A Comparative Study of VANET Simulators

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October 27, 2024

Introduction

Vehicular ad-hoc networks (VANETs) enable inter-vehicle communication (IVC) and road traffic simulations. The applications for such technology include accident and traffic jam detection and avoidance, optimized route planning and advanced safety features such as vehicular distance measurements. More cars today are shipped with installed sensor packages and communication hardware in part so they are equipped to use anticipated large-scale vehicle networks.

VANET Simulators

The deployment and testing of VANETs in the real world is both incredibly expensive and labor intensive. Alternatively the use of simulation is a much more cost effective substitute that can be used to test this technology prior to vehicle testing and commercial release. Therefore it is very important that these simulation frameworks are accurate to current technological advancements.

Background

Traffic congestion in urban areas has increased in recent years, a trend exacerbated as employees return to the office during the transition away from COVID-era work from home policies. This is accompanied by a growing number and variety of autonomous vehicles operating in an increasing number of metropolitan areas. These two forces represent some of the most significant motivation spurring the development of vehicular traffic simulations and communication networks. The goals of such systems include mitigating congestion through the communication of road conditions and notification of accidents allowing the implementation of alternate routes when needed, accident avoidance through the use of distance measuring, alerts and autonomous intervention such as automatic braking, and a better understanding of how traffic conditions can impact the performance of such vehicular communication networks as measured by network throughput and packet delivery ratio.

The platform upon which such simulations and communication have been developed are called VANETs or vehicular ad-hoc networks. VANETs, based on and considered a subset of MANETs or mobile ad-hoc networks, are designed to both simulate and support vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication where vehicles communicate with road-side units (RSUs) using on-board unit (OBU) devices. Architectures of VANETs can be of either only one type, or can utilize a hybrid approach involving both V2V and V2I communication simultaneously.

VANET routing protocols are divided into two main categories. Topology-based protocols can be either unicast or multicast, and rely on the layout of connections in the network. Topology-based protocols are further divided into two types. Proactive topology-based routing protocols maintain information about the network topology and continuously update that information in routing tables contained in the nodes. Reactive topology-based routing protocols do not continuously maintain this topology information, and instead update routing information only when a source node needs to transmit data packets to a destination node. Geography-based protocols by contrast use the geographic location of nodes obtained using methods such as GPS coordinates to make routing decisions instead of relying on routing tables or route discovery processes.

Simulations

The available literature that reviews the VANET landscape identifies a collection of features which distinguish the capabilities of the various solutions available today. Map quality and accuracy can differ between simulation packages. Some do not support real-world maps while others are capable of importing real-world maps from various sources, and not all are capable of resolving different road traffic densities and different speeds. Only some solutions are capable of representing vehicular acceleration and deceleration while others handle changes in speed as discrete and instantaneous. There are varying degrees of capability of VANETs to model obstacles to signals, such as buildings that may interrupt wireless transmissions, or road-traffic obstacles which can be static like road closures, or complex such as nearby vehicles, and pedestrians. Another feature to consider is whether the VANET is capable of simulating weather, and traffic conditions such as rain, fog, rush hours, weekends and school zones.

VANET simulations typically employ mobility traces generated by real-world experiments or dedicated road traffic simulators which are typically created offline to aid network simulation performance. However, as cited in the Sommer et al paper, the major drawback to using such offline mobility traces is that they only model the effect of road traffic on network traffic, and cannot demonstrate any effect network traffic might have on road traffic. In response to this limitation, more complex simulation techniques which include bidirectional coupling between network and road traffic simulations have been developed.

One such bidirectional simulator is the well-established Vehicles in Network Simulation known as Veins which combines two simulators in a convenient package considered easy to install and only moderately difficult to use according to the survey conducted by I. A. Aljabry and G. A. Al-Suhail. Veins integrates the network traffic simulator OMNeT++ with the microscopic road traffic simulator SUMO (Simulation of Urban Mobility) and can support both geography-based and topology-based protocols. The SUMO integration enables the modeling of road vehicles, public transport, and pedestrians. It supports a wide variety of map import formats such as OpenStreetMap, NavTeq MATsim, VISSIM, VISUM, and OpenDRIVE, and can handle tasks such as finding routes, visualizations, and emission calculations.

Applications for which Veins has been used include traffic optimization, safety applications, traffic infrastructure communication, security, and platooning where vehicles autonomously follow a lead car at reduced distance to improve fuel efficiency, and improve traffic flow and safety. One potential drawback to Veins is the increased potential for unreliable results as bugs in either the OMNeT++ or SUMO component can adversely impact data.

Another VANET is Eclipse MOSAIC, an open-source, multi-domain simulation framework that provides users the flexibility of performing vehicle-to-everything (V2X) simulations with simulators of their choosing through the use of management modules which coordinate the simulators with Eclipse MOSAIC. Specifically it uses a federate manager to receive and send data between Eclipse MOSAIC's runtime infrastructure and other simulators, a time manager to synchronize the simulators and the federates and ensure events occur in the correct order, and an interaction manager which enables the exchange of data between federates through a publish-subscribe program. Another benefit to Eclipse MOSAIC is the capability of visualizing data in different ways using a variety of tools which include both 2-D and 3-D visualizers.

A shortcoming of Eclipse MOSAIC in comparison to more established VANETs like Veins is the lack of established research in several areas. According to the VANET simulator review by J. Weber, M. Neves and T. Ferreto, there is no significant research done in the field of software-defined networking (SDN) using Eclipse MOSAIC. SDN uses software applications to centrally control networks and is well-suited to dynamic network environments with a large number of connected devices such as VANETs. In contrast there are several examples cited where Veins is utilized in this field such as supporting SDN controllers working with RSUs to control an entire network, and in the rapid and reliable emergency message dissemination in areas with sparse RSU coverage.

VANETsim is a security-focused microscopic VANET capable of utilizing real-world maps imported from OpenStreetMap, and provides detailed visualizations through a GUI interface. Unfortunately, VANETsim does not have the capability to support 3D environments. It is distributed with several security and privacy modules, and although no longer maintained, has well-documented features and an easy to follow guide according to J. Weber et al. Like Eclipse MOSAIC, there is no available information indicating it can be used to explore SDN applications, and it would be difficult to extend the simulator to support new technology because all its components are directly integrated.

The CIA triad is clearly an important aspect of VANETs, because they represent dynamic environments full of fast-moving vehicles capable of causing severe injury and death, and are of vital importance in urban environments. The three VANET solutions presented in this paper have varying capabilities when it comes to confidentiality, integrity and availability. None of the three are capable of performing encryption and decryption, however Veins and Eclipse MOSAIC allow users to import cryptographic libraries such as Crypto++. VANETsim can only represent whether a message is encrypted through the use of a boolean flag and assumes that attacks cannot break such encryption.

As with encryption, Veins and Eclipse MOSAIC allow users to import integrity services through the use of third-party libraries. VANETsim by contrast uses an intrusion detection system (IDS) which monitors application layer data to detect malicious actors and associated false data in VANETs.

There is less research available concerning the security concept of availability in VANETs, however both Veins and Eclipse MOSAIC are well-suited to work in this area as protocols that implement redundancy need simply be implemented in their network simulators. Additionally, watchdog nodes which monitor the status of other nodes may also be implemented in their network simulators. There is no information available regarding VANETsim's capabilities in this area.

Contributions

To create any valuable contributions to these network simulators the choice of software is paramount in the development process. The VANET environment we considered is as follows:

1. OMNeT++ 5.6.2 is an open source event-based network simulator which has a large amount of pre-established projects and research. This makes it an ideal choice for VANET development.
   a. Veins 5.2 was selected for multiple reasons. Veins is a free/open source project, has direct compatibility with OMNeT++, its feature set is extremely extensive and outcompetes many existing VANET simulators on the market.
   b. SUMO 1.8.0 was chosen because it is a Veins dependent and its compatibility with OpenStreetMaps.
   c. INET 4.2.1 was chosen because it is an open source Veins dependent.

This development stack comes with its own set of difficulties not limited to runtime errors on Windows 10/11 operating systems. However due to its open source nature it remains an ideal choice.

Our project intends to create a VANET simulation of San Antonio downtown that we can use to calculate network throughput and delivered packet ratios.

SUMO 1.8.0

SUMO (Simulation of Urban Mobility) 1.8.0 is a VANET dependency but it is also a standalone mobility simulator. It allows for the modeling of intermodal traffic systems including vehicles, public transport and pedestrians. It is an invaluable tool for a large majority of vehicle simulation related projects and analysis tools. Its synergy with OpenStreetMap makes it perfect for testing real world streets in a closed simulation environment. This makes SUMO a good candidate for traffic forecasting and realistic AI-based simulation.

VANETsim

Eclipse MOSAIC

Conclusion

VANETs represent a mature field of network research spanning decades, and there are a robust variety of solutions and capabilities available. In particular Veins stands out as a framework involved in extensive research and utilizes two well-established simulators for network and road traffic simulations. These characteristics and its open-source nature led our team to select Veins as the framework for implementing a new traffic scenario using an OpenStreetMap of downtown San Antonio to measure the effect of varying traffic densities and speeds on network throughput and delivered packet ratios.

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