Performance Evaluation of Multi-Channel Operation For Safety And Non-Safety Application On Vehicular Ad Hoc Network IEEE 1609.4

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***Abstract* — The IEEE 1609.4 standard for Vehicular ad hoc network has been proposed to enhance the IEEE 802.11p MAC to support multi-channel operation. Multi-channel operation separate safety and non-safety related applications on a different channel. The vehicles must periodically switch between control channel and service channel to concurrently exchange the safety and non-safety related messages so that the problem of contention between applications can be avoided. In this work we measure the performance of both safety and non-safety related applications on multi-channel operations and compared to the single-channel operation. We analyze the performance of safety message dissemination model for two distinct cases: single-hop and multi-hop. Our experiment shows that multi-channel operation can provide better QoS performance than single channel. Using of the multi channel scheme can reduce the level of contention between safety and non safety applications that impact the amount of packet loss is reduced by 47% than single channel.**

Keywords - VANET, Multi-Channel, IEEE 1609.4, Safety and Non Safety Applications, Network Simulator

I. INTRODUCTION

Vehicular ad-hoc network (VANET) is a new form of data communication for vehicles on the road with short range wireless communication. In VANET, vehicle can communicate directly with neighbor vehicles or between vehicles and roadside infrastructure. The transfer of information between vehicles and infrastructure will enable applications to improve road safety, efficiency and comfort related services to the vehicle users.

Though VANET is a type of mobile ad-hoc network (MANET), but the specific nature of VANET makes this network different from MANET. Some of its characteristics, such as very high mobility, high changes of network topology, density of vehicles cannot be predicted, and short communication periods [1]. Due to these unique features, providing a reliable data distribution is one of the most challenging areas in VANET.

Recently, IEEE task group of IEEE 802.11 working group developed an amendment to the 802.11 standard for enhancement required to support vehicular ad hoc network. This standard is known as 802.11p [2]. It defines physical and medium access control layers of vehicular wireless network. In addition, the IEEE 1609 working group [3] defined IEEE 1609 protocol family which developed higher layer specification based on 802.11p. This protocol consists of four standards [3]:

(i) IEEE 1609.1: describes resource manager specification
(ii) IEEE 1609.2: defines secure message formats and processing
(iii) IEEE 1609.3: defines network and transport layer services, including addressing and routing, in support of secure data exchange.
(iv) IEEE 1609.4: specifies enhancements to the IEEE 802.11p MAC to support multi-channel operation

Collectively, IEEE 802.11p and 1609 are called wireless access in vehicular environments (WAVE).

Several recent papers have evaluated the performance of safety related applications over the multi-channel operation based on IEEE 1609.4. Di Felice, M. et al. [4] analyzed the impact of synchronous channel switching enforced by the IEEE 1609.4 scheme on the packet delivery ratio of safety applications in vehicular network. The modeling and simulation of the periodic CCH and SCH switching operations based multi-channel vehicular ad hoc network IEEE 1609.4 in network simulator 2 (NS-2) is contributed by [5] and [6]. Authors in [7] evaluate the performance safety message dissemination of the IEEE 1609.4 based on multi-hop and single-hop. In [8] [9], the authors study the performance of the IEEE 1609 WAVE and IEEE 802.11p for different WAVE channels and traffic prioritization schemes using different access categories.

We carried out the simulation using NS-2 simulator [10] version 2.34 and the implementation of WAVE 1609.4 based multi-channel vehicular ad hoc network [5] in NS-2. In addition, we add the non-safety application function to simulate the transmission of non-safety messages over multi-channel operations in IEEE 1609.4.

The remainder of this paper is structured as follows. In Section II, we discuss related work and literature review. This section explains the multi-channel operation of IEEE 1609.4 standard, application on VANET and safety messages dissemination model. Section III describes the evaluation criteria applied in our experiments, the simulation scenario and the result of the simulations with some analysis. Finally, we conclude our findings and propose future work in Section IV.

II. TECHNICAL BACKGROUND

A. Multi-Channel Operation of IEEE 1609.4

Multi-channel operation IEEE 1609.4 [11] is a standard of the IEEE 1609 protocol family, which manages channel coordination and supports MAC service data unit delivery. This standard describes seven different channels with different features and usages. To this aim, the FCC has allocated 75 MHz of Dedicated Short Range Communication (DSRC) spectrum for vehicular usage at 5.9 GHz. The bandwidth of each channel is 10 MHz. There are six service channels (SCH) and one control channel (CCH). The control channel is used for system control and safety data transmission. On the other hand, service channels are assigned for exchange of non-safety related data. In addition, these channels use different frequencies and transmit powers.

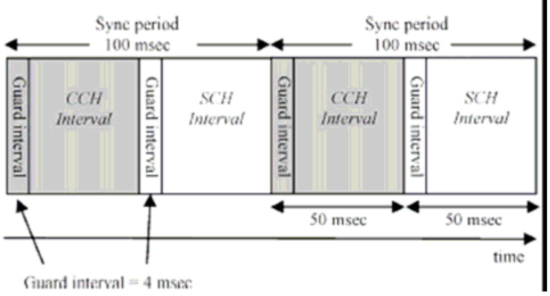

Figure 1. Allocation CCH interval and SCH interval [12]

WAVE device exchanges the safety messages in the control channel and the non-safety communications are limited to service channels. For the purpose of supporting the coexistence of safety and non-safety applications, WAVE device may periodically and synchronously switch the control channel and one of the service channels, according to rules defined by the IEEE 1609.4 standard [11]. Multi-channel operation helps both types of communication simultaneously so that the problem of contention between applications can be avoided. Based on this standard, vehicles must monitor CCH and SCH at a regular interval by synchronous switching scheme between CCH Interval and SCH Interval with 50 ms of each as shown in Figure 1. At the beginning of each scheduled channel interval, there shall be a guard interval.

Channel access options include continuous access at single-channel, and alternating control channel and service channel as illustrated in Figure 2. In single-channel mode, there is no channel switching occurs, and all vehicles are always tuned on a single-channel to transmit safety and non safety related messages simultaneously. On the contrary, multi-channel operations, in which the vehicles periodically switch between CCH and SCH intervals to transmit safety related messages on CCH interval and transmit data of non-safety applications on service channels.

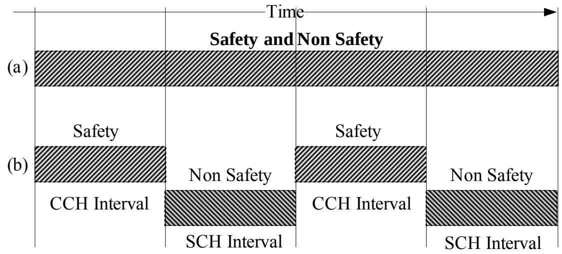

Figure 2. Single-channel and multi-channel operation

B. Application on VANET

A typical VANET application includes communication components that allows for vehicle-to-vehicle or vehicle-to-infrastructure communications. VANET applications can be divided into two main categories: safety and non-safety applications. Safety applications are intended to improve road safety by provide the drivers early warnings before the moment of collision [13]. It is one possible way of decreasing the number of road accidents. Meanwhile, non-safety applications can provide additional information, advertisements, and entertainment during their journey.

As shown in Figure 3, the broadcast transmission method is used by safety applications, which need to distribute the safety messages to every vehicle within the range of the broadcasting. A safety message is sent only once and not repeated, so there is no guarantee of any given vehicle receiving the message. Most of the non-safety related message sending through vehicle networks are unicast, in which a packet is sent from a vehicle to another vehicle or roadside infrastructure. The non-safety applications using unicast take into account the fact that unicast transmission is a more reliable method for delivering data. If the non-safety message is properly received, the receiver will send back an acknowledgment or ACK.

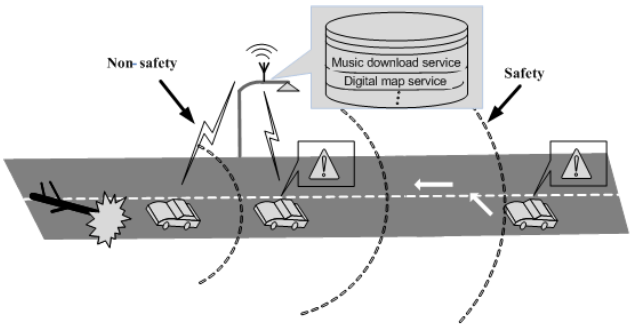

Figure 3. Safety and non safety related applications on VANET

The processing procedure of sending safety and non safety message as pseudo code shown in Figure 4.

```
In case a safety message
{
  Safety message enqueued into CCH queue
  Wait until the start of the next CCH period
  Waiting for Guard interval
  The next packet in the CCH queue is dequeued
  Send broadcast safety message at MAC layer and
transmitted at the control channel
}
In case a non safety message
{
  Non safety message enqueued into SCH queue
  Wait until the start of the next SCH period
  Waiting for Guard interval
  The next packet in the SCH queue is dequeued
  Send unicast non safety message at MAC layer
and transmitted at the service channel
}
```

Figure 4. Pseudocode of the sending message on multi-channel mechanism

C. *Safety Message Dissemination Mechanism*

In VANET, every vehicle will exchange the safety messages with the purpose of preventing accident on the road. There are various techniques by which a safety message could be disseminated over the vehicular network. The simple technique to disseminate the safety message to other vehicles uses broadcast or flooding mechanisms. Many studies [7], [14], [15], have been done to efficiently disseminate broadcast safety messages over the network. The single-hop and multi-hop scheme in vehicular networks can be used to disseminate safety messages [7], [16]. In the multi-hop mechanism, vehicles sending broadcast packets and the receiver vehicle receive the packet will be rebroadcast the received packet, so it can contact a significantly larger number of vehicles. In addition, multi-hop mechanism used to increase the coverage area. On the contrary, in single-hop method, the broadcasted message will not be rebroadcasted by any other vehicles. Figure 5 and 6 depict the single-hop and multi-hop scheme to safety messages dissemination.

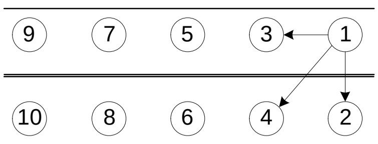

Figure 5. Safety message on single-hop dissemination

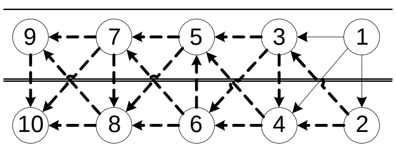

Figure 6. Safety message on multi-hop dissemination

III. Scenario and Simulation

A. *Simulation Scenario*

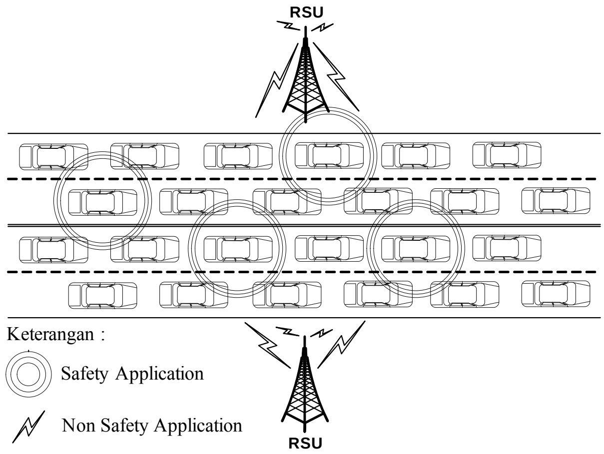

Figure 7. Simulation scenario

Based on the NS-2 simulator [9] version 2.34, we observed the performance of multi-channel operation of the IEEE 1609.4 for safety and non safety application on VANET with periodic switching channel SCH and CCH. We compared this channel allocation scheme with single-channel operation, which sends a packet of safety and non safety application to be performing together on the same channel. We also evaluated the performance of safety traffic transmission method based on single-hop and multi-hop. Different vehicular safety and non safety communication scenarios are simulated in this work in order to observe the performance of IEEE 1609.4 on VANET. Each scenario is constructed with the payload size of 400 bytes, the bit rate 3 Mbps and varying number of vehicles (4-100 vehicles). We observed the impact of the number of vehicles to the average delay, packet delivery ratio, packet loss and throughput. The simulation scenario is shown in Figure 7.

The simulation parameters are listed in Table 1.

TABLE I. SIMULATION PARAMETER

Parameter	Value
Simulation time	2 s
Range transmission	250 m
Number of vehicles	4 -100
Channel data rate (R)	3 Mb/s
Number of channels	7
SCH interval	50 ms
CCH interval	50 ms
Guard interval	4 ms
Packet size	400 bytes

B. Performance Evaluation

Based on the scenario implemented in the simulation, we analyzed four important metrics in order to evaluate the performance of IEEE 1609.4 standards.

1) Average Delay

The average delay refers to the time required by a data packet to be generated, transmitted across the network, and received by the destination. Based on the theoretical analysis from [5], the average delay E[d] is defined :

$$E[d] = E[q] + E[c] \quad (1)$$

where E[q] is the sum of the average queuing delay defined from :

$$E[q] = \frac{CH_d}{2} + GI_d \quad (2)$$

where CH_d is the length of the channel interval and GI_d is the length of the guard interval. The equation for calculating average contention delay E[c] is described as in equation (3) – (6) as follow :

$$E[c] = E[CW].T_{slot} = \frac{CW_{max}-1}{2}.T_{slot} \quad (3)$$

$$T_{slot} = (1 - P_{busy}).\ \sigma + T_{success}\ .\ P_{success} + T_{coll}\ .\ P_{coll} \quad (4)$$

$$T_{success} = DIFS + \sigma + \frac{S}{R} + T_{PRE} \quad (5)$$

$$T_{coll} = EIFS + \sigma + \frac{S}{R} + T_{PRE} \quad (6)$$

Where :

T_{slot} = the average duration of each logical slot

$T_{success}$ = the time required for a successful transmission

T_{coll} = the average time of a collision event

2) Packet Delivery Ratio

Packet delivery ratio is the ratio of the number of received packets to the total number of sent packets.

Packet delivery ratio= (Σ Received packets / Σ Sent packets) x 100 % (7)

3) Packet Loss

This metric is the difference between the number of packets sent and the number of packets received.

Packet lost= Number of packet send – Number of packet received (8)

4) Throughput

Throughput is the rate of successful packet delivery through a network connection per unit of time.

Throughput= (Σ Total successful packet received / Σ Unit of time) x 100 % (9)

C. Simulation Result and Analysis

1) Performance comparison of single-channel and multi-channel

The objective of the first scenario presented in this section is to evaluate the performance metrics of single-channel and multi-channel.

a) Average Delay

The delay is one of the parameters that determines the performance of a system. Significant differences in their respective QoS parameters can be seen in the end-to-end delay. Delay on the network is influenced by the density of traffic due to the increasing number of vehicles, causing the transmission queues. Figure 8 shows the performance comparison of the average delay safety and non safety applications of single-channel and multi-channel.

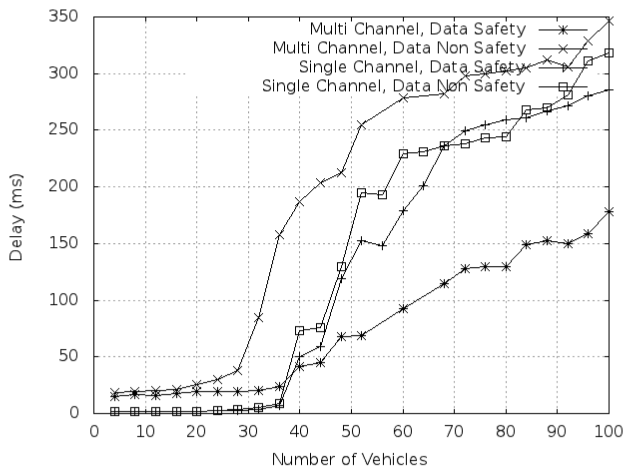

Figure 8. Comparison of delay single-channel versus multi-channel

The impact of the relationship between the number of vehicles and the average delay is that an the increasing number of vehicles implies the number of average delay [17]. From Figure 8, we found that at a small number of vehicles, delay of single-channel is lower than multi-channel operation. For example, if the number of vehicles is 4, the single-channel delay will be 1 ms and multi-channel will be 15 ms. On the contrary, when the number of vehicles are large, the average delay of single-channel is greater than multi-channel operation. It can be seen from Figure 8 that at 40 vehicles the single-channel delay is 50 ms while the multi-channel is 41 ms.

In the single-channel operation, data packet safety can collide with non safety data packet when being sent on the same channel. The data will be corrupt when a collision happen, so it is necessary to retransmit the packet. A lot of collisions, that impact on delay between the two applications is fluctuating. In contrast, in multi-channel operation transmission of data for safety and non safety applications is at different channel and time, so there is no data collision between the two applications.

In the non-safety application with the multi-channel scheme, the high delay as a consequence of the untransmitted non safety related messages there is queue during all the CCH interval before performing a new transmission attempt on the service channel.

b) Packet Delivery Ratio

Figure 9 demonstrates the packet delivery ratio in single-channel and multi-channel for safety and non safety applications. As the density of the vehicles increase, the packet delivery ratio will also decrease. The increase of data traffic exceeds the channel capacity, will cause a decrease in quality of packet delivery ratio. The decrease is due to many contentions and collisions. A lot of collision causing the probability of message reception will reduce.

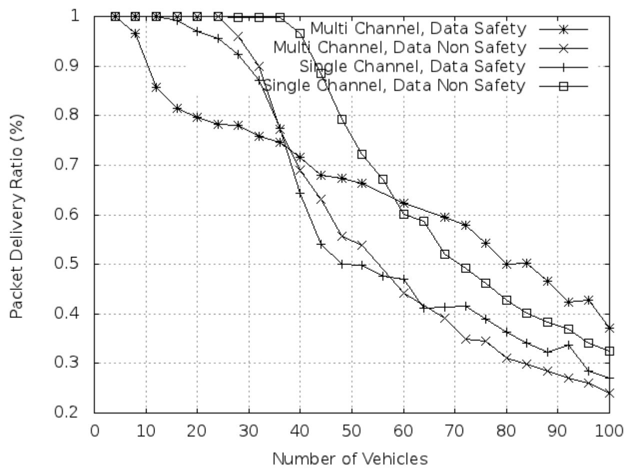

Figure 9. The comparison between the packet delivery ratio single-channel and multi-channel

According to Figure 9, we can see that multi-channel operation provides the higher packet delivery ratio for the safety message compared to single-channel (approximately 10%), but lower for data non safety (approximately 10%).

c) Packet Loss

Packet loss shows the number of lost data packets during the data transmission in the network. Packet loss is caused by several factors, including received signal strength, number of packets in the queue, messages scheduling on the channel and packet collision. Packet loss parameter is closely related to the packet delivery ratio. Overall, increasing the number of vehicles in the network will also increase the packet loss. The comparison of loss in single-channel and multi-channel for safety and non safety applications is depicted in Figure 10.

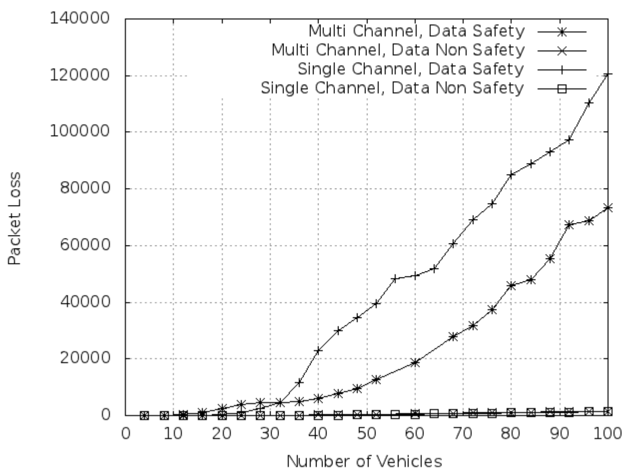

Figure 10. Comparison of packet loss single-channel versus multi-channel

Based on the analysis of the packet loss result, the number of packet loss of the multi-channel for safety message in low vehicle density situation is higher than the single-channel. As seen in the N=28 vehicles, packet loss of single-channel is 2598 packets and multi-channel is 4557 packets. When number of vehicles increase, packet loss of multi-channel will be lower than the single-channel as shown in the density of N=100 vehicles, packet loss of single-channel is 120535 packets, and multi-channel is 73258 packets. In the transmission data of non safety application, the number of packet loss the single-channel is slightly lower than the multi-channel.

d) Throughput

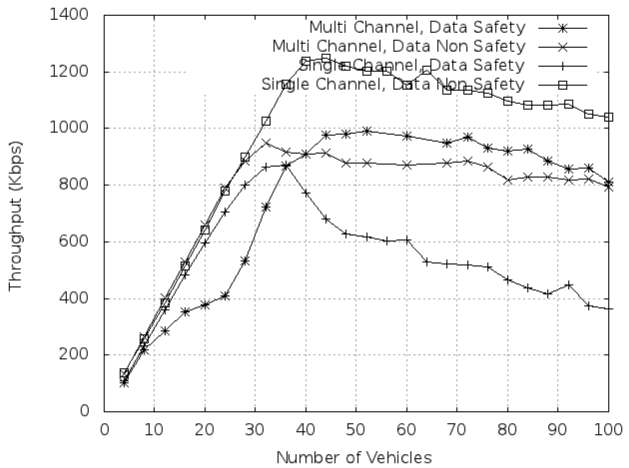

Figure 11. Comparison of throughput single-channel versus multi-channel

Throughput is one of the parameters that determine the performance of a network. This parameter indicates the amount of data which could have been transmitted on the network at one time. As the number of vehicles increased, the aggregate throughput will be increase. Figure 11 demonstrates the throughput of the single-channel and multi-channel. As shown in this figure, that finds high performance throughput on the multi-channel operation.

For safety applications, the highest throughput by using multi-channel operation is 991 Kbps at N=52 vehicles and single-channel throughput increases the most at N=36 vehicles which is 870 Kbps, but with an increasing number of vehicles it is being drastically decrease. It affects of packet loss in the network due to a collision and contention in the sending of data safety and non safety in a single-channel. Meanwhile, the single-channel operation is slightly higher than the multi-channel for throughput of non safety application.

2) Performance comparison of single-hop and multi-hop

In this second scenario, we are going to evaluate the performance of single-hop and multi-hop the safety message dissemination.

a) Average Delay

Figure 12 illustrates the average delay of single-hop and multi-hop dissemination. According to this figure the average delay of multi-hop scenarios is high for safety application compared to the single-hop. This is due to the fact that multi-hop dissemination will flood safety packets in the network. Since the vehicles in the network are asked to forward the flooded packets, traffic fluctuation will occur. In the non safety application, the average delay is not much different from both these schemes. In the non safety application, the average delay is not much different from both schemes.

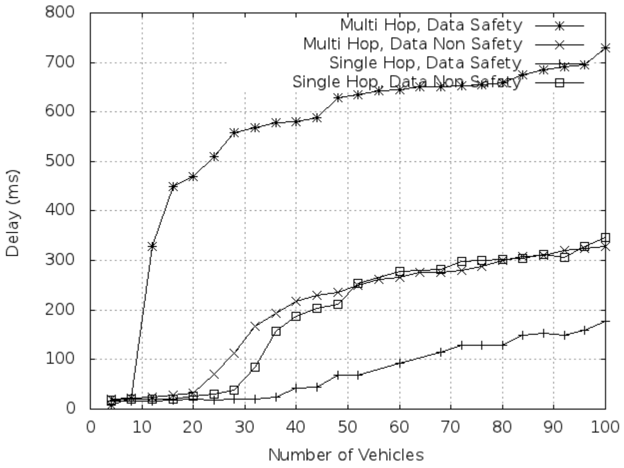

Figure 12. Comparison of delay single-hop versus multi-hop

b) Packet Delivery Ratio

The packet delivery ratio with the single-hop and multi-hop is shown in Figure 13. It is found that there is a significant difference between both types in terms of packet delivery ratio on data safety. For multi-hop dissemination, packet delivery success rate decreased dramatically ranging from 4 vehicles at 80% and 100 vehicles will decrease at 24%, but on multi-hop dissemination which packet delivery ratio for 4 vehicles is 100% and will decrease 37% at 100 vehicles. This shows that the packet delivery ratio for multi-hop dissemination is less than single-hop. In the non safety application, it can be seen in Figure 13 that single-hop and multi-hop have nearly similar packet delivery ratio.

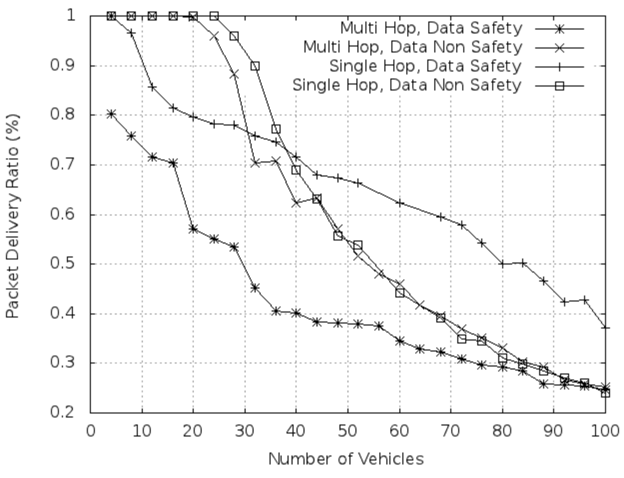

Figure 13. Comparison of packet delivery ratio single-hop versus multi-hop

c) Packet Loss

Figure 14 depicted the number of the packet loss of safety and non safety traffic based on the single-hop and multi-hop dissemination.

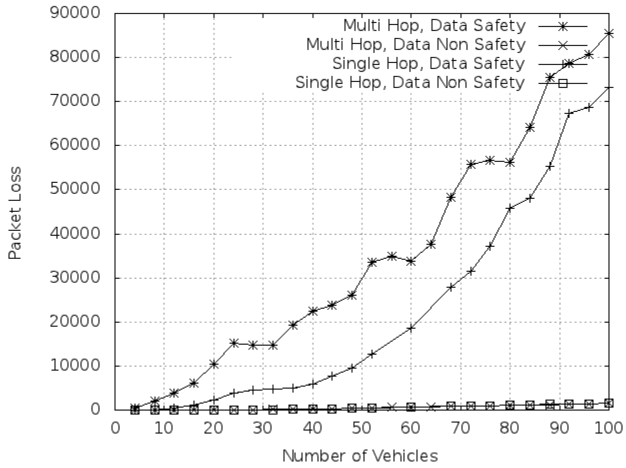

Figure 14. Comparison of packet loss single-hop versus multi-hop

Based on our simulation, data comparison of packet loss between single-hop and multi-hop can be obtained as shown by Figure 14. Based on the analysis of the simulation result, we get the packet loss of single-hop always lower than of multi-hop as shown in Figure 14.

d) Throughput

Based on our simulation, data comparison of throughput between single-hop and multi-hop can be obtained as shown in Figure 15. The increasing number of vehicles in the network will have an impact on the throughput values. The simulation result shows that the throughput of safety data with a single-hop scheme is higher than the multi-hop. Based on multi-hop, the network throughput will decrease with an the increase number of vehicles. This is caused by the increasing of traffic exponentially so that the extremely high load on the network.

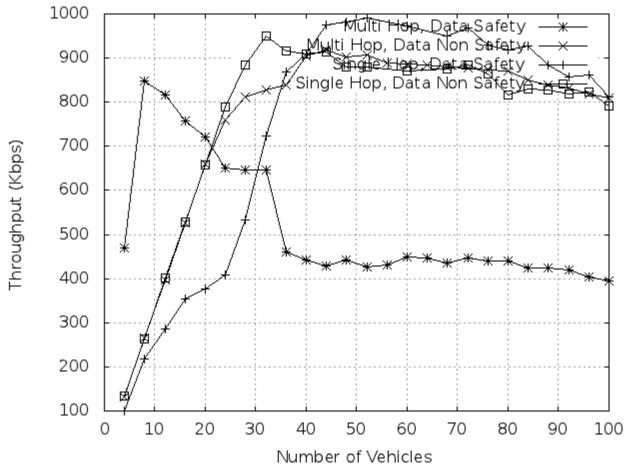

Figure 15. Comparison of throughput single-hop versus multi-hop

IV. CONCLUSION

In this work, we analyzed the performance of safety and non-safety related applications over multi-channel operations in vehicular communication. First, we demonstrated that the synchronous channel switching enforced by the IEEE 1609.4 scheme might significantly affect the average delay, packet delivery rate of safety applications and throughput. Simulation results confirm that multi-channel operation can significantly enhance the packet delivery ratio and throughput of safety applications on the multi-channel operation, and decrease the average delay. The performance of safety message dissemination model for two distinct cases, i.e., single-hop and multi-hop, have shown that the average delay of multi-hop is relatively high for safety application, which degraded the packet delivery ratio and throughput compared to the single-hop.

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