

A Study on Performance of Inter-Vehicle Communications in Bidirectional Traffic Streams

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Abstract—Inter-vehicle communication (IVC) network has become an important topic in research for its potential advantages in enhancing traffic security and efficiency. This paper investigates the communication performance of IVC networks in two-lane bidirectional traffic streams. By changing the transmission range of communication units and penetration rate of equipped vehicles, we studied several performance measures, such as average throughput, end to end delay and number of hops. The simulations were conducted in network simulator 2 (ns-2) with Monte Carlo method and the equipped vehicles were generated randomly according to the penetration rate. From the simulation results we found that the bidirectional traffic streams indeed affect each other's communication performance. In addition, the average throughput and end to end delay can be improved by increasing the transmission range and penetration rate. The study could help to fix some network parameters such as transmission range to advance the communication performance of IVC networks.

Keywords-inter-vehicle communication, IVC, network simulator 2, bidirectional traffic

I. INTRODUCTION

Inter-vehicle communication (IVC) has attracted many researchers' attention in recent years. It has the potential to greatly improve road traffic safety and efficiency. The equipped vehicles in an IVC system form a special mobile ad hoc network (MANET), which is known as vehicular ad hoc networks (VANET). The characteristic of VANET is that the mobile communication nodes have special mobility patterns: the positions of nodes are limited to road network topology, and the density of vehicles may vary dramatically due to the driving behaviors [1]. The network topology changes quickly due to the high mobility of vehicles and it may be difficult to maintain a stable multi-hop communication path between two communication nodes. In addition, we have to consider that not all the vehicles in traffic streams are equipped with communication units, so that we can define penetration rate as the probability of the vehicles which are equipped with communication units. When the penetration rate is low, it will lead to more challenges for the vehicles to set up a routing path.

There have been many studies about IVC systems and the performance analysis of communication networks. Many literatures [2], [3] try to modify the protocols for different layers of ad hoc networks, for example, MAC layer protocols. More

information about MAC protocols can be found in [4]. Some literatures even just focus on the pure protocols' improvement and do not consider the characteristics of vehicles' mobility.

Some other literatures study the multi-hop connectivity in IVC systems from the perspective of traffic streams. Due to the high mobility of vehicles, the low penetration rate, and different transmission ranges, the source vehicle and destination vehicle can not always set up an instantaneous routing path. Therefore, [5] studies on the probability of successfully establishing a communication path along bidirectional traffic streams. [6]–[8] propose a model to analyze the relationship between the connectivity of IVC networks and some parameters, such as the transmission range of wireless units and the penetration rate of equipped vehicles. [9] studies the throughput of an IVC network along a unidirectional traffic stream. The author simulates different transmission ranges and traffic densities, compares the results with [6] and obtains high consistency with it. [10] investigates the performance of the IEEE 802.11 protocol in networks with high mobility like vehicular networks. According to different traffic densities and inter-packet delays, it analyzes some performance measures of IVC networks, such as end to end delay and data loss rate, etc. But in that paper, all the vehicles are equipped which means the penetration rate is 100%. However, this is quite different from the real life conditions. [11] studies the influence of penetration rate on the performance of a one-lane IVC network both with simulation method and analytical method. We are interested in the affect of penetration rate on the communication process. Meanwhile, because bidirectional traffic streams are common in real life, we are also concerned that whether they will influence each other's communication performance.

In this paper, we simulate a network consisting of a main lane and a disturbing lane. The main lane contains 560 vehicles and the disturbing lane contains 20 vehicles. On the main lane, we assume a certain penetration rate of equipped vehicles. Whether a vehicle is equipped or not follows a Bernoulli distribution. On the disturbing lane, all vehicles are equipped. We simulate the IVC networks to analyze the throughput, end to end delay and number of hops by changing the transmission range of wireless units and the penetration rate of equipped vehicles. The simulation tool is network simulator 2 (ns-2) [12] and we adopt Monte Carlo as the simulation model.

The paper is organized as follows. In section 2 we introduce the traffic flow theories which are applied in the simulation and the definition of some performance measures. Section 3 describes the simulation scenarios and parameter configuration in ns-2. In section 4, we present and analyze the results. Finally in section 5 we conclude our work.

II. MODEL BACKGROUND

A. Traffic Flow Theories

The traffic flow theories can be classified into two categories: macroscopic and microscopic models. The conservation equation of Lighthill Whitham Richards (LWR) model which is macroscopic can be used to calculate the vehicles' trajectories:

$$\frac{\partial \rho(x, t)}{\partial t} + \frac{\partial q(x, t)}{\partial x} = 0 \quad (1)$$

where $q(x, t) = v(x, t)\rho(x, t)$, $q(x, t)$ is the flow rate of a traffic flow, $v(x, t)$ is the speed of a traffic flow and $\rho(x, t)$ is the density of a traffic flow.

Car-following model which is microscopic can be described by (2).

$$\frac{d^2}{dt^2}x_{i+1}(t+T) = \lambda \frac{d}{dt}[x_i(t) - x_{i+1}(t)] \quad (2)$$

where $x_i(t)$ is the coordinate of vehicle i and λ is the sensitive coefficient. Here the stimulus is the relative speed of the two vehicles, and the response is the following car's acceleration.

B. Definition of Performance Measures

In our study, we use several measures to analyze the performance of IVC networks: throughput, end to end delay, and number of hops. These measures can be defined from different perspectives and we define them as follows:

- Throughput can be calculated by (3) as follows:

$$T = \frac{\sum_i p_i}{t_i - t_0}, \quad i = 1, 2, 3 \dots \quad (3)$$

Where i is the sequence number of packets, t_i is the time when packet i is received by the destination node, t_0 is the time when packet 0 is received by the destination node, p_i is the packet size of packet i .

- Average end to end delay represents the average transmission delay between the emission of a packet by a source node till its reception by a destination node:

$$D = \frac{\sum_i (t_r(i) - t_s(i))}{n}, \quad i = 0, 1, 2 \dots \quad (4)$$

Where i is the sequence number of packets, $t_r(i)$ is the time when the packet is received by the destination node, $t_s(i)$ is the time when the packet is sent by the source node, n is the total number of packets received by the destination node.

- Average number of hops needed when a packet is delivered from the source node to the destination node can be computed by:

$$H = \frac{\sum_i h_i}{n}, \quad i = 0, 1, 2 \dots \quad (5)$$

Where i is the sequence number of packets, h_i is the number of hops when packet i is delivered from the source node to the destination node, n is the total number of packets received by the destination node.

III. SIMULATION FRAMEWORK

A. Mobility Models for ns-2

In the simulation of IVC network, we have to get the positions of every mobile node in the whole simulation process. In our study, we assume the traffic stream is uniform: the vehicles are distributed along a one-dimensional road in an equivalent distance; they move to a destination in the same speed. Thus the initial coordinates of mobile nodes at time $t = 0$ can be computed by (6).

$$x_k(0) = x_0(0) + k\Delta x \quad (6)$$

Where $x_k(0)$ is the position of vehicle k at time $t = 0$, $x_0(0)$ is the initial position of vehicle 0 at time $t = 0$, Δx is the spacing between two consecutive vehicles which can be calculated by $\Delta x = \frac{1}{\rho}$, ρ is the density of the traffic stream.

The coordinates of vehicle k at time $t = \tau$ can be computed by (7).

$$x_k(\tau) = x_k(0) + v\tau \quad (7)$$

Here v is the vehicles' speed.

B. Simulation Implementation

In real life, some vehicles are equipped with communication units and some are not. So in our study, equipped vehicles are chosen randomly according to the penetration rate. In ns-2, we get the node ID of equipped vehicles with RNG (random number generator). Because of the random distribution of them, it is possible that no equipped cars are available in a certain forward node's transmission range. So whether a routing path can be established between the source node and destination node is random. Then it is meaningless and unstable to carry out a trial for one time and analyze the result. Therefore, we adopt the Monte Carlo simulation model [9] to carry out repeated, random realizations of Bernoulli trials. After M times experiments, an equipped vehicle's average throughput, end to end delay and number of hops at position x can be calculated by (8)(9) and (10).

$$T_M = \frac{\sum_j T_j}{M}, \quad j = 1, 2, \dots M \quad (8)$$

$$D_M = \frac{\sum_j D_j}{M}, \quad j = 1, 2, \dots M \quad (9)$$

$$H_M = \frac{\sum_j H_j}{M}, \quad j = 1, 2, \dots M \quad (10)$$

Here, T_j , D_j and H_j are respectively the average throughput, end to end delay and number of hops of each experiment.

We configure parameters in ns-2 according to [9]. One of the reasons is that some comparisons will be made with the study results in this paper. Because the two-ray ground model considers the paths of reflections from ground and is proper for

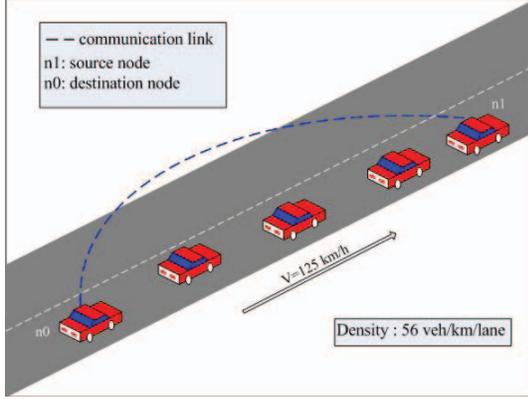


Fig. 1. Unidirectional, uniform traffic stream on one lane

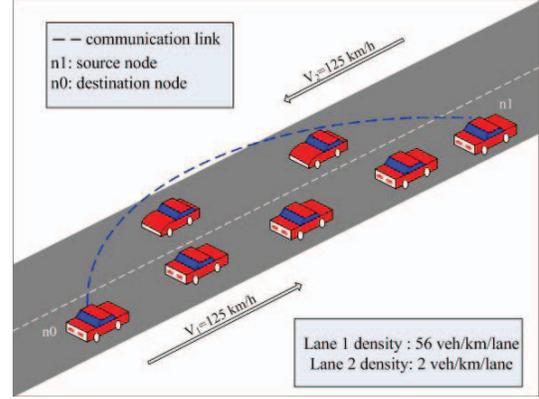


Fig. 2. Bidirectional, uniform traffic streams on two lanes

long distance communication, we adopt it at the physical layer. IEEE 802.11 DCF is the set up for ns-2.33 at the MAC layer. From the analysis of [10], connections with UDP protocol will get better results and be easier to analyze than TCP protocol. So considering the unstable factors of vehicular ad hoc networks, we choose UDP protocol at the transportation layer. At the application layer, we use constant bit rate (CBR) generator with packet size 230 bytes and inter-packet delay 0.02s. AODV is the protocol for network layer because from previous experiments, it takes shorter time to set up a routing path than DSR. For each Bernoulli trial, the ns-2 simulation time is 120s. In this paper, the simulation times M is 500. It has been proved to get relatively stable results by our former tests.

C. Simulation Scenarios

This study simulates two different scenarios to analyze the performance measures of the IVC networks. Some parameters could be determined according to [9], [10]:

- the penetration rate of equipped vehicles μ : 10% or 50%;
- the transmission range of wireless communication units: 500 m, 200 m, or 100 m;
- the number of vehicles on the disturbing lane: 20.

1) *Scenario 1-unidirectional, uniform traffic stream on one lane*: This scenario has been simulated and analyzed in [9]. We repeat his work in order to compare the communication performance of the following scenario with this scenario to obtain some useful results. In this simulation, we only consider one lane of 50km. The length of the traffic stream is 10km. The traffic density ρ_1 is 56 veh/km/lane and vehicles' travel speed v_1 is 125km/h. The penetration rate is 10% or 50% as mentioned before (Fig. 1).

2) *Scenario 2-bidirectional, uniform traffic stream on two lanes*: During this part of simulation, we study the communication performance of a unidirectional two-lane traffic stream: a main lane and a disturbing lane. The width of each lane is 3.5 meters. The parameters on the main lane are the same with scenario 1. The disturbing lane is of the same length with the main lane but the traffic density ρ_2 is 2 veh/km/lane.

The traffic streams on the two lanes are running cross each other with a speed of 125 km/h. What we should point out is that, all the vehicles on the disturbing lane are equipped. This assumption is made to get rid of randomness and to analyze the result clearly. Through this scenario, we could get a clear vision about the influence of two bidirectional traffic flows on each other's communication performance (Fig. 2).

IV. SIMULATION RESULT AND DISCUSSION

In this section, we present the simulation results and discuss the relationship between communication performance and some parameters, such as transmission range and penetration rate.

First, we analyze the relationship between performance measures and transmission range. For scenario 1 and scenario 2 with a penetration rate $\mu=10\%$, we change the transmission range to 500 m, 200 m, or 100 m respectively and get Fig. 3 to Fig. 5. Fig. 3 presents the average throughput of a receiver from senders at different locations.

With the same transmission ranges, it is clear that the average throughput in bidirectional, uniform traffic stream on two lanes is better than that in unidirectional, uniform traffic stream on one lane. This is because the relative positions of vehicles on the two lanes vary with time. Therefore, vehicles on the disturbing lane decrease the distance between equipped vehicles on the main lane and make it easier to set up communication paths between the source nodes and the destination nodes. When the transmission range is 200m, for example, information can be delivered to a distance of about 2700m in the bidirectional traffic stream, but just to a distance of about 1800m in the unidirectional traffic stream. Actually, low throughput can be attributed to two factors: First, few equipped vehicles can be used to establish a communication link. Second, it is possible to have a large number of equipped vehicles in a limited area due to the random distribution of them in the whole traffic stream. As a result, no buffer space in the interface queue can be used to delivery so much packets and collisions in the MAC layer are formed. From Fig. 4, we notice that with the same transmission range, the average end to end delay of scenario 2 is much longer than that of scenario

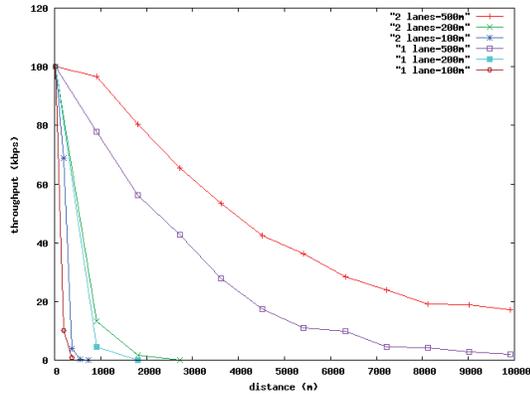


Fig. 3. Average throughput with a penetration rate of 0.1

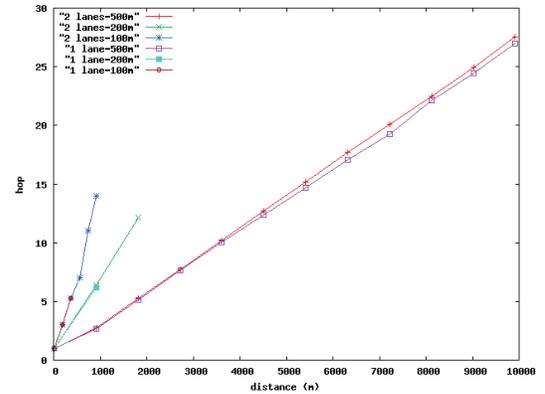


Fig. 5. Average number of hops with a penetration rate of 0.1

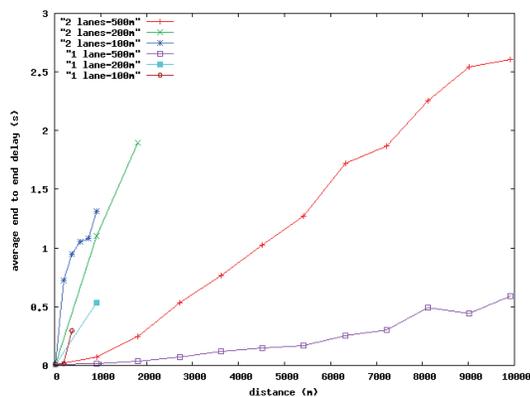


Fig. 4. Average end to end delay with a penetration rate of 0.1

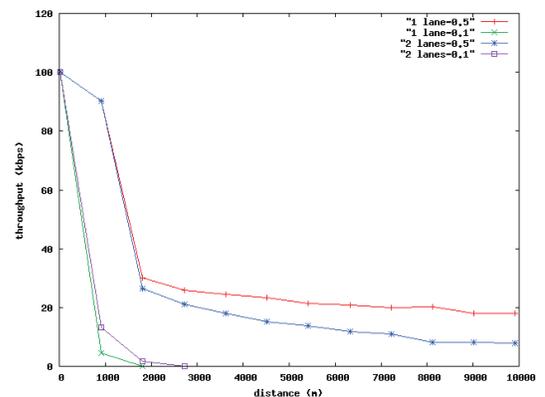


Fig. 6. Average throughput with a transmission range of 200m

1. Because the hops needed in the two scenarios are the same with a certain transmission range (Fig. 5), the longer end to end delay of scenario 2 is caused by the high relative speed of the two traffic streams. Compared to scenario 1, the network in scenario 2 spends more time establishing routing paths for the high relative speed.

With different transmission ranges, we could see the throughput improves as transmission range increases (Fig. 3) because the higher probability of finding equipped vehicles in a larger transmission range. The average end to end delay is longer when the transmission range is smaller (Fig. 4) because with a smaller transmission range more hops are needed to deliver packets from a source node to the same destination node (Fig. 5). We can also observe from Fig. 5 that the number of hops only depends on transmission range and it has no relationship with the mobility and directions of vehicles.

Second, we analyze the relationship of performance measures and penetration rate. For scenario 1 and scenario 2 with a transmission range of 200m, we change the penetration rate to $\mu=10\%$ and $\mu=50\%$ respectively and get Fig. 6 to Fig. 8. From Fig. 6 we can see that average throughput augments as the penetration rate increases. This is because more vehicles contribute to establish the communication paths. In this experiment, penetration rate plays a greater role than

the disturbing lane in increasing the average throughput. The average throughput is higher in the one-lane unidirectional traffic stream with a penetration rate of 0.5 than that in a two-lane bidirectional traffic stream with a penetration rate of 0.1. But what we should notice is that, compared to one-lane condition, the bidirectional traffic can increase the average throughput when the penetration rate is 0.1 and decrease it when 0.5. The reason is that transmissions interfere with each other when there are a large number of equipped vehicles. The bidirectional traffic aggravates the collisions because the relative positions of nodes change quickly. This explanation can also be revealed in Fig. 7 because when the penetration rate is 0.5, the average end to end delay of scenario 2 is much longer than that of scenario 1. More time is needed to cope with collisions in MAC layer in the bidirectional traffic streams. From the conclusion mentioned above: the number of hops depends on the transmission range, we can see that numbers of hops are equal with the same distance and transmission range (Fig. 8). But the average end to end delay of penetration rate 0.5 is lower than that of 0.1 (Fig. 7) because it takes relatively shorter time to set up the communication paths when more vehicles are available in the transmission range.

In all these result figures, we could notice that when there

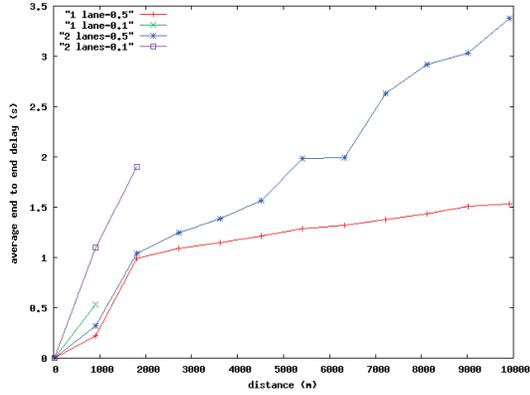


Fig. 7. Average end to end delay with a transmission range of 200m

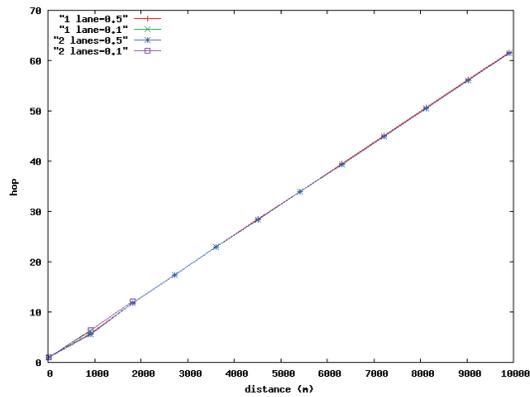


Fig. 8. Average number of hops with a transmission range of 200m

is only one hop, the transmission range and penetration rate have no influence on the communication performance and all the lines converge at one point.

From the discussion above, the average throughput and the average end to end delay can be improved by increasing the penetration rate or transmission range. The disturbing lane can also improve the average throughput of the main lane network but increase end to end delay meanwhile. However, we should notice that if the penetration rate is high, bidirectional traffic streams will increase the average end to end delay and decrease average throughput due to the interferences among several transmissions.

V. CONCLUSION

In this paper, we carried out several simulations in ns-2 to evaluate the performance of IVC networks under different scenarios. The main goal is to investigate the mutual affect of two-lane bidirectional traffic streams. Besides, we also want to know the relationship between several performance measures and network parameters in the two-lane networks. The study is based on the traffic flow theories such as LWR model and Car-following model. In order to better study the performance with a specific penetration, we generate equipped vehicles randomly and adopt the Monte Carlo method to

simulate this network. We observe that the disturbing lane can indeed improve average throughput but increase end to end delay compared to one-lane scenario. Throughput and end to end delay can be improved by enhancing the penetration rate and transmission range. When the penetration rate of communication units is low at the early stage, increasing the transmission range is an effective way to advance communication performance. However, the number of hops from a source node to a destination node in a certain distance remains unchangeable with the same transmission range.

In future, we will apply some traffic scenario generators to obtain other complicated scenarios based on the digital map and study some specific problems about IVC networks. We will also consider other routing protocols to improve the communication performance.

VI. ACKNOWLEDGMENT

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