A NEW FRAMEWORK FOR SIMULATNG INTER-VEHICLE COMMUNICATION

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Abstract: In this paper, we present a new framework for simulating inter-vehicle communication. In this framework, we apply a commodity-based kinematic wave model for simulating traffic dynamics and network simulator 2 (NS-2) for the corresponding communication events. We demonstrate the feasibility of this framework with simulation results for inter-vehicle communication among individual vehicles and along a traffic stream as well as for different routing protocols.

Keywords: Inter-vehicle communication, kinematic wave model, NS-2, routing protocols.

1 Introduction

Wireless communication units are becoming ubiquitous in recent year. For examples, there are more than 400 million cell phone users in China, and a number of cities in the United States are building city-wide WiFi networks. Therefore it is possible and also crucial to take advantage of the development of wireless technologies for the better Intelligent Transportation Systems (ITS). In 1999, the Federal Communication Commission (FCC) allocated the spectrum from 5.850GHz to 5.925GHz for dedicated short range communications (DSRC) in ITS (fcc, 1999), which can be used for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Correspondingly, US Department of Transportation started nine ITS related initiatives in 2004, including Vehicle Infrastructure Integration (VII) (usd, 2004). In a VII system, vehicles equipped with communication units and road-side stations installed by transportation authorities can exchange information with each other. Such a communication system can be used to relay information of traffic conditions and transportation networks and could be helpful for improving safety and mobility of a transportation system. Compared with existing Advanced Transportation Information Systems, this distributed in formation system can develop gradually as internet with costs distributed to transportation authorities and users and is more resilient to disasters such as earthquakes. Therefore, the initiative of VII has been widely accepted by governments, car companies, and drivers.

In a VII system, all communication nodes form a complicated wireless communication network with both V2V and V2I communications. Hereafter we refer to wireless communications in a VII system simply as inter-vehicle communication (IVC). As early as in 1990s, IVC has been used to help drivers respond more promptly to emergencies on a road in the California PATH automatic highway project (Hedrick et al., 1994). In 2002, the CarTalk project in Europe studied Advanced Driver Assistance Systems based on IVC (car, 2000). Safety related applications have been an important driving force for the development of IVC. In these applications, however, only localized information is utilized. Since the concept of Carnet (Morris et al., 2000) and the project of Fleetnet (fle, 2000) were introduced in 2000, an IVC system has been studied as a special case

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of mobile ad hoc networks (MANet) and termed as vehicular ad hoc networks (VANet). On this communication platform, vehicles far apart from each other can also communication through multihop relays of information. Thus, VANet could develop into "Internet on the road" (fle, 2000), which can be used to publish advertisements and propagate importation information. Since IVC is coupled with traffic system, it is a natural idea to use IVC to relay important traffic information. For example, (Ziliaskopoulos and Zhang, 2003) was among the earliest to check out the possibility of an Advanced Transportation Information System based on IVC.

To integrate IVC into various Intelligent Transportation Systems (ITS) strategies, the California Institute of Telecommunications and Information Technology and the Institute of Transportation Studies of the University of California, Irvine, initiated a comprehensive research project called Autonet (Recker et al., 2007), which is aimed to be an autonomous, self-organizing, transportation management, information, and control system. Different from the aforementioned projects, the Autonet project focuses on effective management of traffic flow with communications among vehicles, roadways, stations and consumers (drivers). Since an Autonet system is a coupled traffic and information network, the performance of such a system can be affected by transportation network structure, traffic conditions, wireless units, communication protocols, information management, etc. Through theoretical (Jin and Recker, 2006, 2007, 2005, Jin and Wang, 2007), simulation-based (Yang, 2003, Yangand Recker, 2005), and field studies (Harmon et al., 2007), it has been found that the multihop connectivity of an IVC system is highly related to distribution of vehicles on a road, transmission range of wireless units, and market penetration rate of equipped vehicles.

To address many challenges with respect to IVC (Blum et al., 2004), we can make use of Network Simulator 2 (NS-2) (McCanne et al.), with which we will be able to evaluate communication protocols and select the appropriate once for the ATIS applications. In an IVC system, at least at initial stage, we are more interested in broadcast other than unicast (Luo and Hubaux, 2004, Chennikara-Varghese et al., 2006). To evaluate different protocols, such as in (Stojmenovic and Lin, 2001, Wischhof et al., 2003), and especially their effects under different traffic conditions and road network structure; ns-2 simulation will be helpful.

There have been a number of studies of IVC with NS-2 in literature (Wang et al., 2005, Saito et al., 2005, Sawant et al., 2005). In (Singh et al., 2002), various performances of IVC were studied by driving under different road and traffic conditions. In (Saha and Johnson, 2004), transportation network is studied with TIGER database and vehicles move on a road network with random waypoint model. In (Khaled et al.), performances of IVC were studied with NS-2 simulation for a number of simple traffic situations. In (Naumov et al., 2006), NS-2 and a microscopic traffic simulator based on cellular automata are integrated to study IVC.

In this paper, we propose a new framework for simulating inter-vehicle communication by integrating a commodity-based kinematic wave model of network vehicular traffic and NS-2. In Section 2, we introduce the framework. In Section 3, we present some preliminary simulation results. In Section 4, we conclude our study and discuss some future studies.

2. A new framework for simulating inter-vehicle communication

2.1. NS-2

NS-2 stands for Network Simulation version 2, which is a discrete event simulator developed for networking research. It is written in C++ and Otcl and an open source platform. The latest NS-2 package is version 2.31 released Mar 10, 2007. The NS project is now a part of VINT project for display and analysis of simulation results. It is designed for easy use and study and has been widely used in the field of network study. NS-2 provides substantial support for implementing TCP&UDP, traffic source behavior such as FTP, Telnet, CBR and VBR, routing protocols, and multicast protocols over networks.

2.2. A commodity-based kinematic wave model of network vehicular traffic

In this model, we track the evolution of macroscopic traffic quantities in time-space domain with the discrete form of the LWR theory (Lighthill and Whitham, 1955, Richards, 1956): simulation time duration T is discretized into K time steps with time-step size of Δt; link l is partitioned into N_l cells with length of Δx_l^i for cell i; $\rho_l^{i,j}$ is the traffic density in cell i of link l at time-step j. Then from traffic conservation, we can obtain an equation for $\rho_l^{i,j+1}$ as

$$\rho_l^{i,j+1} = \rho_l^{i,j} + \frac{\Delta t}{\Delta x_l^i}\left(f_l^{i-1/2,j} - f_l^{i+1/2,j} \right), \tag{1}$$

where $f_l^{i-1/2,j}$ is the flux through the upstream boundary of cell i from time step j to time step $j+1$, and similarly $f_l^{i+1/2,j}$ is the downstream boundary flux. Note that Δt and Δx have to satisfy the so-called CFL condition (Courant et al., 1928): $\max\{V_l^i(\rho_l^{i,j})\}\frac{\Delta t}{\Delta x_l^i} \le 1$, where $V_l^i(\rho)$ gives the density-speed relation in cell i of link l.

In the commodity-based kinematic wave model, fluxes through a boundary with U upstream links and D downstream links are computed with supply-demand method, where traffic supply and demand are defined as follows (Daganzo, 1995, Lebacque, 1996): traffic demand of the last cell of link u can be written as

$$D_u = \begin{cases} Q_u(\rho_u), & \text{when } \rho_u \text{ is under} - \text{critical (UC)} \\ Q_u^{\max}, & \text{when } \rho_u \text{ is over} - \text{critical (OC)} \end{cases} \tag{2}$$

and traffic supply of the first cell of link d as

$$S_d = \begin{cases} Q_d^{\max}, & \text{when } \rho_d \text{ is UC} \\ Q_d(\rho_d), & \text{when } \rho_d \text{ is OC} \end{cases} \tag{3}$$

where $Q_u(\cdot)$ and $Q_d(\cdot)$ are the density-flow-rate relationships on links u and d, respectively.

Then in an intersection model (Jin and Chen, 2007),

$$f_{u\to d} = \min_{e\in D(u)}\left\{D_u\xi_{u\to d}, S_e\frac{D_u\xi_{u\to d}}{\sum_{v\in U(e)} D_v\xi_{v\to e}}\right\} = \min_{e\in D(u)}\left\{1, \frac{S_e}{\sum_{v\in U(e)} D_v\xi_{v\to e}}\right\}D_u\xi_{u\to d} \quad (4)$$

where $D(u)$ is the set of downstream links of link u, and $U(e)$ the set of upstream links of link e.

To compute turning proportions $\xi_{u\to d}$ at an intersection, we track changes in commodity densities, i.e., densities of vehicles using different paths in this study. We define a link-commodity incidence variable, $\delta_{p,l}$, which equals 1 if commodity p uses link l and 0 otherwise. We denote $\xi_{p,u}$ as the proportion of commodity p in the last cell of upstream link u at time step j with superscript of cell number and time step suppressed. Similarly, we denote $\xi_{p,d}$ as the proportion of commodity p in the first cell of downstream link d.

With the properties discussed above, the turning proportion $\xi_{u\to d}$ can be obtained by

$$\xi_{u\to d} = \sum_{p=1}^{P}\xi_{p,u}\delta_{p,d} = \sum_{p=1}^{P}\xi_{p,u\to d}, \quad (5)$$

where $\xi_{p,u\to d}$ is the proportion of commodity p in the last cell of link u traveling to downstream link d. For commodity p, if its density and proportion in cell i at time step j are given by $\rho_{p,l}^{i,j}$ and $\xi_{p,l}^{i,j} = \rho_{p,l}^{i,j}/\rho_l^{i,j}$, respectively, we can then update commodity density with the following conservation equation

$$\rho_{p,l}^{i,j+1} = \rho_{p,l}^{i,j} + \frac{\Delta t}{\Delta x_l^i}\left(f_{p,l}^{i-1/2,j} - f_{p,l}^{i+1/2,j}\right) \quad (6)$$

From FIFO principle (Lebacque, 1996, Jin and Zhang, 2004), the proportions of commodities in out-flux of a cell are the same as those in the cell. That is,

$$f_{p,l}^{i+1/2,j}/f_l^{i+1/2,j} = \rho_{p,l}^{i,j}/\rho_l^{i,j} = \xi_{p,l}^{i,j} \quad (7)$$

Therefore, commodity conservation law can be written as

$$\rho_{p,l}^{i,j+1} = \rho_{p,l}^{i,j} + \frac{\Delta t}{\Delta x_l^i}\left(f_{p,l}^{i-1/2,j} - \xi_{p,l}^{i,j} f_l^{i+1/2,j}\right). \quad (8)$$

Obviously, if the upstream boundary of a cell is inside a link; i.e., if the boundary has only one upstream cell and one downstream cell, then we can obtain commodity in-flux with proportions in the upstream cell. For a general intersection, traffic conservation in commodity p can be written as $(f_u\xi_{p,u} - f_d\xi_{p,d})\delta_{p,u}\delta_{p,d} = 0$, or $f_{p,u\to d} = f_u\xi_{p,u}\delta_{p,d} = f_d\xi_{p,d}\delta_{p,u}$. Note that $\xi_{p,u}$ and

$\xi_{p,d}$ are values on the boundary of the intersection, the former is the same as that in the last cell of link u, but the latter may not be the same as that in the first cell of link d. Therefore, we can find $f_{p,u\to d} = \xi_{p,u\to d} f_u = \xi_{p,u}\delta_{p,d} f_u$, where $\xi_{p,u}$ is the proportion of commodity p in the last cell of link u. Then we can compute in-flux for commodity p for the first cell of link d as

$$f_{p,d} = \sum_{u=1}^{U} f_{p,u\to d} = \sum_{u=1}^{U} \xi_{p,u}\delta_{p,d} f_u. \quad (9)$$

With in-flux and out-flux for all cells, we can then update commodity density with Equation 8.

2.3. A framework by integrating NS-2 and CKW

With the aforementioned CKW model, we can obtain fluxes and cumulative flows of all commodities at any boundary. From the commodity cumulative flows we can compute the positions of all vehicles at any time step. In this sense, vehicle trajectories can be simulated with the CKW model.

In the first approach, we can integrate NS-2 and CKW into an offline simulation platform, in which we first use CKW to obtain positions of all vehicles. Then we store positions of all equipped vehicles in the traffic pattern file for NS-2 simulation. Here the equipped vehicles can be determined by Monte Carlo simulations with market penetration rate as the probability for a vehicle to be equipped. In the second approach, we can integrate NS-2 and CKW into an online simulation platform through a middle-ware connecting NS-2 and CKW. With this simulation platform, we can also simulate the impact of IVC on traffic dynamics and drivers' route choice behaviors.

In communication networks, many parameters are used to evaluate the performance of it, such as throughput, End to end delay, Packet loss rate, and so on (Tanenbaum, 2002). Throughput is the amount of digital data per time unit that is delivered over a physical or logical link, or that is passing through a certain network node. For example, it may be the amount of data that is delivered to a certain network terminal or host computer, or between two specific computers. The throughput is usually measured in bit per second (bit/s or bps), occasionally in data packets per second or data packets per timeslot. The term corresponds to digital bandwidth consumption. End to end delay is the time interval of digital data transmitted on one link in communication networks. Jitter is the stability of end to end delay, the formula is

$$J = delay[i] - delay[j]/(i-j) \quad (10)$$

i is the end to end delay of packet i. Packet loss rate is used to evaluate the successful rate of data on one link. The formula is,

$$R = (N_1 - N_2)/N_1 \quad (11)$$

R is the packet loss rate, N_1 is the total numbers of packets are sent on the sending node in some time, N_2 is the numbers of packets are successfully received on the destination node on this link.

3. Simulation results

In this study, we consider IVC among individual vehicles and within a traffic stream. We also consider the impact of routing protocols on IVC. Generally, routing protocols in a Mobile Ad Hoc Network can be classified as table-driven or source-driven. Table-driven protocols include DSDV, GSR, CGSR, WRP, FSR and source-driven include DSR, AODV, TORA, ABR, SSR.

3.1. IVC among individual vehicles

In these scenarios, we mainly use some quantitative metrics such as the network throughput, delay, and packets-loss to assess the performance of mobile ad-hoc network in inter-vehicle communication scenarios. Here, we mainly talk about the influence by the different vehicle speeds and routing protocols. We simulated two kinds of moving scenarios. One is that the two vehicles move toward each other, and the other is that the two vehicles move in the same direction. For the opposite direction scenario, It is supposed that the two vehicles move in the same speed at 10m/s and 15m/s. And we set the transport protocol as UDP and routing protocol as AODV and DSR. We will analyze the influence of speeds and protocols separately. First, we set an unchangeable protocol (here is AODV) to discuss the results of different speeds. The throughputs of both two speeds can be seen as Figure 1. From it, we can find that the average bandwidth (throughput) is 134kbps around. It is a little big than the nominal throughput value (110kbps), because before the packets being sent they were added an overhead automatically, which contained the necessary information about the data transfer. As the speed increasing, the time that starts communication also moves up but the communication time decreases. When the two vehicles move at an increasing speed, they meet with each other more quickly and the communication time decreases naturally due to the unchangeable communication range.

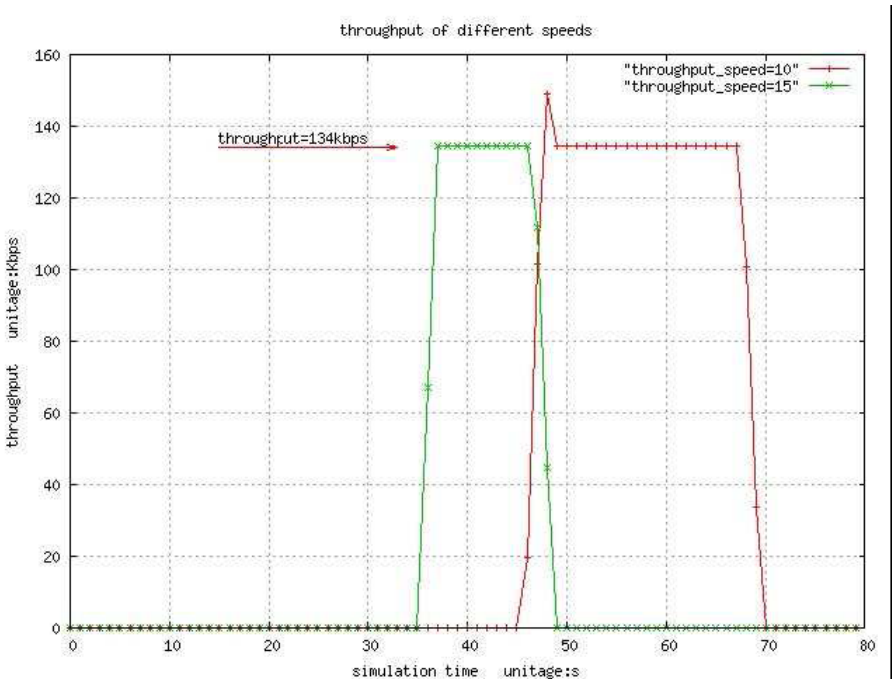

Figure 1 Throughput of Different Vehicular Speeds for Two Vehicles

For the delay time in the IVC networks (as Figure 4.6), the average time for both two speeds are nearly 0.005s in despite of a little shock at the beginning of communication scenario. In this way, we can assume that the vehicle speeds have no significant influence for simple networks, just as our two vehicles scenario. After analysis the trace file, the number of packet loss for the two speeds are both 0, which means there are no packet lost during the communication. This is due to that there is no noise information in this two nodes simple scenario. All the packets sent by node0 are successfully received by node1 in application layer. In this opposite direction scenario, we still need considering the influence of different routing protocols. Here, we set the speed as 10m/s and choose the AODV and DSR for discussion. We can find that there is no significant difference between AODV and DSR in Figure 2. The only difference is that the throughput of AODV is a little bigger than DSR. This is due to their respective routing mechanism. The overhead of AODV is bigger than DSR. As a result, the whole size of the packet in AODV is larger than that in DSR, which makes the bandwidth in DSR smaller than that in AODV.

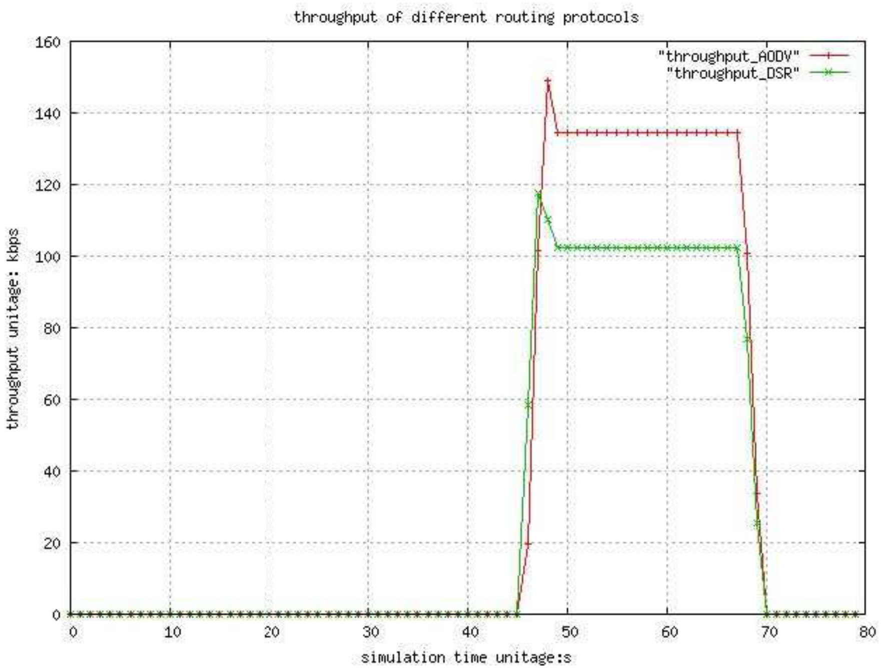

Figure 2 Throughput of Different Routing Protocols for Two Vehicles

Besides this point, the start time and end time of the communications between the two vehicles are nearly the same. This proves that there is no distinct influence of different routing protocols for two vehicles communication scenario in throughput. In other words, for this two vehicle scenario, there is no routing path choice when packets transmission because it is a single hop network for the two vehicles communication scenario. From this point of view, the routing protocols do not affect the simulation results. By the way, we also simulated the delay time and packet loss for different routing protocols. From the analysis of trace file, we can conclude that the delay time is also 0.005s and there is no packets loss in application layer. In normal traffic applications, many cars need to communicate with driving in the same direction. This calls for the stability of the communication platform. In this subsection, we discuss the performance of our IVC system for the uniform direction scenario. Here, the relative speed of the two vehicles is 0. In this scenario, we emphasize on the normal performance of this scenario. We set the simulation time as 80 seconds and other parameters as the same in opposite direction scenario. The packets are sent from node(0) to node(1) at the time 10s till the end of simulation. The throughput for unidirectional scenario is plotted in Figure 3. We can find that the throughput is stable during the communication between the two vehicles. This is because there is no interference during the packets sending. The delay time is still 0.005s and the number of lost packets in application layer is also zero. These results prove that using MANET for inter-vehicle communication system is feasible and we can adopt it for further studies.

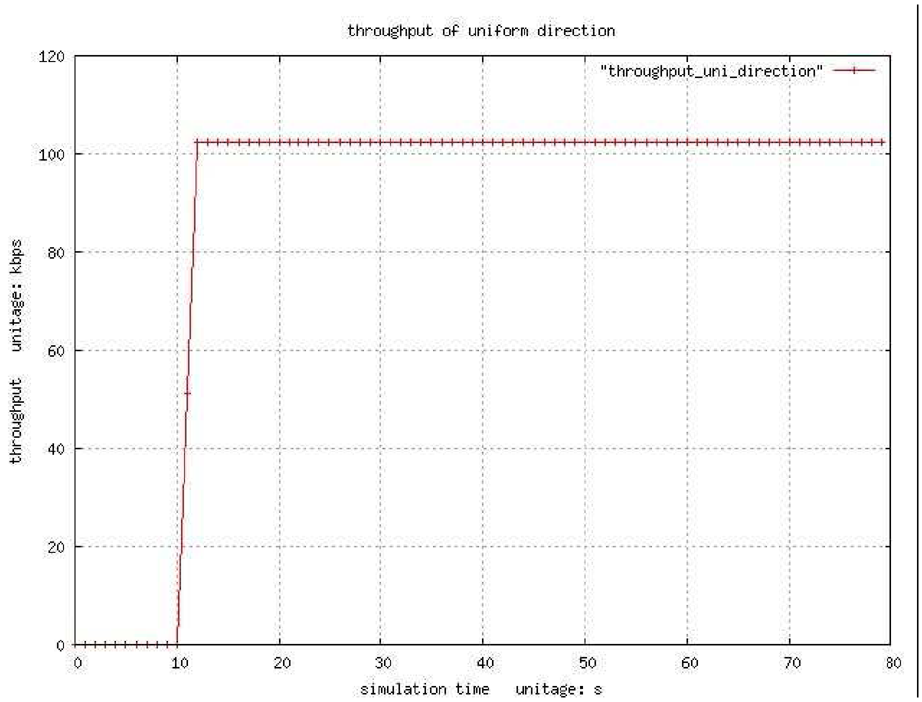

Figure 3 Throughput of Uniform Direction Scenario for Two Vehicles

3.2. IVC in a traffic stream

In this section, we use NS-2 to simulate four different protocols and analyze the information propagation on Shock Wave Model in a traffic stream. The structure is shown in Figure 1.

We consider information propagation on an infinitely long road within a stream of traffic subjected to a shock wave. It is generally accepted that, for uninterrupted traffic flow, there is a density–speed relationship $v = V(\rho)$ (Hall et al., 1986). In this example, we assume the so-called triangular fundamental diagram (Munjal et al., 1971; Newell, 1993),

$$V(\rho) = \begin{cases} v_{f,} & 0 \le \rho \le \rho_c, \\ \dfrac{\rho_c}{\rho_j - \rho_c} \dfrac{\rho_j - \rho}{\rho} v_{f,} & \rho_c < \rho \le \rho_j, \end{cases} \tag{12}$$

for conditions in which $v_f = 104$ km/h is the free flow speed, $\rho_j = 150$ veh/km/lane the jam density, and $\rho_c = 0.2\rho_j = 30$ veh/km/lane the critical density where flow-rate,

$q = \rho v$, attains its maximum, i.e., the capacity. Based on the triangular diagram, we examine information propagation on a unidirectional road of two homogeneous lanes of traffic. We assume that initially we have capacity flow with $\rho_- = 30$ veh/km/lane for traffic upstream to $x = 0$ and congested flow $\rho_+ = 40\ veh/km/lane$ for downstream traffic. From the fundamental diagram, we then have the corresponding speeds at $v_- =$ 104 km/h and $v_+ =$ 71.5 km/h. Under these conditions, a shock wave forms and travels backward at speed $v_s =$ -26 km/h. Further, we assume that $\mu = 10\%$ and $R = 1\ km$. If initially information is carried by a vehicle at $x_0 < 0$, the vehicle will cross the shock wave at time $t_c = |x_0|/(v_- - v_s)$.

According to shock wave model, we analyze the communication performance in terms of packet end to end delay, throughput and jitter. We construct one UDP link from the 60th vehicle to the 40th vehicle, here one vehicle is one node, the CBR generator send one 200 Bytes packet every two seconds from starting time 0 s and stop transmission at 1800 s.

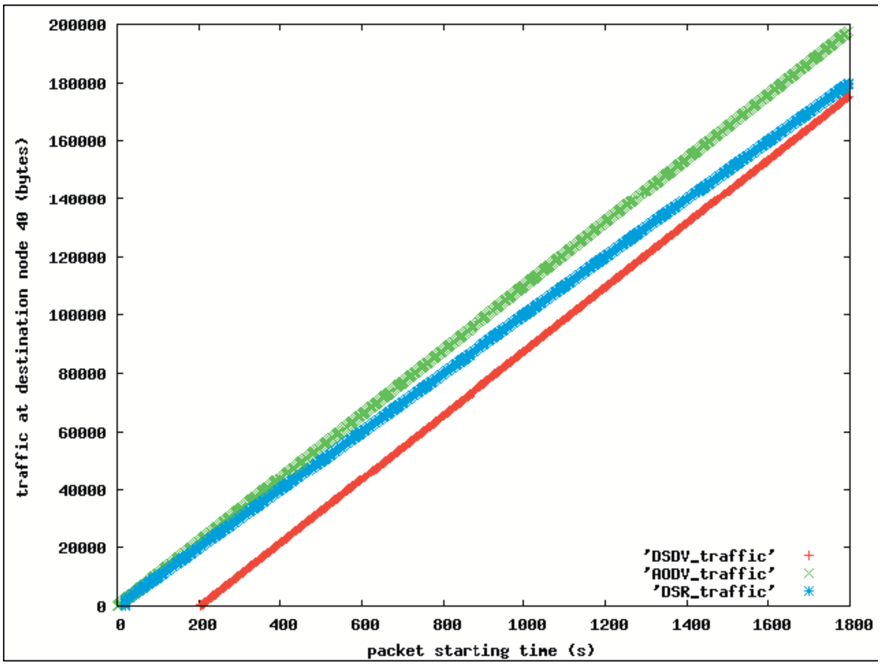

Figure 4 Traffic at the 40th vehicle for different routing protocols

The UDP packets traffic for different routing protocols at the destination node (the 40th vehicle) are show in Figure 4. We can get the UDP throughput on the link from the 60th vehicle to the fortieth vehicle at any moment, the UDP throughput are highest when we adopt AODV protocol, because the speed of vehicle on this link is very fast and the limited hops on routing layer, the throughput is relatively lower for DSR and DSDV routing protocols.

The topology change of shock wave model is fast when the CBR generator starts to send UDP packet, so the packet loss is obvious round this time interval, the first UDP packet is received at 20.34s for DSR and 200.34s for DSDV, however, the first UDP packet is received at 0.29s for AODV, it is shown that the throughput is relatively stable in shock wave model for AODV routing protocol. Besides throughput, also we can get a glance of system throughput and the end-to-end delay, for example, we can easily get the system throughput is 0.88 Kbps for AODV routing protocol.

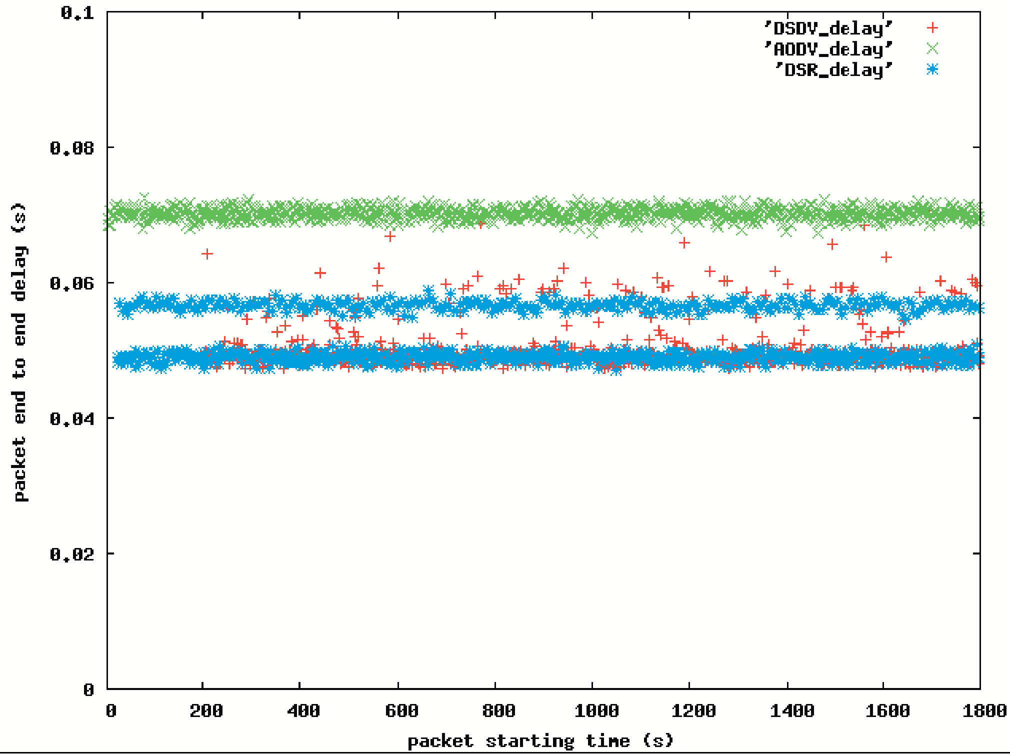

Figure 5 End to end delay for different routing protocols

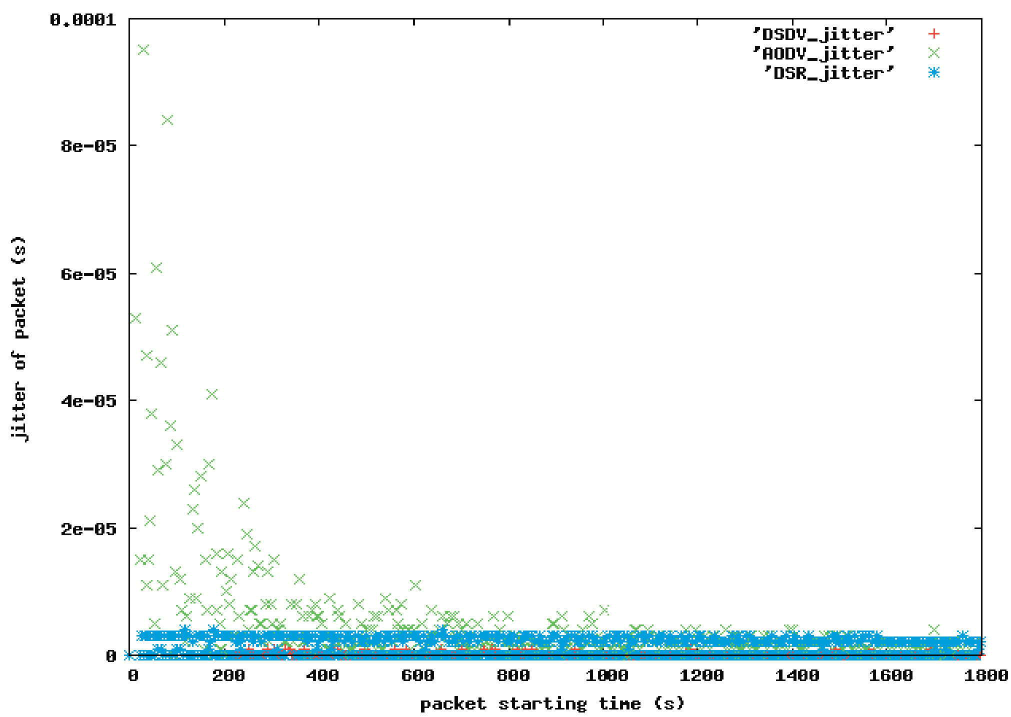

Figure 6 Jitter for different routing protocols

From Figure 5 and Figure 6, we can obviously see that the end to end delay is highest and the jitter is most strong for AODV protocol, and the end to end delay seems disordered for DSR and DSDV routing protocols, but the delay is lower than AODV, and also the jitter is more stable than DSR and DSDV, However, the delay is relatively low for these three protocols, and the highest for AODV, so the AODV routing protocols should be best choice in shock wave model.

5. CONCLUSION

In this paper, we proposed a new framework for simulation inter-vehicle communication by integrating a commodity-based kinematic wave model and NS-S online or offline. In this simulation platform, vehicles' positions are simulated by CKW model, and NS-2 simulates communication between equipped vehicles. This simulation platform can be used to evaluate performance of IVC for different communication protocols and traffic scenarios. With some preliminary simulations, we study impacts on IVC of vehicle speeds, driving directions of vehicles, and traffic congestion level. We also study impacts on IVC for different communication and routing protocols.

In the future, we will be interested in studying IVC for more traffic scenarios and various routing protocols in a transportation network. With these studies, we would be able to determine the most efficient routing protocols for different transportation networks and traffic patterns.

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