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PERFORMANCE EVALUATION OF ROUTING PROTOCOLS USING NS-2 AND REALISTIC TRACES ON DRIVING SIMULATOR

A Thesis

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of

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ABBREVIATIONS

VANET	Vehicular Ad hoc Networks
MANET	Mobile Ad hoc Networks
DSRC	Dedicated Short Range Communication
WAVE	Wireless Access in Vehicular Environment
NHTSA	National Highway Traffic Safety Administration
U.S.DOT	U.S. Department of Transportation
AAA	Association of America
ITS	Intelligent Transportation Systems
EEBL	Emergency electronic brake lights
RWP	Random Way Point
TIGER	Topologically Integrated Geographic Encoding and Referencing
GDF	Geographic Data File
KM	Krauss Model
GM	General Motors Model
IDM	Intelligent Driver Model
IDM-IM	Intelligent Driver Model with Intersection Management
IDM-LC	Intelligent Driver Model with Lane Change
CanuMobiSim	Communication in Ad Hoc Networks for Ubiquitous Computing
NS2	Network Simulator 2
GlomoSim	Global Mobile Information System Simulator
MOVE	MObility model generator for VEhicular networks
SUMO	Simulation of Urban MObility
TraCI	Traffic Control Interface
TraNs	Traffic and Network Simulator

NCTUns	National Chiao Tung University Network Simulator
PDR	Packet Delivery Ratio
OLSR	Optimized Link Sate Routing
DSR	Dynamic Source Routing
AODV	Ad hoc On-Demand Vector routing

ABSTRACT

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With the rapid growth in wireless mobile communication technology, Vehicular Ad-hoc Network (VANET) has emerged as a promising method to effectively solve transportation-related issues. So far, most of researches on VANETs have been conducted with simulations as the real-world experiment is expensive. A core problem affecting the fidelity of simulation is the mobility model employed. In this thesis, a sophisticated traffic simulator capable of generating realistic vehicle traces is introduced. Combined with network simulator NS-2, we used this tool to evaluate the general performance of several routing protocols and studied the impact of intersections on simulation results. We show that static nodes near the intersection tend to become more active in packet delivery with higher transferred throughput.

1. INTRODUCTION

1.1 Background

The evolution of wireless communication technology could be traced back to 19th century to early 20th century, when several great pioneers in scientific area made breakthrough in engineering science. Thirteen years after Hertz discovery in 1888, Guglielmo Marconi successfully transmitted wireless signals across the Atlantic between Poldhu, Cornwall and St. Johns Newfoundland. This unprecedented achievement enlarged the wireless transmission range to 3500 km. Stepping into the 20th century, wireless technology has become the most widely adopted and rapidly developed digital cellular standard. And currently, many applications derived from wireless communication that could save life and energy is now applied in daily human life, which has made wireless communications one of the hottest research topics.

With potential of providing high-speed data transmission and reducing cost, wireless communication technologies are the best candidates for a wide range of applications. Among them, a newly flourished one is Vehicular Ad hoc Networks (VANETs). Ad hoc networks refer to the networks with the absence of central or pre-established infrastructure.

Ad hoc Networks are collection of self-governing mobile nodes [24]. Vehicular Ad hoc Networks is the technology of establishing a mobile network composed of vehicles capable of exchanging information with each other, it stands for a special type of Mobile ad hoc Networks (MANETs). Since the late 1990s, A great deal of efforts have been made in the research area of MANETs, vehicle-to-vehicle (V2V), and vehicle-to-infrastructure (V2I) communications. VANET is one of the most significant areas for the improvement of Intelligent Transportation System (ITS).

In general, the vehicular networks consist of two types of mobile nodes: Vehicles and roadside units. Vehicles equipped with On Board Units (OBU) are able to communicate with each other and Road Side Units (RSUs). RSUs are supposed to be placed at area with high vehicle density. They also play indispensable roles in many scenarios, such as providing Internet gateway. However vehicular networks should not rely on RSUs, as a high number of RSUs will increase the cost of this technology drastically.

The primary motivation for VANETs was to improve driving safety and provide optimized traffic management to avoid congestion by interchanging data in real time. Also, this rapidly emerging technology showed great potentials for Internet access, inter-vehicle gaming, fast-flourishing infotainment industry, and other network-related applications. These features have made VANETs gain a great deal of foci over the past decades. The importance and potential impact of VANETs have been confirmed by the rapid proliferation of consortia involving car manufacturers, various government agencies, and academia.

Each year there are several national and international projects worldwide by government agencies, industry, and university focusing on the improvement and extension of VANET technology. Examples include, among many others, Vehicle Safety Communications Consortium, the Advanced Safety Vehicle Program, the Car2Car Communication Consortium (Europe), Vehicle Infrastructure Integration Program [27], and efforts made on the standardization such as 'WAVE'(Wireless Access in Vehicular Environment), IEEE 802.11p [22].

Automotive manufacturers such as BMW, Toyota, and Ford have also announced the plan to equip their vehicles with more powerful computational capability. Chrysler was among the first manufacturers to integrate access to Internet in some of its 2009 line of products. As this trend continues, the number of vehicles equipped with communication devices and wireless network interfaces will go high dramatically in the near future. These vehicles will be able to run network protocols that by exchanging messages, serve for a safer, and more fluid traffic on the roads.

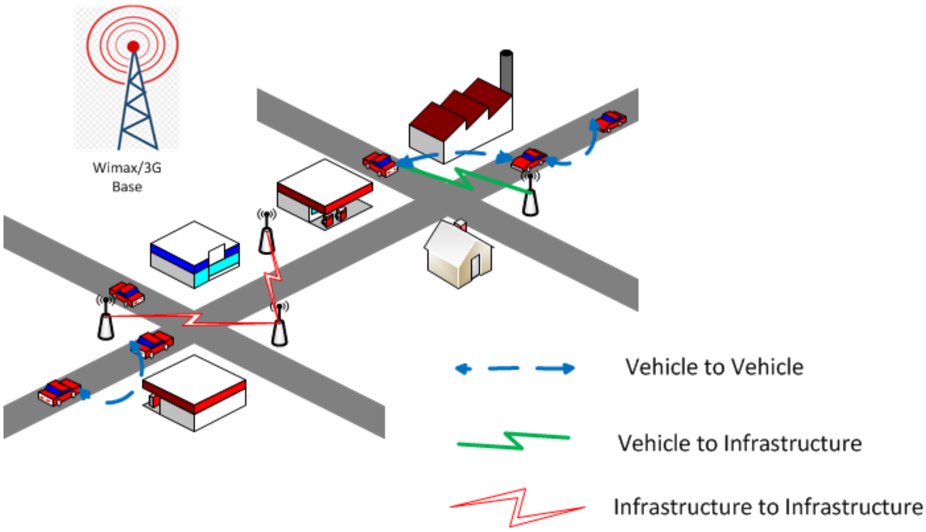


Fig. 1.1. Vehicular networks include two parts: Vehicles and Infrastructures

1.2 Why VANET

Traffic accidents and congestion on the roads nowadays are among the most severe issues in people′s daily life. The safety-related issues kept threatening human lives and traffic congestion consumes tons of resources and time, they are both problems that take tolls on personal life and national property.

A report from the Automobile Association of America (AAA) in 2008 stated that according to the Federal Highway Administration [48], the cost of traffic per person in 2005 is $3.2 million and $68,170 for deaths and injuries respectively. AAA also estimates that traffic crashes each year will cost $166.7 billion, including emergency, medical services, property damage, and productivity loss.

In 2010, more than 30000 people were killed in traffic accidents and more than 2 million people were injured, according to the U.S. Department of Transportation (U.S.DOT) [46]. In 2011, 32,367 people died in car crashes and 2,217,000 people were injured in motor vehicle crashes. An estimation by The National Highway Traffic Safety Administration (NHTSA) [47] claimed that there are about 10 million unreported crashes each year.

Also, a new report from the Texas A&M Transportation Institute claimed that American people spent up to 5.5 billion additional hours sitting in traffic in 2011, and 2.9 billion gallons of gasoline were burned while sitting in traffic congestion.

In order to improve driving safety, there have been several generations of technologies, from passive precautions like seatbelts and airbags that reduce the damage caused by crash to active safety technologies aiming to prevent collisions before they occur.

However passive methods are not so effective against accidents, since in most cases airbags and seatbelts cannot protect drivers and passengers from being injured or even killed in collisions. So the best solution is to give driver the ability to foresee the unsafe situations before accidents take place, in particular, the active safety, using systems with devices such as radar and camera to detect possible hazard and give alarm to drivers or even take over to prevent incidents from happening. Nevertheless, device like radar and camera can only detect collisions in a limited angle, thus possible incidents could still remain undetected in situations like sharp curves or traffic signal violation at intersections. To achieve full awareness of possible accidents, construction of a network that enables vehicles to exchange information is in need.

1.3 VANET applications

1.3.1 Overview

Dedicated Short Range Communication (DSRC) [44] which works in the 5.9 GHz band in the US is specifically designed for applications in vehicular wireless application. The maximum signal range of DSRC is 1000 meters.

DSRC is mainly composed by two types of communications: Vehicle to Vehicle (V2V) or Vehicle Ad-hoc Networks (VANETs) and Vehicle to Infrastructure (V2I). V2V refers to the data exchange among vehicles for safety and other purposes while the communication between vehicles and road-side infrastructures serves as an extension to V2V such as Internet Gateway. However, the V2I part requires long-period hardware construction which costs tremendous expenses and time, as a result this thesis primarily focused on the V2V communication.

Most applications in VANET are based on periodical message exchange, and some safety-related applications also send critical information triggered by emergency. Thus the former is defined as periodical messages and the latter is defined as event-driven messages.

1.3.2 Periodic messages

Depending on the purpose of certain types of applications, they will either require data from sensors or from other vehicles. Hence, periodic messages are sent for awareness of the vicinity and detection of dangerous situations. Each vehicle will include its current speed, position and direction in this type of data exchange. By collection of this information, potential collision or congestion could be evacuated through calculation. Apart from this functionality, there is another type of periodic messages in uni-cast routing known as the Hello messages which is exchanged with regular cycle to detect communication neighbors in the aspect of routing.

Since VANET is a large-scale network, too frequent exchange of periodic messages could lead to the "Broadcast storm problem " [41] and hinder the reception of messages containing critical information.

1.3.3 Event-driven messages

Event-driven messages are sent when emergency occurs. This type of messages needs to be generated and disseminated extremely fast. As a result, event-driven messages are usually assigned with high priority to ensure its correctness and quickness.

1.3.4 Safety-related applications

Current active safety technology is mainly based on single vehicle. The restriction of single-vehicle-based safety technology has been stated above (e.g. the limited detection area). Using DSRC, the V2V-based applications could be categorized into the following parts [29]:

1. *Intersection collision avoidance*
2. *Public safety*
3. *Sign extension*
4. *Vehicle diagnostics and maintenance*
5. *Information from other vehicles*

Table 1.1 describes some of the applications designed for vehicular network, including their function and features. Fig. 1.2 is an illustration of one of the emergency-triggered applications, Emergency Electronic Brake Lights warning.

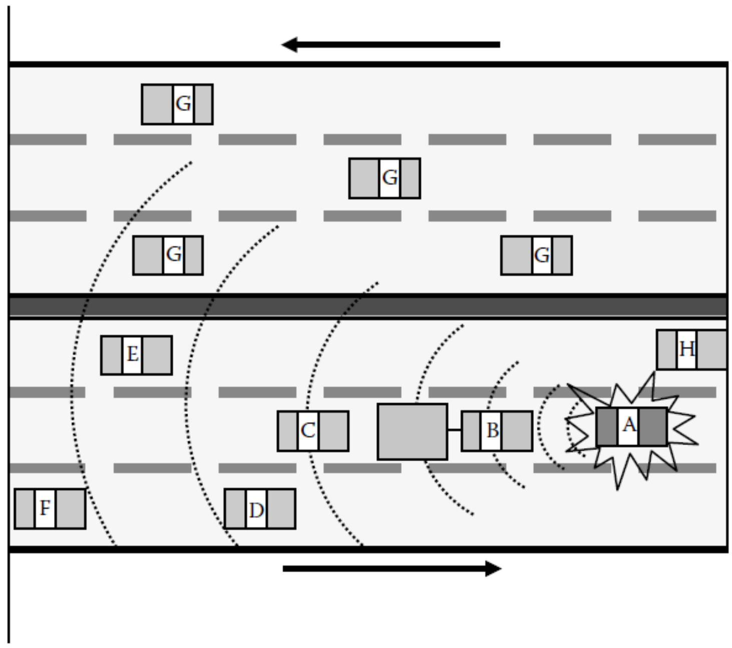


Fig. 1.2. An example of EEBL warning when Vehicle A is braking hard. [29]

Table 1.1: Safety-related applications

Classifications	Applications	Type of Transmission	Data exchanged
Intersection collision avoidance	Stop sign violation warning	Periodic	Directionality, position of the stopping location, weather condition, road and surface type near the stop sign
	Left turn assistant	Periodic	Traffic signal light status, cycle, and direction; road type and intersection information; vehicle position, velocity, and heading
	Intersection Collision Warning	Periodic	
	Traffic signal violation warning	Periodic	Traffic signal light status, cycle, direction, position of the traffic signal location, weather condition, road shape
	Stop sign movement assistance	Periodic	Vehicle speed, location, and direction
Public Safety	Approaching emergency vehicle warning	Event-driven	Emergency vehicle speed, location, lane position, and intended routes

continued on next page

Table 1.1: *continued*

Classifications	Applications	Type of Transmission	Data exchanged
	Emergency vehicle signal preemption	Event-driven	Emergency vehicle position, lane information
	SOS services	Event-driven	Location, vehicle information, and time
	Post-collision warning	Event-driven	vehicle information, collision location
Sign extension	Wrong way driver warning	Periodic	Position, heading, and warning
	Work zone warning	Periodic	Distance to work zone and reduced speed limits
	Curve speed warning	Periodic	Curve location, curve speed limits, bank, and road surface type
Vehicle Diagnostics and Maintenance	Safety recall notice	Event-driven	Safety recall message
Information from Other Vehicles	Cooperative forward collision warning	Periodic	Position, velocity, acceleration, heading, and yaw-rate
	Emergency electronic brake lights	Event-driven	Position, direction, speed, and deceleration

continued on next page

Table 1.1: *continued*

Classifications	Applications	Type of Transmission	Data exchanged
	Lane change warning	Periodic	Lane position, speed, direction, and acceleration
	Blind spot warning	Periodic	Speed, position, direction, acceleration, and warning for detection of vehicle at blind spot

1.4 Thesis contributions

The focus of this thesis is a systematic analysis of VANET simulations. By the development of parser between the driving simulator and ns2, the improvement of the mobility models used in VANET simulation is achieved. The main contributions are:

1) The extension of functionality on the driving simulator. The data of driving simulator outputs are well organized with network simulator so that its application in terms of network simulation is made possible.

2) The construction of a simulation platform that is able to generate realistic traffic flow and vehicle movement trace for accurate VANET simulations. By an integral comparison with the state-of-art simulators, the advantage of the proposed simulator is validated.

3) Through protocol testing based on the simulator, some featured effects have been observed which are helpful for further protocol development. These effects require a simulator that can generate highly detailed and accurate traffic trace, hence the importance of a good traffic simulator in VANET simulation is revealed.

2. ROUTING AND BROADCASTING

2.1 Multi-hop communication

Unlike traditional wireless communication, one of the features of ad hoc mobile networks is that nodes aim to send messages to receivers out of the radio range. In order to achieve this function, before reaching the destination, the messages will first go through some intermediate mobile nodes which serve as relays to help forward the data to the intended receiver. And each intermediate node is called a hop, and this type of communication in ad hoc network is defined as multi-hop communication. Hence, when the destination is several hops away from the sender, certain algorithms should be used to find a path to eventually deliver the message. And therefore routing protocol development has become one of the most challenging issues in ad hoc networks.

Same as MANETs, the multi-hop communication is a core component of VANETs as well. As stated in the previous chapters, the applications of VANETs primarily rely on the data exchange: periodic messages for regular environment detection and event-driven messages for some urgent situations. Thus gathering and disseminating information with the help of neighboring vehicles has become an indispensable enabler for many vehicular applications.

As we know, VANET is a subclass of MANET, though their difference mainly lies in the movement pattern and scalability, they still share lots of attribute in terms of ad hot network. Thus, many proposed strategies for routing in MANET could be a good starting point for VANET routing development. For this reason, we will briefly introduce some of relevant routing protocols in MANET and their feasibility.

2.2 Proactive Routing

In proactive routing algorithms, nodes gradually learn the network topology by exchanging messages. Each node originally gathers information to confirm the existence of its one-hop neighbors, and then through information from one-hop neighbors, it continuously learns the neighbor of neighbors over and over again. In this way, routes are established to any destinations in the network and stored in the routing tables.

2.2.1 OLSR

One of proactive routing strategies is Optimized Link State Routing (OLSR) protocol [20] designed by the IETF community. It extends the traditional link state routing with reduction of link state update overhead in ad hoc networks with high node density.

As in proactive routing, nodes sense their neighborhood by periodically exchanging HELLO messages. After the local vicinity is learned and the link state with neighbors are confirmed, the local information is broadcasted via periodic topology control (TC) messages throughout the whole network. Based on these TC messages, each node then stretches its paths to further receivers. Each message is also tagged with sequence number to be distinct with stale information.

However, when the size of network becomes large, the increment of TC messages could become a huge burden of the network. In connection with this issue, the OLSR takes advantage the multi point relay (MPR) technique [33] aiming to reduce the amount of message flooding. The MPR approach requires a node to have known routes to at least 2-hop neighbors. Then, the node selects among its 1-hop neighbors a subset of these neighbors with minimum number of nodes as relays, which still covers the routes to the complete 2-hop neighbors as the same 1-hop neighborhood does. This subset of 1-hop neighbors is defined as the MPR set. If a message is intended to reach the 2-hop neighborhood, only those nodes in the MPR set by the

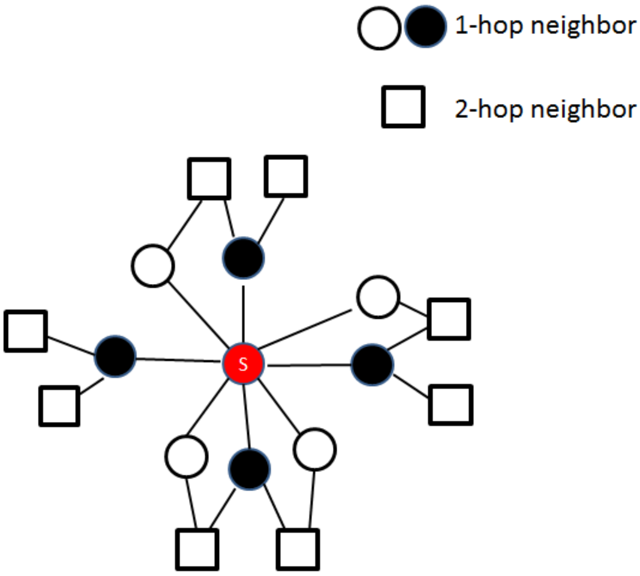


Fig. 2.1. Illustration of the MPR. The MPR set of the source is marked as black nodes. The times of retransmission have been reduced.

source are chosen to forward the message. Fig. 2.1 is an example of how MPR reduces the retransmission.

Obviously, the smaller the size of the MPR sets, the less the times the TC messages need to be forwarded. Unfortunately, the finding the minimal MPR set is known to be a problem of NP-complete [34] complexity level. A greedy heuristic has been proposed in [33] with source node S:

1. Define a set MPR $'$(S) with all the 2-hop neighbors of node S as its elements.

2. If there exist some direct neighbors that the only access to some of the 2-hop neighbors of node S, then include these 1-hop neighbors in the set MPR(S), and correspondingly delete all the 2-hop neighbors covered by these elements in MPR(S).

3. Until MRP$'$(S) is an empty set, keep picking elements out of the 1-hop neighbors of node S left from MPR(S). Always choose the 1-hop neighbors with connections to

the largest number of elements left in MPR′(S) first. In the case of ties, select the 1-hop neighbors with the greatest scale of neighborhood.

Although the OLSR did great improvement in terms of reducing TC messages flooding using the MPRs, the VANETs′ nature of being highly mobile frequently changes the network topology. As a result, the routing overhead issue caused by TC messages still has not been fully resolved despite that the OLSR is one of most successful proactive routing protocols.

2.3 Reactive routing

Reactive routing (also known as on-demand routing) is another mechanism. The main difference from proactive routing is that routes are only created when there is need to transmit messages to destination in reactive routing. Otherwise, the network remains silent.

2.3.1 DSR

A representation for the reactive routing is the Dynamic Source Routing (DSR) protocol [19] made up of two main processes: route discovery and routing maintenance.

When a node needs to send data, it first checks if there already exists a path stored previously. If no routes have been established before, it starts to broadcast route request (RREQ) to nearby nodes. The RREQ messages contain the destination information and are rebroadcasted to further nodes until the destination is found or the maximum count is reached. Those nodes that help forward the RREQ messages also add their own addresses in the route, thus a full path is recorded in the message in this way upon the arrival of RREQ at the intended destination. Then the destination node simply returns a route reply (RREP) using the path stored in the RREQ back to the source. A route is set up after the source successfully receives the RREP. In addition, the route discovery process can easily avoid loop of RREQ forwarding by discarding all the messages that already contained the receivers address.

As a result of the frequent change of network topology, a route could be possibly broken. As part of the route maintenance process, every node within an active route will sense the link state with its 1-hop neighbors through the link layer such as the IEEE802.11 acknowledgement (ACK) [35]. If a link disconnection has been detected, the transmitter will inform all the nodes using this link through route error (RERR) messages. In this case, nodes will use either use an alternative route or begin a new route search.

2.3.2 AODV

Ad hoc On-Demand Distance Vector (AODV) routing protocol [18] is another approach of reactive routing. The route discovery process is similar with that of DSR. AODV makes use of sequence number to indicate the freshness of messages thus avoid RREQ messages loop. Any node in the network will automatically discard the RREQ with lower sequence number.

In general, the reactive routing protocols generates relatively low overhead, however the response time is high because route discovery will take some time before message is sent.

3. ISSUES IN VANET SIMULATION

3.1 Mobility Models

Apparently, the most accurate and persuasive way to test VANET protocols performance is the real-world experiment, but this evaluation implementation does have some inevitable drawbacks:

1) It is neither easy nor cheap to have such a high number of vehicles in real testbed as well as huge amount of drivers required. Under most circumstances, real-world evaluation is infeasible for its most probably unaffordable cost.

2) The performance of VANET protocols vary conspicuously as the road conditions changes. It is though difficult to obtain test field of different characters in reality.

3) Test scenarios cannot be perfectly duplicated over times, thus it is extremely hard to compare between the performances of different protocols in exactly the same condition.

As a result, simulation programs become the only appropriate evaluation tool. The Simulation for VANETs is primarily a combination of two parts: Network communication model and Mobility Model.

The mobility model refers to the node movement pattern in the simulation. It is the only new issue in VANET simulation that significantly differs from MANET. In particular, these differences mainly lie in the following aspects:

1) nodes in VANETs move much faster and speed limit could vary under different circumstances;

2) movement in VANETs is not completely random since it is limited by street layout and also traffic rules. Therefore, in order to develop a more realistic environment for simulation, we need to take into consideration the specific limitations for vehicle movement.

Mobility models used are usually considered from both macroscopic and microscopic view: While from the macroscopic aspects of a mobility model, we intend vehicular movement constraints such as street layout, road characterizations including number of lanes per road, traffic signs established at intersections, and traffic flow attributes involving vehicular density, average speed, etc. For microsopic features, we instead account for individual driver behavior and its interaction with other entities such as vehicle, obstacle and intersections. The microscopic description of mobility models is a decisive factor of generating realistic vehicular traces. A realistic mobility model should contain the following elements [29]:

• *Accurate and realistic street layout*: The road topology used in VANET simulation should include roads that consist of various number of lanes and confine effective area for vehicle movements.

• Intersections governed by traffic signs: Maps should contain intersections which vehicles should be able to recognize and take corresponding reactions. For instance, deceleration upon stop signs are desired and left turn vehicles should give right of way to those going straight without the protected left turn arrows,

• *Lane changing models*: Drivers are not supposed to keep drive in the same manner throughout the course of the entire trip. Instead, lane changing and speed variation should be considered apart from single car-following model.

• *Smooth speed variation*: Since vehicle speed does not stop or start up abruptly, proper deceleration and acceleration values should be accounted for a more natural speed variation.

• *Intelligent driving patterns*: Drivers interact with their environments, not only with respect to static obstacles, but also to dynamic obstacles, such as neighboring cars and pedestrians.

• *Human behaviors*: The driver behaviors should be concerned with humans factors.

• *Non-uniform distribution of vehicles*: The distribution of vehicles in urban are should not be considered as uniform, as the traffic density should vary in different sectors.

• *Different types of vehicles*: Similar with the logic to concern multiple driver models, different types of vehicles present their own attribute in size, speed, acceleration, etc.

• *Effect of the implemented applications*: If the goal of a simulation also includes the part of performance evaluation for some particular applications, then the influence on the mobility pattern from applications should also be accounted. This is especially necessary for routing management related applications as the preferred paths are being changed in real time. This is usually accomplished by a bidirectional coupled simulator, which also allows the feedback from network simulator to the traffic generator part.

3.2 Impact of Mobility Models

Mobility models describe the location of mobile nodes as a function of time in simulation area. Mobility Models in MANETs simulations always consider synthetic models that aim to describe mobility patterns for nodes using mathematic equations. Although a mobility model at a more detailed level will definitely increase the simulation time, the author in [21] still argued that realistic traffic pattern is in need continuously, as it could give a more precise evaluation of VANETs applications and protocols. Indeed, lots papers present that mobility pattern could largely influence the simulation result. From [1] [3] [4] [21] [22], we know the mobility patterns adopted play vital roles in VANETs simulations and directly change the performance of routing protocols.

The performance of routing protocols is compared using different mobility models in terms of delivery ratio, link duration and routing overhead in [1]. Literature [30] showed us the problem of speed decay in which during the first period of simulation time, the node speed could decrease to some long-term steady value, and this could undermine the averaged results over time. And in [3] the author one step further explained the problem and proposed the corresponding solutions to it. And this in turn reflects that the very detailed parts of the node movement patterns in mobile network simulation could affect the simulation result and conclusions to draw.

The relationship between the fidelity of a traffic model and the routing protocols performance is uncertain and complex. This is primarily because, even with the same initial start points and destinations, vehicles tend to move completely with different patterns under different models, and some changes of patterns will improve the simulation results while the rest could result in worse performance on the contrary.

In [4], author systematically studied the impact of a few different types of mobility models on routing protocol performance using the following metrics: Average link duration, delivery ratio (ratio of the number of packets delivered to the number of packets sent) and routing overhead (number of routing control packets sent). According to an integral comparison of routing protocol performance under various mobility models, the author concluded that the movement patterns of nodes in simulations do have influence on performance of routing protocols and there is no clear winner in terms of the metrics used in this thesis. In addition, the author also admitted that the test-suite also has some impact on the performance of routing protocols, which in turn, reflects that although mobility models could make the simulation result different, the relation between them is not easy to define.

Some earlier stochastic models cannot provide an appropriate representation for real-world traffic wave, such as the popular Random Walk Model [16] (also known as Brownian motion) that assumes nodes move continuously without restriction in open area. Random Waypoint Model (RWM) is an extension of the Random Walk Model, added with additional pauses between variations in heading and speed. However the realism of these models in terms of geographical movement is far from being realistic. These models suffer from aggregation of nodes in the central simulation area while vehicle movements can barely be defined as random motion as it is restricted firstly by street bound, and subsequently by traffic rules, individual driving behavior. Detailed studies have been done on the comparison of VANET simulations based on RWM and comparatively realistic traffic models in [5] [8] [9], all these works demonstrate a significant difference of results. The RWM has been modified, for instance in [2] [13] [14][15], to better meet VANETs simulation requirements, however, in these models nodes move in velocity chosen independently from others behaviors, leaving the necessary interactions among them ignored.

In order to tackle these drawbacks, many researchers have developed node movement patterns able to better model realistic traffic. In [11], the author proposed VANETMobiSim, a VANET simulator that integrates increasingly detailed levels of models for urban traffic, namely the Stop Sign Model (SSM), the Probabilistic Traffic Sign Model (PTSM), and the Traffic Light Model (TLM) where the vehicles will stop for certain amount of time at intersections according to specific traffic signs. Also the evaluation of these models shows the impact of node cluster at intersections on the routing protocol performance that the longer vehicles stop at intersections, the higher delivery ratio achieved. There are several literatures [6] [7] applied Social Network Theory on mobility patterns and emphasized the importance of considering interactive effects individual drivers have on each other.

3.3 Classifications of Mobility Models

In simulation of mobile networks, there are primarily two methods of generating movement patterns: Trace and Synthetic Models [28]. Ideally, real-world trace, which refers to position data generated by observation and collection of real-world system movement patterns, is the most convincing data to be integrated in VANETs simulations. Nevertheless, since the VANETs have not yet been fully deployed, so far it is extremely difficult to gather real-world vehicle traces. Hence, lots of the work has been devoting in the area of synthetic modeling.

Synthetic models are characterized by mathematical equations that try to capture the movement of mobile nodes. The advantage of such model is obvious: Having a mathematical model gives a formal description of a mobility model, and by changing parameters in the equations used we can study the details how mobility pattern could affect simulation results. There have been several works [1], [40] that systematically studied and classified the mobility models used in MANETs and VANETs simulations from different perspectives.

Camp et al [1] discussed several Synthetic Models in MANETs. These models could be classified into the following two categories:

(1) Entity Mobility Models: The core of Entity Mobility Model is imitation of natural movement of a single mobile node in the network. Following are some examples of Entity Mobility Models:

- Random Walk Model
- Random Waypoint Model
- Random Direction Model
- A Boundless Simulation Area Model
- Gauss-Markov Model
- A Probabilistic Version of the Random Walk Model
- City Section Model

(2) Group Mobility Models: Group Mobility Models try to mimic the interactions among nodes in a group on the decision where to move. Following are some examples:

- Exponential Correlated Random Model
- Column Mobility Model
- Nomadic Community Mobility Model
- Pursue Mobility Model
- Reference Point Group Mobility Model

In [40], the synthetic models are divided into the 5 main types due to different criteria of traffic patterns:

- Stochastic model: generates motion of entire randomness.

- Traffic Stream model: focuses on the mechanical properties of mobility model.
- Car Following model: vehicle to vehicle interaction within the same lane (speed adjustment).
- Queue model: considers streets as buffers and vehicles enqueued in the buffers.
- Behavioral models: examines how movement is influenced by social interaction.

One of the deadly drawbacks of synthetic models is that the movement behaviors generated are simply unnatural, which has been confirmed by examination of collected real traces in [32].

3.4 Artificial traces

Though real-world vehicle traces are not available in most cases, lots of traffic simulators have been developed to generate artificial vehicle movements. The simulators able to provide vehicle traces include commercial tools such as TSIS-CORSIM (Traffic Software Integrated SystemCCorridor Simulation) [23], VISSIM [24], and PARAMICS [25] and publicly available open-source tool like VanetMobiSim [5], and SUMO (Simulation of Urban Mobility) [26] [27]. These tools could generate comparatively realistic traces based on real-world map from resources such as TIGER (Topologically Integrated Geographic Encoding and Referencing system) database [31], while issues are that some of simulators are not freely accessible and those free tools developed by universities or groups either have limited scenario selection or fidelity in traffic generation. A more detailed comparison will be presented in later chapters.

4. SIMULATOR COMPARISON

4.1 VANET simulator overview

The simulation of VANETs is essentially different from that of MANETs, because apart from the network modeling, it also needs to account for lots of elements of traffic pattern at a detailed level: movement constrained by street layout, interactive driving behavior, and intersection management. Therefore a complete VANET simulator should at least consist of two main components: a network simulator and a traffic simulator. However, traditional MANET simulations usually are more leaning to consider network part and use simple mobility models. Therefore current VANET simulation research has been focusing on development of traffic simulators that could closely imitate real-world traffic flows and the integration with network simulators. Fig. 4.1 listed some VANET simulator developed universities and their structure. This section will introduce some of the freely available simulators and their features and weaknesses by looking into the network and traffic simulator separately. Fig. 4.1 listed some VANET simulator developed universities and their structure.

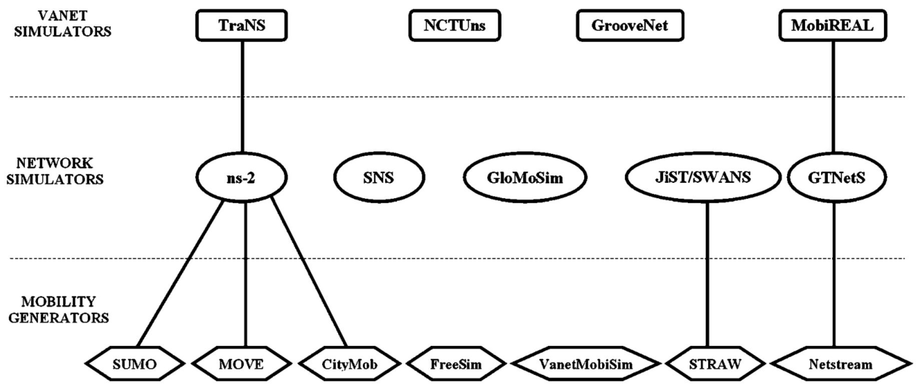


Fig. 4.1. The structure of some VANET simulators [43]

Currently there is no standard regarding what properties simulators should possess to accurately simulate mobile networks under vehicular environments. But in general, as many researchers have been stepping up their effort, a good VANETs simulator should be able to reflect real traffic scenarios as much as possible. There already exist a few VANET simulators, while they can rarely provide a proper simulation environment. Some of traffic simulators are powerful such as the TSIS-CORSIM, VISSIM [24], and PARAMICS [25], but they are not publicly available with a single license of above 9000 USD, plus there is no effort taken to couple them with network simulators. And other traffic simulators suffer from various problems such as unnatural driving behavior and limited interaction with objects and intersections.

4.2 SUMO-based simulator

SUMO (Simulation of Urban Mobility) [26][27] is a widely used open-source mobility generator written in C++ based on the Random Waypoint and the Krauçar-following model. The advantage of this simulator is its integration with TIGER database to generate real-world-based topology. SUMO supports output files with multiple forms to be compatible with various network simulators such as NS-2 [10]. Its input files are nodes.xml with the following information: node id, X coordinate and Y coordinate. The other input file is edges.xml which defines road topology including origin node, destination node, edge ID and number of lanes. Fig. 4.2 gives a detailed description of SUMO structure.

4.2.1 MOVE

MOVE (Mobility model generator for Vehicular networks) [36] is an extension to SUMO based on JAVA. The main contribution of MOVE is providing user-friendly interface that allows user to finish all the configuration procedure by several mouse clicking. MOVE also adds function of Google Earth maps that allows user to define topology with real world information.

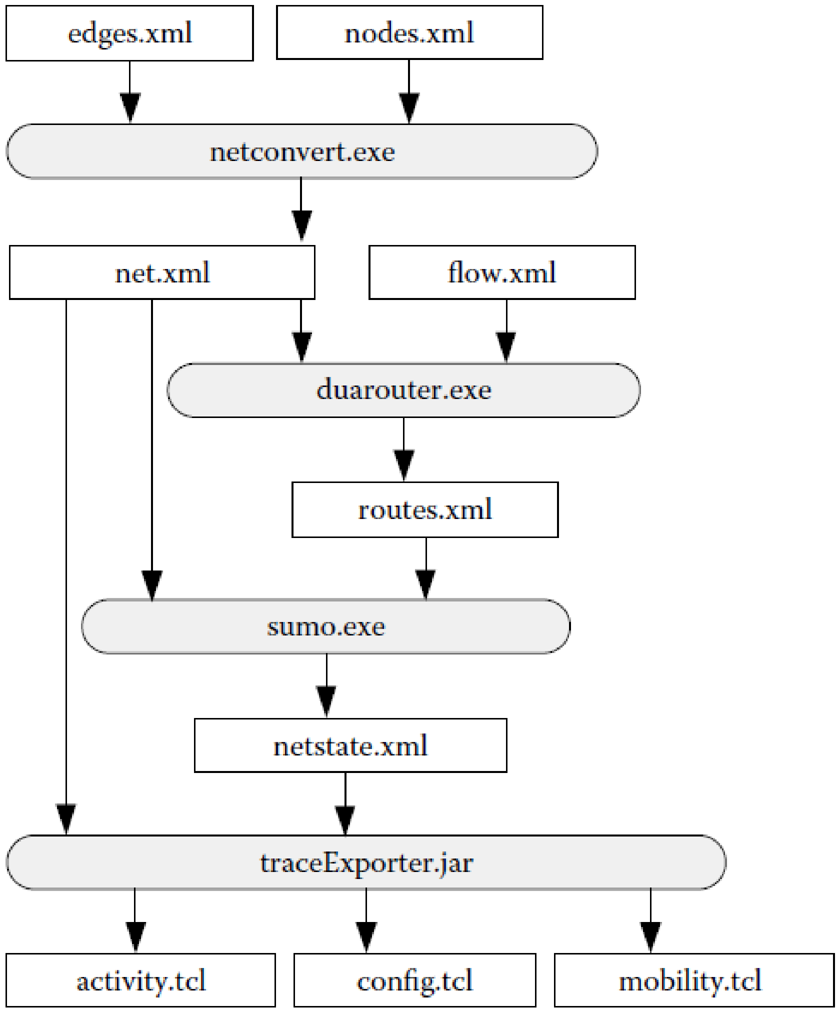


Fig. 4.2. The structure of SUMO [26]

While generating vehicle traces, MOVE accounts for some mircoscopic-level factors such as car-following. However lane-changing and intersection management is completely ignored in this application.

4.2.2 TraNS

TraNS (Traffic and Network Simulation Environment) [36] is a VANET simulator written in JAVA. It is the first effort that combines the network simulator (NS-2) and the traffic simulator (SUMO). TraNS translates the output from SUMO into NS-2 readable form.

TraNS provides two modes: network-centric and application-centric mode. The former does not have bidirectional feedback between network simulator and traffic simulator while the later does. The application-centric mode synchronizes using TraCI (Traffic Control Interface) [37]. MOVE, TraNS and some other SUMO based simulator have made some effort in terms of generating realistic data for VANET simulation from various perspectives. However, since SUMO can only support realistic road topology but lack the ability to simulate naturalistic driving behavior, hence the core issue of VANET simulation still remains unresolved in this series of simulators.

4.3 NCTUns

NCTUns (National Chiao Tung University Network Simulator) [38] is a tightly coupled VANET simulator which allows bidirectional communication between network simulator and traffic simulator. Its first version NCTUns 1.0 was a mere network simulator.

The vehicle movement pattern in NCTUns considers different types of road and vehicle parameters like initial speed, desired speed, initial and maximum acceleration/deceleration, and so on. The main drawback is the network part of this simulator is not validated and the code for vehicle movement is tightly integrated with the network simulation code which makes it difficult to extend.

4.4 VanetMobiSim

VanetMobiSim is an extension to CanuMobiSim [39]. The CanuMobisim is originally designed for MANET simulation use, it is unable to produce high levels of realistic vehicular scenarios as it is mainly based on stochastic mobility models.

VanetMobisim extends CanuMobisim with implementations of IDM-IM (IDM with Intersection Management) and IDM-LC (IDM with Lane Changes) mobility models such that vehicles will behave accordingly in connection with intersections and other drivers. VanetMobisim is one of the most advanced simulators compared with other freely available ones since it has been validated against some commercial traffic generator.

4.5 Summary

This chapter introduces the state-of-art of simulator in VANET research. Though these tools pave the way from MANET to VANET simulation, they still have many weakness hence cannot provide a completely suitable environment for VANET simulation. Table 4.1 gives a summary of features of these simulators.

Table 4.1
VANET simulator features

Features	SUMO/MOVE/TraNs	VanetMobisim	NCTuns
Custom Graphs	Supported	Supported	Supported
Random Graphs	Grid Based	Clustered Voronoi Graphs	SHAPE-File
Graphs from Maps	Topologically Integrated Geographic Encoding and Referencing system (TIGER) database	Geographic Data File (GDF)	Bitmap image
Multilane Graphs	Supported	Supported	Supported
Start/End location	Random	Random	Random
Path	Random Walk	Random Walk	Random Walk
Velocity	Road Dependent	Road Dependent	Road Dependent
Driving Patterns	Car following Model	Car Following Models, Intelligent driver model, extended with Lane Changes (IDM-LC) and Intersection Management (IDM-IM)	
Lane changing	Not supported	MOBIL	Supported

5. SIMULATION SETUP

5.1 Introduction to driving simulator

5.1.1 Comparison with other models

For macro-traffic model, we usually consider the type of roads (one-way or bi-directional), number of lanes, environment (urban, suburban, freeway, etc.), traffic density, and speed limits. However, our simulator uses completely different mechanism to generate traffic flow compared with some relatively advanced simulators at present that also aim to mimic the very detailed part of vehicle movement [11] [42]. Models in these simulators also consider the effect of intersections, but vehicles behave unnaturally (e.g. stop for a prescribed amount of period) though they eventually stop according to traffic rules. Besides, for traffic flows, these simulators usually use probability models for vehicles to randomly choose a direction to go. In our case, we can specify trip for each individual driver, hence there is no random component in our simulation. In other words we control all the details of the test scenarios. As a result, average speed is not as much valid a metric to measure our model. It is simply insufficient to model realistic traffic flow with macroscopic features only.

Nevertheless, the difference could still be found in the traffic density at intersections. Fig. 5.2 describes the vehicle density of Intelligent Driver Model and its extension with Intersection Management. It is already a great progress in terms of driver behavior coordination with traffic rules. From macroscopic view, it gives a perfect representation for realistic traffic flows, from microscopic point of view however, it has several defects:

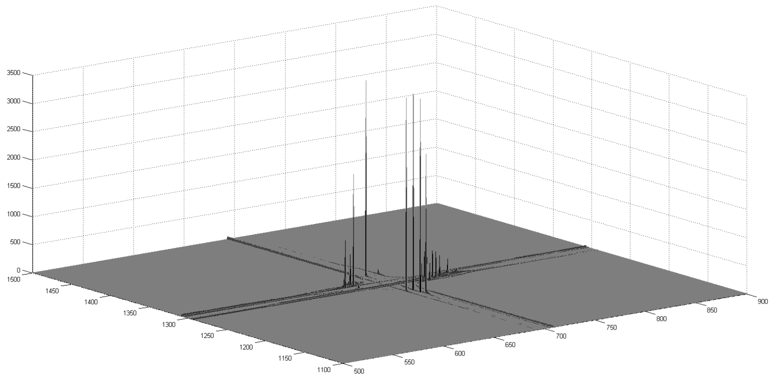
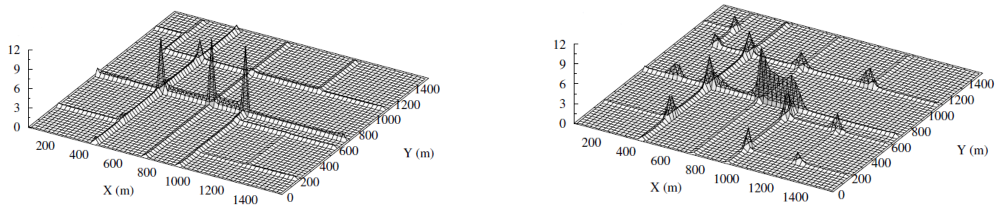


Fig. 5.1. Traffic Density at Intersection



(a) (b)

Fig. 5.2. Vehicular density [11]: (a) IDM model (b) IDM-IM traffic light model

(1) The main problem is that the peak value appears at the center of intersections which is basically unrealistic, because vehicles only stops at the edges of intersections so that traffic density around this area is higher.

(2) The vehicle density on the road apparently should be lower but not completely homogeneous.

Fig. 5.1 gives an example of vehicular density at a intersection in our simulation scenario with pre-defined traffic.

The Microscopic aspect of a traffic model is intended to describe the kinetic characteristics of a particular vehicle. These kinetic factors include acceleration, deceleration, and drivers reaction towards surrounding objects. The micro feature of a traffic model has significant impact on the realism of simulations, as the mobility pattern of nodes could affect the route discovery process, link living time, and thus fundamentally determines if a network could be feasibly supported by a specific routing protocol. For instance, link breaks could take place frequently when nodes are highly mobile. The Intelligent Driver Model (IDM) [12] characterized the dynamics of a particular vehicle as a function of multiple elements including the behavior of the vehicles in front. As a time-continuous car following model, the IDM calculates the instantaneous velocity and acceleration of a vehicle using the following differential equations:

$$\dot{x}_\alpha = \frac{dx_\alpha}{dt} = v_\alpha \tag{5.1}$$

$$\dot{v}_\alpha = \frac{dv_\alpha}{dt} = a(1 - (\frac{v_\alpha}{v_0})^4 - (\frac{s^*(v_\alpha, \Delta v_\alpha)}{s_\alpha})^2) \tag{5.2}$$

$$s^*(v_\alpha, \Delta v_\alpha) = s_0 + v_\alpha T + \frac{v_\alpha \Delta v_\alpha}{2\sqrt{ab}} \tag{5.3}$$

In these equations, x_α and v_α are the position and velocity of vehicle α , s_α and Δv_α are defined as the current distance and velocity difference with vehicle $\alpha - 1$ in front, v_0 stands for the ideal speed the driver desires to drive at, T denotes the safe headway time to the front vehicle and thus s^* is calculated as comfortable distance to keep based on the minimum distance s_0 between two vehicles in a traffic jam.

The IDM is a pure car following model that considers only the adjustment of vehicle speed on the basis of parameters of the front vehicle, this works well with roads with single lane, while in most scenarios (i.e. urban or freeway) roads are more likely to be multi-lanes which makes the lane change possible. Because of this limitation, the IDM was extended with Lane Changes (IDM-LC) and Intersection Management (IDM-IM) in [11] to solve the issues explained above.

However, models like PTSM, TLM, SSM, IDM-IM, and IDM-LC mentioned above did not give a detailed description of the intersection control. In this thesis, we focus on the simulation of interactions between vehicles going straight and those turning left at intersections. In connection to these factors, we use the driving simulator together with the HyperDrive Suite [15] as our mobility generator for its integration of the following components:

Intersection Control: Traffic signs could lead to special vehicle movement features at intersections, because vehicles tend to decelerate and then stop before crossing the intersection given corresponding traffic signals. As a result, the node density at intersections should be much higher and thus provides longer living time for links among this area. In our model, vehicles will slow down with the prescribed deceleration value when approaching the intersection. Fig. 5.3 shows an example of four cars trying to decelerate orderly in the same lane getting close to an intersection. This shows sharp contrast with mobility models used in other traffic simulators as depicted in Fig. 5.4: the intersection is either ignored or the vehicle did not entirely stop.

The status of traffic signal lights could be manually changed by the *Intersection-SetSignalState* command with additional augments specifying the corresponding type, direction and cycle of signal lights to configure.

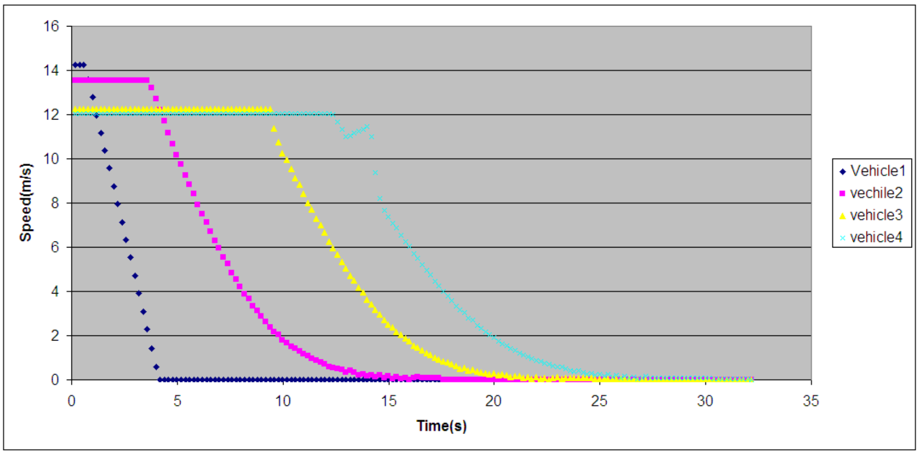


Fig. 5.3. Speed variation of 4 vehicles in a row appoaching red light

In attempt to simulate the traffic lights at intersections, we coordinated the signal controlling traffic flows from different directions. It should be noticed that left turn

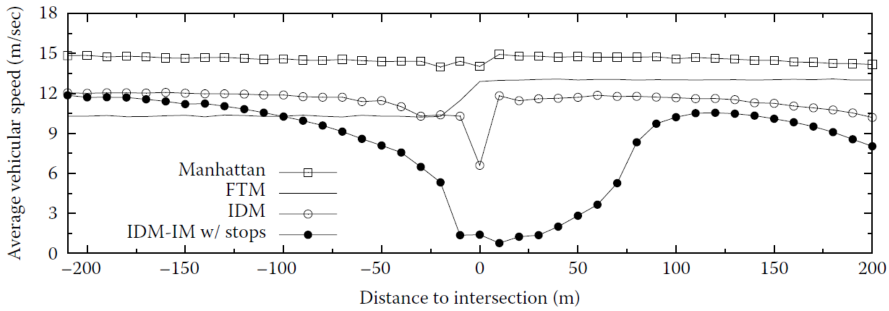


Fig. 5.4. Speed variation of vehicles approaching intersections in other models [29]

signal does not necessarily turn green in each cycle, instead it depends on if there are vehicles stopping at left turn only lanes. We have created some sample scenarios to testify the correctness of the interactions between vehicle movements and traffic signals. Fig. 5.5 illustrates the variation of all 8 traffic lights status from 4 directions with time. In this scenario, we defined some traffic flows crossing the intersection with only one direction (facing west) with vehicles turning left. This explains why only the left turn signal facing west turns green from 40s to around 60s. Fig. 5.6 further describes drivers response approaching this intersection considering the right of way with appropriate acceleration and deceleration actions taken. We may notice that the green arrow gives left turn vehicle the priority.

With these examples we are confident that the logic of driver behavior is strictly according to corresponding traffic signs. By observation of the speed curve showed above, the speed variation is generally natural with proper acceleration and deceleration.

Driving behavior: To better understand the real-world traffic, we need to consider both individual driving behavior and interactions between them. In our work, by default each vehicle placed in the scenario is configured to obey traffic rules such as speed limit and take necessary actions with safety as the first priority.

However, it is though unreflective to assume that all vehicles move with the same pattern as some aggressive driver could take more offensive actions while driving such

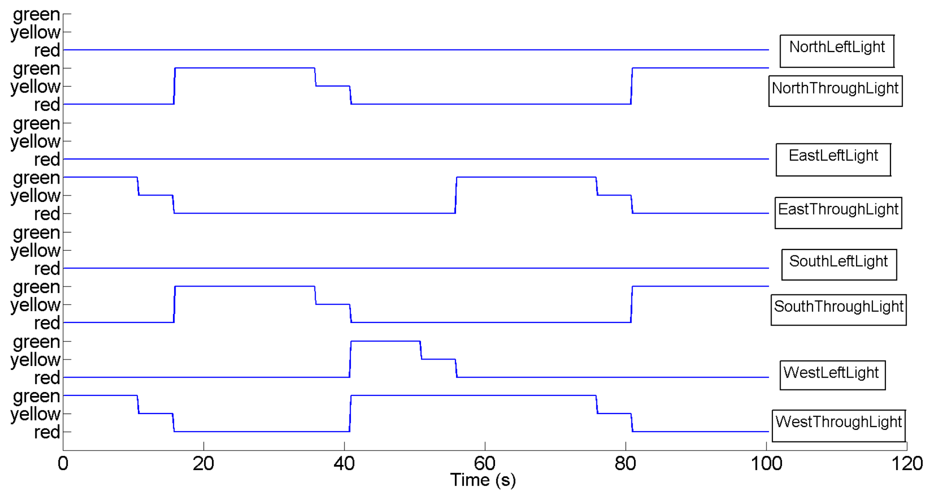


Fig. 5.5. Traffic light signal transition over time

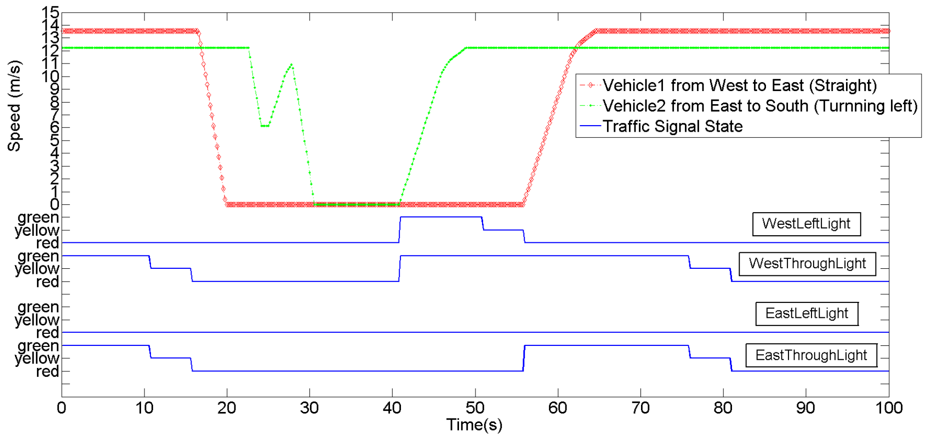


Fig. 5.6. Evolution of vehicle speed from opposite directions where left-turn vehicle has the right of way

as overtake or even traffic sign violation. Regarding this, we change the following characters of driving behavior to define different levels of aggressive driving:

• By *EntityChangeRoadwaySpeed* we increase the speed limit for some of the vehicles, and they will try to overtake when possible.

• Considering some drivers choose to run yellow lights, the *EntityChangeYellow-LightGoTime* is in charge of configuring the threshold time deciding whether the specified vehicle will drive through a yellow light. If the vehicle is specified time or less away from an intersection when the traffic signal turns yellow, then it chooses to cross, otherwise the vehicle will stop as usual.

• In car-following mode, *EntitySetHeadWay* is used to determine the time interval between the target vehicle and the entity in front of it. Additional augments *AnyoneInLane* and *UseLanePosition* specify how the named entity will determine which entity is in front of it. The option *AnyoneInLane*, which is the default behavior, will cause the entity to stay behind anyone in the same lane regardless where in the lane the entities are positioned. The other option, *UseLanePosition* will cause the named entity to ignore entities that are not directly in front of it based on the lane offsets and vehicle widths.

• When turning left without the right of way, the *EntitySetLeftTurnGap* makes vehicles to wait for a gap in seconds of the specified size or larger before making a turn.

• The *EntityIgnoreIntersectionControl* command causes the named vehicle to ignore all intersection controls, such as traffic lights and stop signs. Neither will the vehicle check for other vehicles entering the intersection.

5.1.2 Architecture

In this section, we primarily introduce our method to create scenario and trace vehicle movement. Our simulation platform is composed of two parts: Driving simulator as our mobility generator and NS-2 as network simulator. The general architecture is shown in Fig. 5.7 The driving simulator with HyperDrive Suite is implemented with Tool Command Language (TCL). The construction of scenarios includes the following procedures:

• Authoring: The user defines the virtual world and all components that will enable the driving scenarios. This includes specification of the roadway network, traffic control devices, and events to be encountered as the scenario going on. Scripts

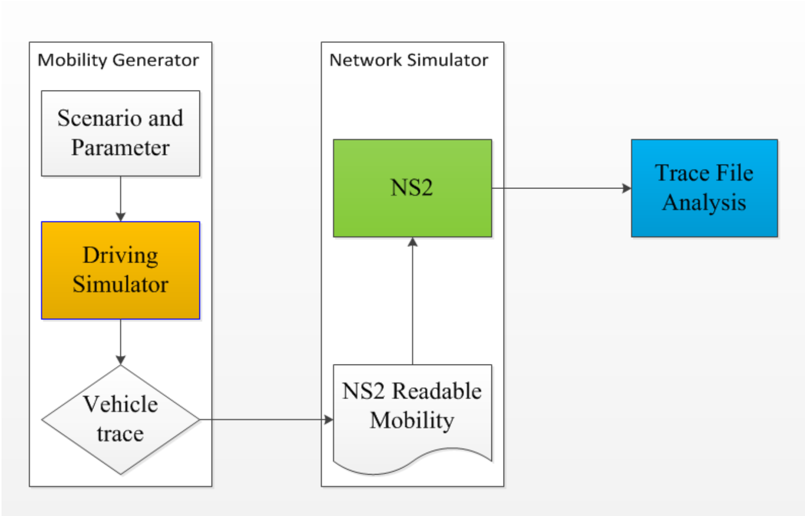


Fig. 5.7. Architecture of proposed simulation platform

are developed to control the logic for how the entities and scenario elements combine to produce a realistic and interactive driving environment.

• Running: The driving simulator as a subject vehicle also participates in each run of scenarios. During this session, the predefined data will be collected in real time. In our case, we are more interested in the vehicle position and speed information.

• Reviewing: Our traffic simulator supports a powerful data recording system. Multiple elements including vehicle speed, heading, acceleration, lane number, lane offset, and position could be recorded in real time with specified frequency. After the scenario ends, all the selected elements will be recorded in the data file. In our case we are more interested in the vehicle trace, thus we choose the X, Y coordinates of each vehicle in the simulation as output in 30Hz frequency.

The completion of a test scenario includes the following steps:

1) Creating Road Topology:

We build up the road topology by choosing tiles provided by the map editor shown in Fig. 5.8 and then putting them together. A roadway tile is a square area with the street layout inside. The library of HyperDrive Suite contains over 400 tiles, each with

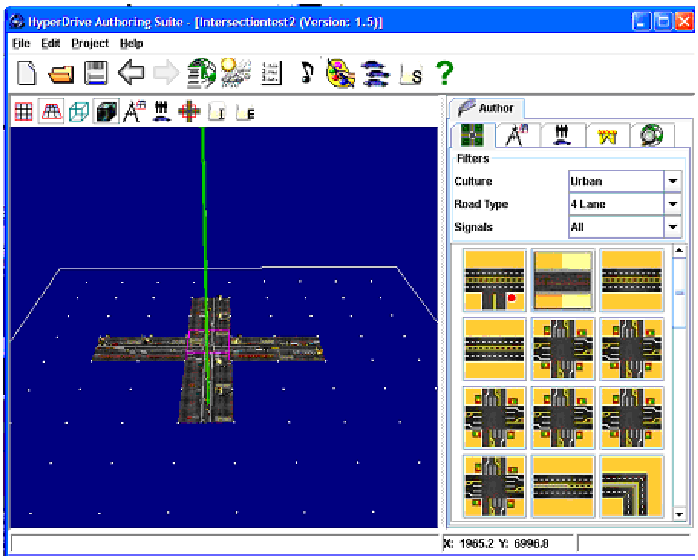
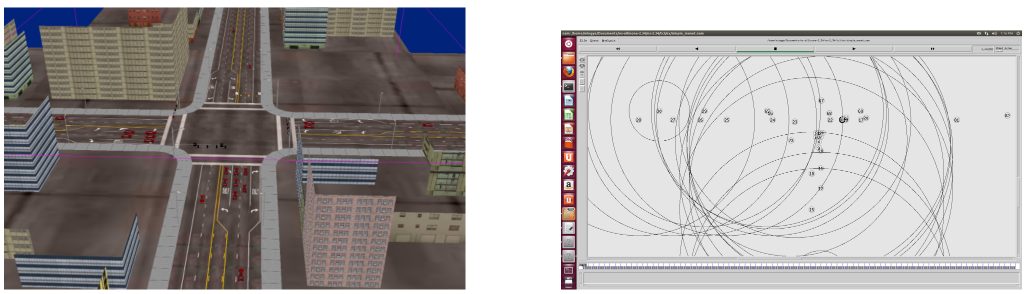


Fig. 5.8. Map editor of HyperDrive

varying environment cultures (rural, urban, freeway, etc.) and road types defined by number of lanes and traffic signals at intersections.

2) Encountered Events and Vehicle Movement:

The concept Trigger is used to define events taking place in scenarios in terms of time and space. For instance, when specified vehicle reaches certain location then events such as a pedestrian crossing street or traffic signal altering could be activated.



(a) (b)

Fig. 5.9. Visualization of traffic scenario and network animator with movement traces imported: (a) HyperDrive. (b) NAM.

As with vehicle movement, we can manually place vehicles at any position on the roadway as start point or use trigger to specify the time and location for a vehicle to appear. We then use corresponding commands to define their behavior. In particular we can specify the destinations or even the paths they will take.

5.2 Simulation

Our experiment is based on ns version 2.34. We evaluated the performance of Adhoc On-Demand Distance Vector Routing (AODV), Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR) protocols. For mobility trace, we collect position data of all 80 vehicles in 30Hz frequency to ensure the replication of vehicle traces and then use MATLAB to convert them into NS-2 readable format. A snap shot of the animation of our simulation is given in Fig. 5.9 (b) using network animator (NAM). We used the Two-ray Ground Reflection model as our radio wave propagation model. The Two-ray Ground Reflection model [45] considers possible reflection via ground and predicts the received power P_r at distance d with the following equation:

$$P_r = \frac{P_t G_t G_r h_t^2 h_r^2}{d^2 L} \tag{5.4}$$

Where h_t and h_r stand for the heights of the transmit and receive antennas in meters respectively.

For each simulation with different number of traffic sources, we generate random numbers as nodes IDs for traffic sources and destinations. However for different routing protocols we use the same set of generated traffic sources for equilibrium purpose. Table 5.1 gives a summarization of some other parameters we set for our simulations.

We tested 80 vehicles with fixed initial positions and destinations crossing 4 neighbor intersections controlled by traffic lights in a 2000 by 2000 area. The intersections are equally distributed with 600 meters distance to each other. Most of the nodes in the network are set to obey the speed limit, with other driving behaviors (left turn

Table 5.1
Wireless simulation parameters

Network Simulator	NS-2.34
Routing protocols	AODV, DSR, OLSR
Simulation time	80s
Simulation area	2000m 2000m
Number of nodes	80
Number of traffic sources	5,10,15,20,25,30 (Randomly selected)
Data type	UDP/ Constant byte rate
Packet size	512 bytes
Send Rate	4 packets/s
MAC IEEE	802.11
Transmission range	250m
Propagation Model	Two-ray Ground

Table 5.2
Traffic scenario parameters

Speed Limit	35 mlies/hour
Vehicle Yellow lights Go Time	1.5s
Vehicle Safe Headway	2s
Vehicle Left Turn Gap	7s
Vehicle Lane Change Headway	3s
Maximum Acceleration/Deceleration	3m/s^2
Intersection Traffic Light Cycle	65s
Yellow light interval	3s
Vehicle Yellow lights Go Time	1.5s

gap, yellow light rushing time, headway, etc.) specified in Table 5.2. We randomly picked 10 out of 80 vehicles with modified driving parameters to simulate aggressive drivers.

6. RESULT ANALYSIS

6.1 Evaluation metrics

In order to compare and analyze the performance of routing protocols, we use Packet Delivery Ratio (PDR), Average Packet Delay and end-to-end Throughput as our evaluation metrics.

Fig. 6.1 shows the PDR values of AODV, OLSR, and DSR against number of CBR sources. As we can observe, the general trend of PDR of all protocols is falling as the number of traffic sources increases. This is because of the exponentially increasing routing overhead with larger network scale generated by flooding-based routing protocols. Overall, the AODV and DSR perform significantly better than OLSR, which suggests reactive routing protocols fit VANET better in terms of packet delivery. The Average Packets Delay depicted in Fig. 6.2 displays opposite trend: OLSR is able to deliver packets in less than 0.1s. AODV and DSR show conspicuous increment of packet delay as DSR jumps up to 1.2s average delay (10 times more than that of OLSR) as the number of CBR sources reaches 30, which is completely outperformed by OLSR. This difference could be explained by the mechanisms employed in reactive and proactive routing: Proactive routing updates routing table in real time, thus upon sending a message the node already knows the paths to destinations, while in contrast in reactive routing nodes need to send routing request before sending packets which increases the delay.

6.2 Comparison with RWP model

To illustrate the necessity of using such highly detailed movement trace, we compare our simulation result against the performance simulated under other common-

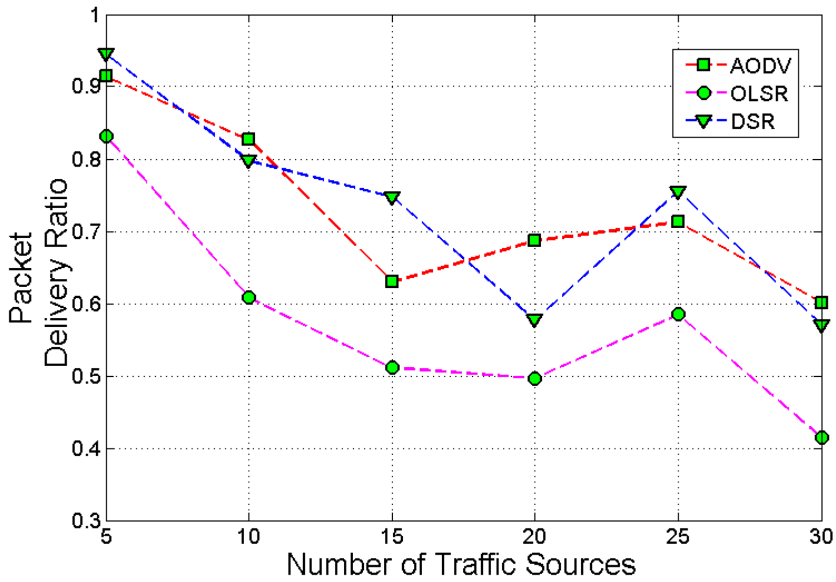


Fig. 6.1. Packet Delivery Ratio with varying number of CBR

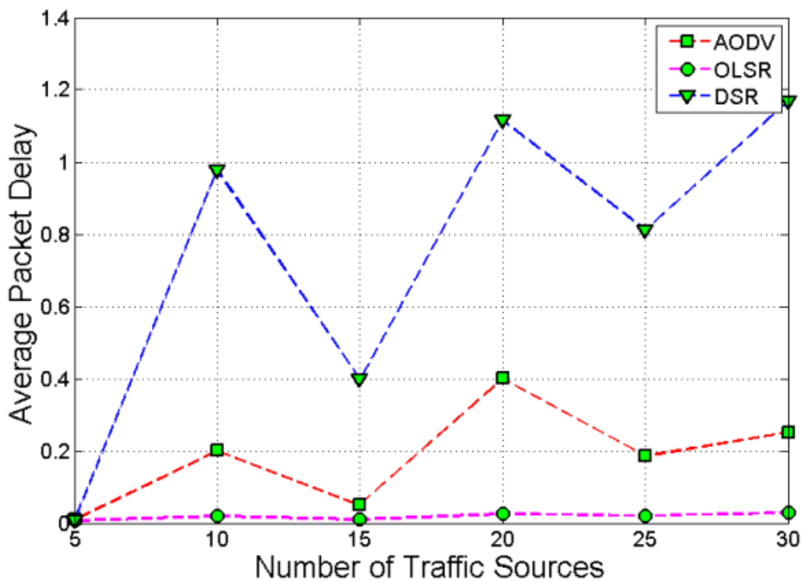


Fig. 6.2. Average Packet Delay with varying number of CBR

ly used mobility environment. Using the completely same simulation area and initial node position, we also conducted some simulations based on the random way point model. For the purpose of identifying the influence by mobility model only, we use the random CBR traffic generator to produce exactly identical set of traffic source/destination pairs.

For random waypoint model, since the node traces are with high randomness, we conducted multiple simulations for each number of CBR sources. (Each point stands for a mean of 6 experiments). The error bar has indicated the scale of variance. But for the driving scenarios in the driving simulator, vehicles tend to move with certain logic (e.g. interaction with drivers and traffic rules), the traces are only with slight difference each run, hence the error is not that obvious.

Fig. 6.3 shows the packet delivery ratio of OLSR with varying number of CBR sources from 5 to 30. In general, the packet delivery ratio decreases with the increment of traffic sources, which indicates the network is gradually becoming congested as the routing overhead increases drastically. As we can notice, the packet delivery ratio is higher in RWP model. This could be explained by the characteristics of this model: Nodes with fully random and free movement pattern tend to gather and form stable link with each other thus providing a better environment for data delivery. However this does not indicate that sophisticated movement pattern always lead to lower performance compared with random models, the most important revelation here is traffic pattern does have impact on performance evaluation. We have discussed the unclearness of relation between mobility model and simulation result in previous chapters, the point is that we proved the existence of such relation. Hence, the result from Fig. 6.3 has well stated our purpose of using a highly detailed traffic simulator.

6.3 Analysis of throughput at intersections

As mentioned in previous sections, the particular vehicle movement features at intersections could lead to better link state in terms of longer live time, as nodes tend to form a relatively stable network topology. To further study and confirm the impact by intersections, we have deliberately extracted some nodes around intersections from

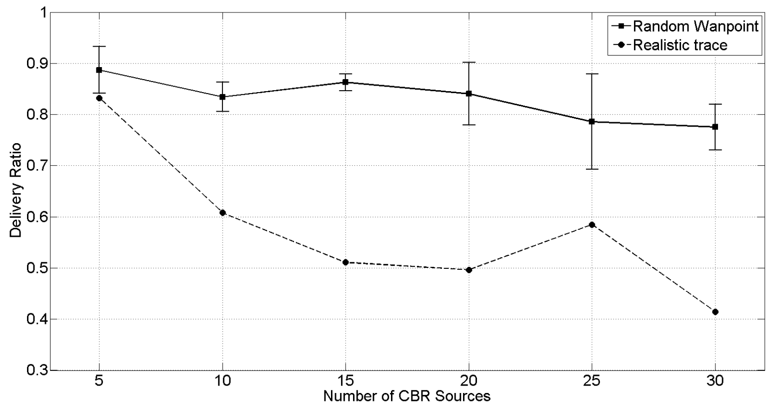
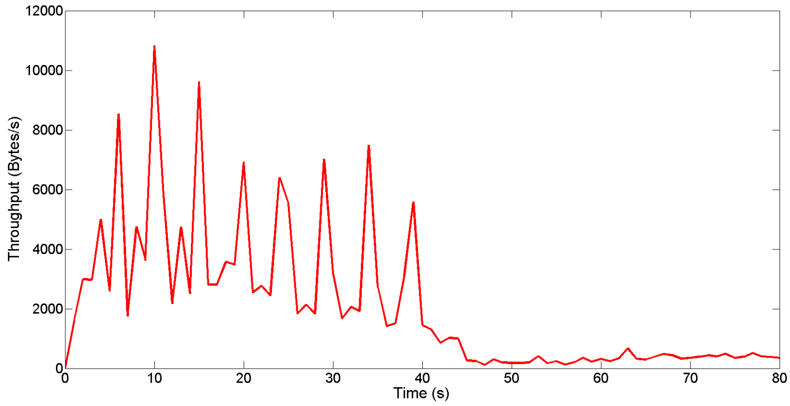
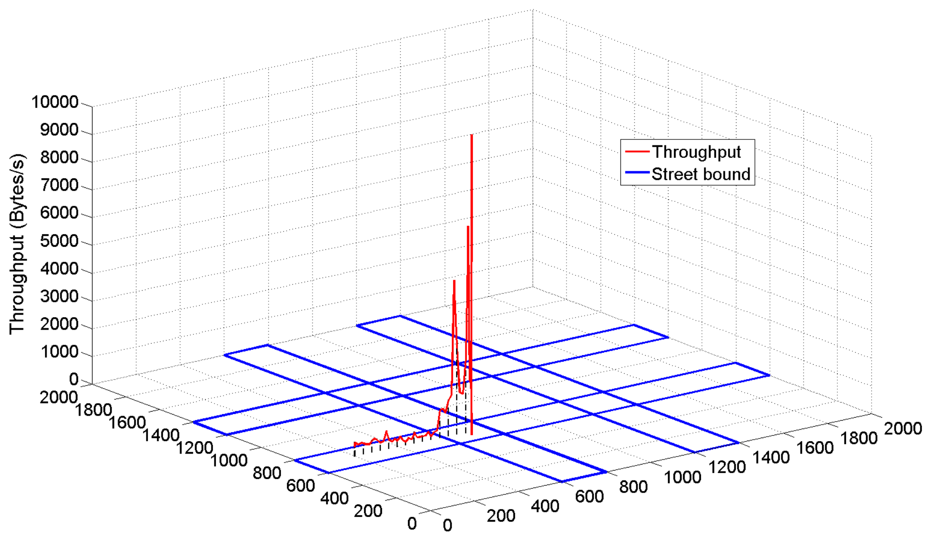


Fig. 6.3. Comparison of Driving Simulator traces and Random Waypoint

our simulation, and compared their throughput when stopping at and leaving the intersection. Fig. 6.4 (a) depicts the transferred throughput at node 5 which stays at the intersection centered near coordinate (700,700) waiting for a chance to take left turn at the beginning of each scenario. The throughput is averaged from all testing scenarios. It is quite obvious that the throughput drops intensively after 40s. Then we map the throughput data into spatial distribution using the position record of node 5. The throughput versus position relationship is given in Fig. 6.4 (b). We find out when placed at intersection, nodes are more likely to be involved as intermediate packet relay to help complete the routing. The sharp comparison confirms our expectation. To support that this phenomenon does not episodically appear at this particular node, Fig. 6.5 (a) together with Fig. 6.5 (b) describes the average transferred throughputs from node 71 in all scenarios. The graph shows similar trends: As we may examine, the throughput reaches maximum at intersection centered at (700, 1300) and begins to head downward after turning right. Upon reaching the next intersection, the throughput regrows.

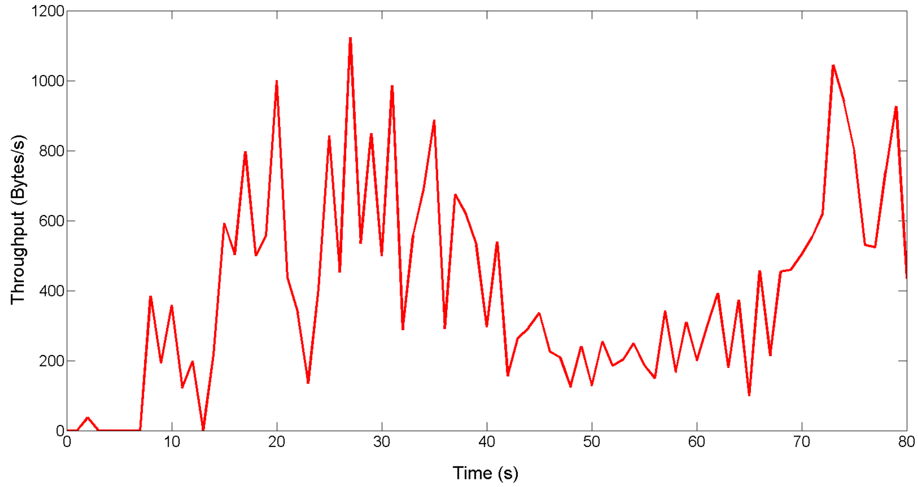


(a)

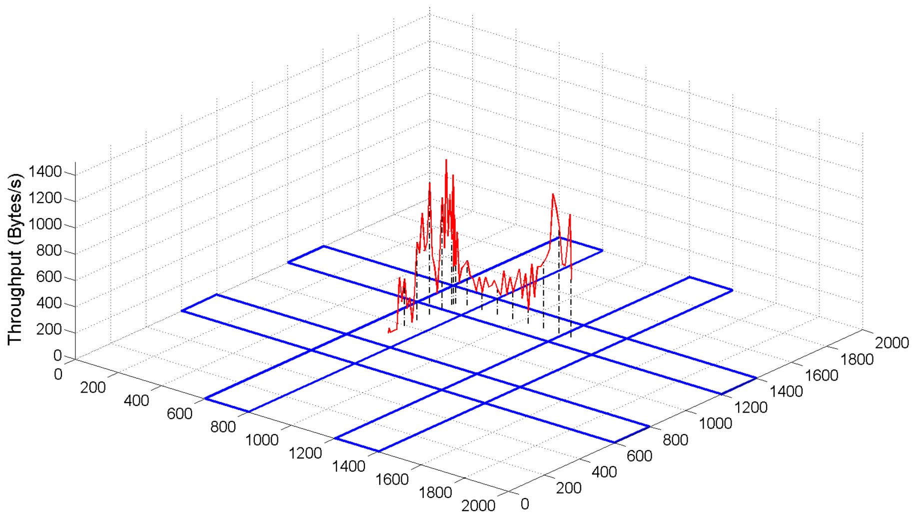


(b)

Fig. 6.4. Average throughput transferred at Node 5. (a) Time distribution (b) spatial distribution.



(a)



(b)

Fig. 6.5. Average throughput transferred at Node 71. (a) Time distribution (b) spatial distribution.

7. CONCLUSION AND FUTURE WORK

A highly realistic VANETs simulation requires lots of factors to be accounted to strengthen the cogency of the simulation result. These factors mainly fall into two aspects, mobility model and propagation model. This work presents a traffic simulator that integrates various benefits from the state-of-the-art of road traffic simulations. By looking into the very details of movement patterns generated, we thereby outlined its accuracy and fidelity of simulating realistic traffic flow especially regarding intersection control.

We introduced our initial efforts of constructing a framework based on the combination of driving simulator and NS-2 to evaluate the performance of several routing protocols. By analysis of the simulation results, we give a summarization of conclusions to draw as following:

• Different routing protocols display their own characteristics when applied in vehicular environment. Specifically, reactive routing strategies can provide relatively higher delivery ratio compared with proactive routings. On the other hand, proactive routing protocols manifest prominence in terms of packet delay. The performance of reactive and proactive routing has presented us a trade-off issue, as in some safety-related applications both the precision and swiftness of packet transmission are desired. It is still premature to say which routing protocol best fits the VANETs.

• By studying the performance metrics of individual node near intersections, we find out vehicles waiting at intersections provide more capability of transferring data as a relay node. This might be helpful in the design of position-based routing protocols

One of the restrictions imposed by our mobility trace is the nature of being off-line generated. We are able to evaluate the impact of mobility on the routing protocols but not vice versa. However, our simulation still remains grounded because only the bidirectional communication between traffic generator and network simulator is only needed when applications (such as warning signal propagation) are accounted. In the future we plan to build up bi-directional coupled simulator to comprehensively study the interactive relation between network protocol and mobility model.

LIST OF REFERENCES

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