applications. All simulators provide microscopic traffic simulation and support different mobility models. NCTUns is hard to setup and TraNS and GrooveNet are mostly preferred.

	ns-2	GloMoSim	JiST/SWANS	SNS
Software				
Portability	✓	✓	✓	✓
Freeware	✓	✓	✓	✓
Opensource	✓	✓	✓	✓
Available examples	✓	✓	✓	✓
Continuous development	✓	×	✓	×
Large networks	×	✓	✓	✓
Console	✓	✓	✓	✓
GUI	✓	✓	✓	✓
Scalability	Poor	High	High	High
Ease of setup	Easy	Moderate	Hard	Easy
Ease of use	Hard	Hard	Hard	Hard
VANET				
802.11p	Only for ns-2.33	×	×	×
Obstacles	×	×	×	×
Vehicular traffic flow model	×	×	×	×

Table II. A Comparison of the Studied Network Simulators

6. CONCLUSION

VANET is the newly developed wireless technology with the increasing popularity and attention among the researchers. In this paper, we make a survey of freely and publicly available network simulators, VANET simulators and mobility generators. The mobility generators include VanetMobiSim, STRAW, SUMO, MOVE, CityMob and FreeSIM. All the simulators have different advantages and disadvantages. Among the network simulators studied, NS-2, GloMoSim, JiST/SWANS, and SNS all exhibit good software support. Nonetheless, both NS-2 and GloMoSim are poor in scalability while JiST/SWANS is harder to apply than others. In fact, all network simulators do not specifically address VANET scenarios and requirements, such as the consideration of 802.11p, obstacles, vehicular traffic flow, etc. Lastly, in terms of VANET simulators, we studied TraNS, GrooveNet, NCTUns, and MobiREAL. TraNS and MobiREAL both involve the coupling of a VANET mobility generator with a network simulator. GrooveNet and NCTUns, however, are self-contained simulators with GrooveNet capable of supporting hybrid simulations, i.e., communications between simulated vehicles and real vehicles.

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