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Evaluation Study of IEEE 1609.4 Performance for safety and non-safety messages dissemination

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Abstract: The IEEE 1609.4 was developed to support multi-channel operation and channel switching procedure in order to provide both safety and non-safety vehicular applications. However, this protocol has some drawback because it does not make efficient usage of channel bandwidth resources for single radio WAVE devices and suffer from high bounded delay and lost packet especially for large-scale networks in terms of the number of active nodes. This paper evaluates IEEE 1609.4 multi-channel protocol performance for safety and non-safety application and compare it with the IEEE 802.11p single channel protocol. Multi-channel and single-channel protocols are analyzed in different environments to investigate their performance. By relying on a realistic dataset and using OMNeT++ simulation tool as network simulator, SUMO as traffic simulator and coupling them by employing Veins framework. Performance evaluation results show that the delay of single-channel protocol IEEE 802.11p has been degraded 36% compared with multi-channel protocol.

Keywords: Beaconing, IEEE 1609.4, IEEE 802.11p, Queue Size, VANET.

Introduction

Due to sharp increase in number of vehicles, fatal road accidents take place in recent years because of drivers' error. Vehicular network help the driver to have a better perspective about the surroundings of a vehicle in order to avoid these potential dangers and thus making driving more safe. Several researches has been made in the field of VANET system in order to limiting the number of fatalities and make the transportation safer and convenience. The applications in vehicular are classified into two categories, safety application and non-safety applications. Safety applications inform driver about critical situation in advance, they required fast and guaranteed access and short transmission delay, so the quality of service need to be ensured. While in non-safety application not to be stringent but it is require heavier data load and less severe timing requirements [1].

In recent years, IEEE development team have been working on variation of 802.11family standards to ensure that the standard remains stable over time for fast changing vehicular environment. the IEEE 802.11p is standardized based on IEEE 802.11a focused on PHY and MAC layer; then the IEEE standardized the whole protocol stack by the 1609 WAVE referring to wireless access in vehicular environments (WAVE) as shown in figure 1. The IEEE 1609 standards defines the higher layer protocols and services requirements based on the IEEE 802.11p. It consists of six documents: IEEE 1609.1, IEEE 1609.2, IEEE 1609.3, and IEEE 1609.4and two unpublished IEEE 1609.0 and IEEE 1609.11 standard documents which describes whole architecture of wireless Access for vehicular environment. In particular, the IEEE 1609.4 [2] provides enhancement to the IEEE 802.11p Media Access Control (MAC) standard by implementing multi-channel operation as shown in figure 2 by dividing the sync interval into two 50ms intervals (control and service channel respectively). The IEEE 1609.4 protocol provides mechanism for priority access, channel switching and routing, and management services. The CCH interval is used for the periodical dissemination of control information. There are two kinds of messages can be sent during control channel: Periodic Safety Message called Beacon which are short messages contain status information about the sender vehicle like position, acceleration, heading….etc. The other type of message called WAVE service advertisement (WSA) messages used to publicize one or more WAVE services available on other SCH frequency. These two types of messages contribute to the main reason of traffic load on the control channel. In addition, dissemination of beacon messages in VANETs is still an open research challenge and needs some efforts to reach an optimum solution to obtain real-time information specifically for safety-related applications.

Several research handled safety and non-safety applications, beaconing in particular, while few publications have considered statistics measurement for realistic large scale data, due to the cost and hard to implement of VANET in real world in different scenarios. So, simulation programs play an important role to measure the beneficial and drawbacks of new technologies before implementing it in real world.

To this purpose, we have implemented our evaluation using varied VANET simulators. As a result SUMO for traffic simulation, OMNeT++ for Network Simulation and Veins framework for integration of OMNeT++ and SUMO, and configured two representative traffic environments that include high density and low density motorway scenarios to make the results more realistic and reliable.

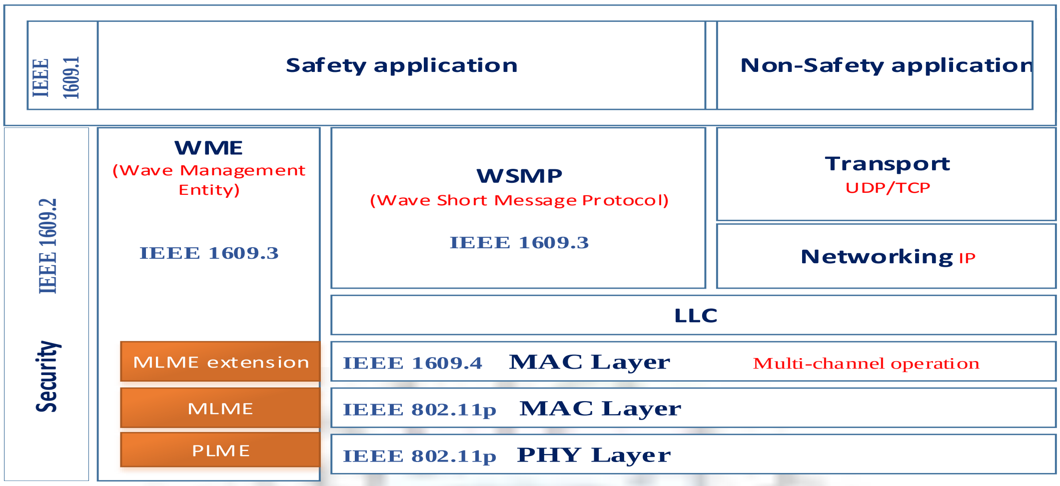


Figure 1. WAVE protocol stack

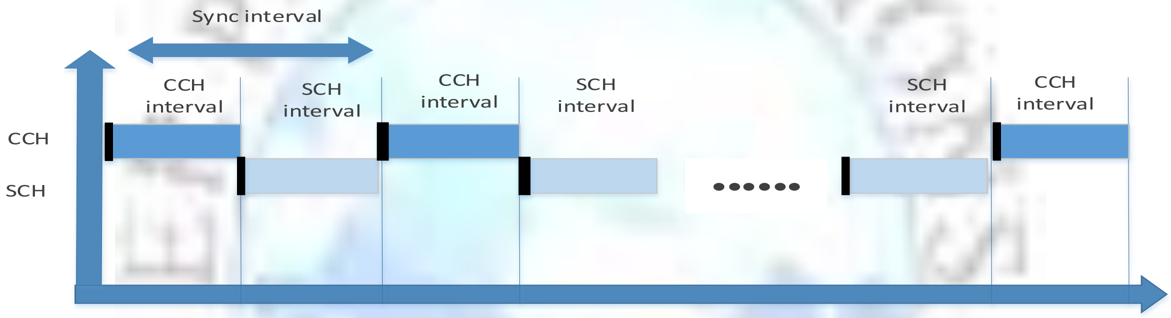


Figure 2. Multi-channel operation

In this work, we focus on comparing between the performance of 1609.4 multi-channel and single-channel in different situations for safety and non-safety application in vehicle-to-vehicle (V2V) context and investigate the impact of channel switching on the reliability of safety messages because it has specific requirements to successfully deliver messages with low latency.

Research Background

Several recent papers have addressed the problem of synchronize switching in multi-channel architecture of 1609.4 protocol. Ghandour et al perform modelling and simulation of the protocol 1609.4 by contributing to improve both packet delivery ratio and delay of safety application in single and multi-hop topologies. This improvement achieved by proposing two enhancement, the first one is enabling the transmission of high priority safety messages during SCH interval to consume the bandwidth resources during SCH interval. The second enhancement is to improve the utilization of the control channel, by alleviating the problem of synchronous collisions at the start of the CCH interval [3]. Noori and Olyaei calculated the Probability of Beacon Delivery (PBD) of 802.11p in realistic large urban area to investigate how the traffic density could affect PBD. The results presented that the PBD of 802.11p is low in high traffic area[4].Their result showed that the PBDs in real simulation is better than the mathematical model. Klingleret al investigated the possibility of a multi-channel approach for adaptive beaconing in vehicular networks by extending the delay sensitive and congestion aware Adaptive Traffic Beacon (ATB) protocol to make full use of IEEE 802.11p/1609.4 DSRC/WAVE [5].they presented a novel channel scheduling algorithm and incorporated it into an improved information dissemination protocol. The result showed that the developed protocol improved both the packet collision rate and channel utilization, while the mean beaconing interval is not increased. Minh Dang et al proposed an Efficient and Reliable MAC protocol for VANETs which allows nodes to broadcast safety packets twice during both the control channel interval and service channel interval to increase the safety broadcast reliability [6]. The results show that the proposed protocol outperforms the IEEE 1609.4 in terms of the PDR of emergency packets and the throughput of service packets. Eenennaam et al analyzed the beaconing performance of channel switching operation in IEEE

1609.4 in different scenarios. They, also, analyzed the impact of channel switching procedure on it and finally presented the available solutions to minimize this impact [7]. Ahyar and Sari measured the performance of both safety and non-safety applications on multi and single channel operation and also for single and multi-hop topologies using NS-2[8].The last two papers: Use limited input data in the evaluated scenario; for example by only evaluating a limited number of nodes in the same transmission range of each other, all vehicles traveling at constant speed and does not take lane changes into account.

Benefits and Drawbacks of 1609.4 Channel Switching

The benefits of this protocol is clear, it can support both safety and non-safety application with different channels. However, it suffers from some problem, such as:

- Channel bandwidth is not efficiently utilized since it splits into two parts: control channel and service channel intervals. So, we cannot use SCH bandwidth during the CCH interval and vice versa.

- Long delay problem, if the node transmit its frame at the end of the current interval and the residual time is shorter than the time expected for transmission. So, the node prevents to send it but wait for the next interval or dropped it if the frame life time become expiry (Other problems also presented in figure 3).

These problems can be reduced by using multi radio devices which is considered by ETSI (European Telecommunications Standards Institute) but it costs more money and at the same time some manufacturers are concerned about this issue [9]. Another problem may take place in the case of multi radios when the node unaware of the underlying switching time. The node may broadcast its safety message during SCH interval or guard interval and the channel will treated as busy and the node go into back off mode. However, till Now there is no clear understanding of how the proposed 1609.4 compliant would coexist with multi-radio devices [10].Recent papers revealed that halving the available bandwidth might seriously compromise the performance of safety and non-safety vehicular applications over realistic scenarios.

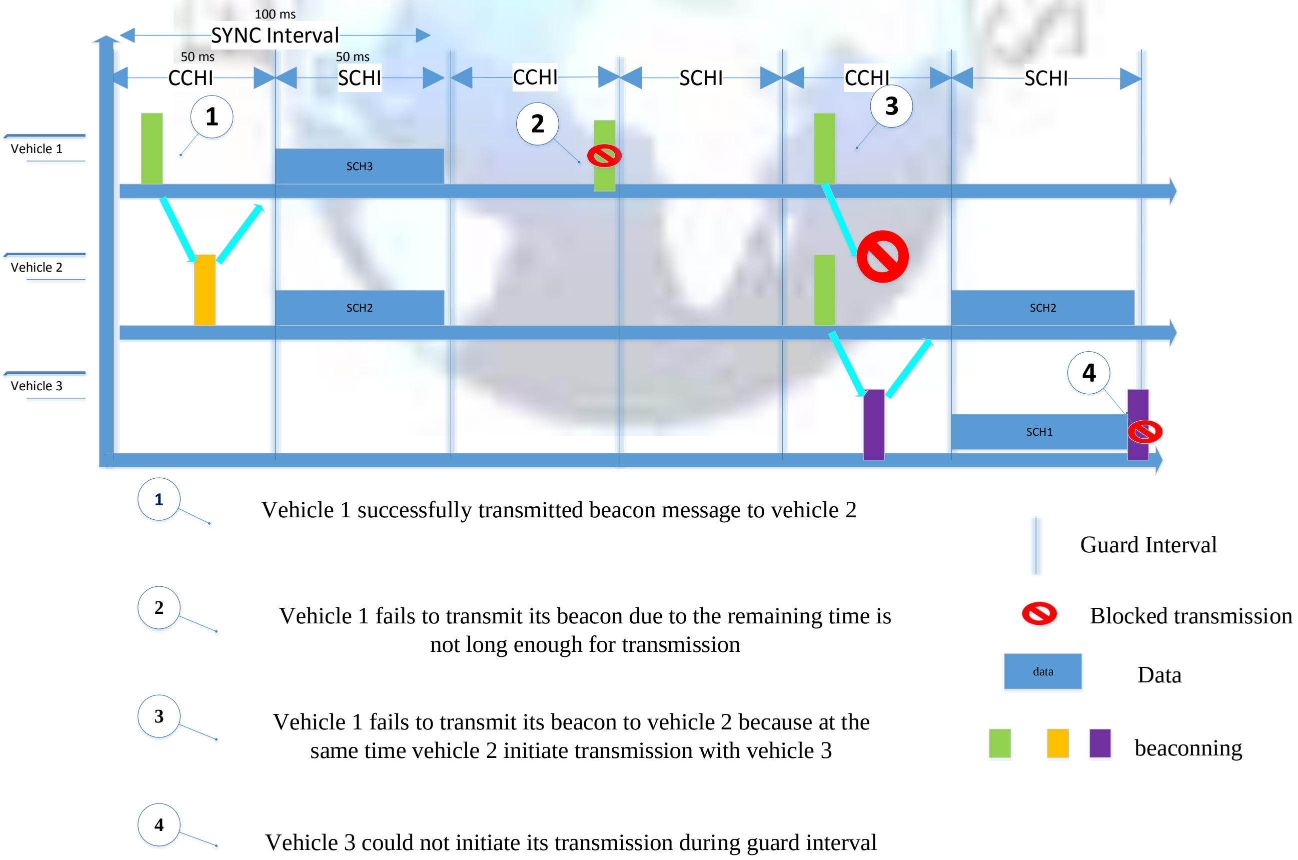


Figure 3. Some problems of multi-channel scheme

Performance Evaluation

We evaluate the performance of IEEE 1609.4 multi-channel protocol in varying VANET environment. The Simulation experiment are conducted by using OMNET++ [11] as network simulator and SUMO (Simulation of Urban Mobility) [12] as road traffic simulator to provide realistic node mobility. The latest version of Veins [13] included in MiXiM framework is used to integrate SUMO and OMNET++ to accurately simulate the communication with realistic map and realistic traffic to generate realistic results. At the start, traffic information of the cars (such as start time and position, stop time and position, origin, destination, maps, traffic lights, etc.) is generated in SUMO and then exported to the OMNeT++ which considers all the cars as nodes in the network simulator and simulates the scenario. If any change occurs in SUMO, Veins can change the cars scenario in the network. Table 1 summarizes the main network simulation parameters used in this study.

A. Realistic Traffic and Map

To generate realistic results, realistic data set is used for road network and traffic demand simulation. The realistic traffic demand for city of Northampton, in United Kingdom with real-word map for this city have been imported from the Open Street Map (OSM) database [14] to ensure real-word traffic test cases. The map shown in "Fig. 4" covers street length of 2 Km with 3 lanes in each direction for both low and high vehicle traffic flow densities. The information of traffic densities are provided by the Institute of transportation systems at United Kingdom for determining realistic car traffic in the city of Northampton. The speed of each vehicle is a random variable with a Gaussian distribution with average values different for each lane; 33.33 m/s (~120 km per hour), 27.77 m/s (~100 km/h) and 22.22 m/s (~80 km/h), and a standard deviation of 1 m/s.

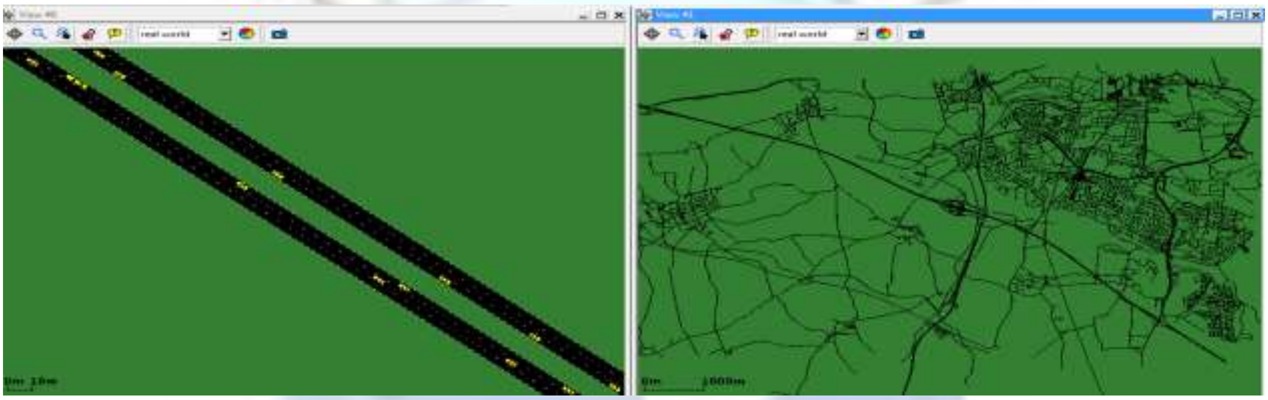


Figure 4. Highway Street in Map

These speeds are chosen with the British highway speed regulations in mind. Two types of vehicles are loaded: cars and trucks. Table 2presents traffic simulation parameters used in this study.

Table 1: Network Simulation Parameters

Parameter	Value
Carrier frequency	5.9 MHz
Data rate	6 Mbps
Number of CCH and SCHs	1 CCH, 4 SCH
Beacon generation rate	10 Hz
Service packet, Beacon length	{100,800}, {400,1000} byte
Maximum transmission power	100 mw
Sensitivity	-89 dBm
CWmin, CWmax	15, 1023

Table 2: Traffic Simulation Parameters

Parameter	Value
Vehicle mobility model	Krauss
Vehicle length	Cars=5 m, tracks=10 m
Min. gab	2.5 m
Max. acceleration	2.6 m/s²
Max. speed	33.33 m/s
Low traffic density	~12 vehicle/km/lane
High traffic density	~25 vehicle/km/lane

B. Simulation Scenarios

The experimental simulation in this paper evaluate the performance of 1609.4 multi-channel protocol for safety and non-safety applications and mainly focus on the safety messages as it is the most important and critical part of VANET safety applications. Two traffic densities are selected based on [15]:nearly 137 and 285 vehicles for the low density and high density tests respectively, which is a realistic number of nodes in range during rush and off-peak traffic times on a motorway road. The simulation length is 200 second. The transmission range of each vehicle is about 300m. In safety application scenario, all vehicles start to broadcast its beacons periodically at the start of CCH interval as soon as they enter the highway. These beacon messages containing information about their speed, position, direction etc., which is called cooperative awareness message with predetermined generation rate of 10 Hz. Beacons are broadcast messages and therefore no one will send an ACK in response. It is assumed that all nodes in the network have the same data rate on control and service channel. In non-safety application scenario, when any node receive a beacon it will send its data through SCH interval. Assuming an accident occurs on the road with vehicle number 100 during simulation scenario which has to send the warning message to its neighboring nodes, to inform other vehicles that an accident has occurred. When the safety message is generated, the node has to contend the control channel and broadcast the safety message within 50ms, otherwise this safety message is dropped. Two main simulation scenarios are analyzed and compared in this paper in order to underline the impact of the strict synchronized channel switching mechanism introduced by the IEEE 1609.4 protocol:

- **Multi-Channel (MC) Scenario:**

Vehicles in the networks periodically perform switching between control and service channel intervals every 50 ms as the legacy behavior specified in the IEEE 1609.4 protocol.

- **Single-Channel (SC) Scenario:**

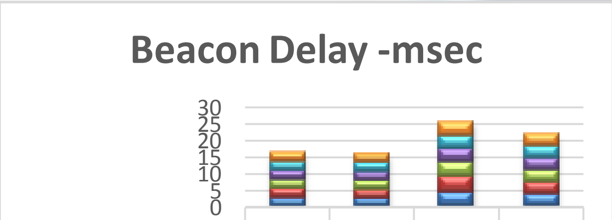
All vehicles in the network stay all the time in the CCH for control and safety message dissemination and no channel switch occurs, as defined in IEEE 802.11p. These two configurations have been evaluated for both safety and non-safety applications when a node tries to contend the channel with other nodes to send only safety messages or both safety and non-safety messages at the same time. A high priority is given to beacon message (assigning it with AC= 3) and the lower priority than beaconing is given to data packet(assigning it with AC=2).The simulation has been carried out with two different beacon lengths: 100 and 400 bytes, two different packet lengths: 800 and 1000 bytes and three different value of queue size: 1, 2, and 5. These queue size values mean how many number of packet will wait in the queue before dropping occurred.We will investigate and understand how these different parameters affect the performance of the standard protocol using different performance metrics.

Simulation Results

Theperformance of the multi-channel and single-channel protocols in realistic environment are studied by analyzing three different metrics:

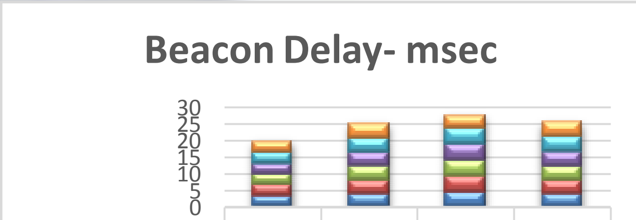
A. Average End-to-End Delay

This metric measures the time taken by a packet to travel from the source node to destination node. “Fig. 5” shows the beacon delay exchanged among vehicles in safety application. In general, as expected the delay in single-channel is lower than the delay in multi-channel due to the impact of synchronize switching between two intervals then all vehicles contend the medium for 46ms control channel interval while in single-channel the vehicles contend the medium for 100ms interval. In particular, the beacon delay in low density is higher than in high density in multi-channel scenario. This is highly unlikely situation,but due to the packet time travel in low density (longer distance) is higher than packet time travel in high density (shorter distance).For non-safety application, the delay at single channel is lower than the multi-channel case as shown in “Fig. 6”. Moreover, the delay of beacon in single-channel with a scenario that transmit both safety and non-safety messages is higher than the scenario transmit only safety messages. This is due to the beacon and packets will contend the same channel at the same time.



	low density, single channel	high density, single channel	low density, multi channel	high density, multi channel
Q=5,Beacon=400byte	2.681	2.564	4.183	3.655
Q=2,Beacon=400byte	2.73	2.79	4.183	3.655
Q=1,Beacon=400byte	2.659	2.79	3.939	3.655
Q=5, ,Beacon=100byte	2.687	2.56	4.37	3.602
Q=2,Beacon=100byte	2.863	2.77	4.936	3.65
Q=1,Beacon=100byte	2.711	2.601	4.232	3.602

Figure 5. Beacon delay (Safety Application)



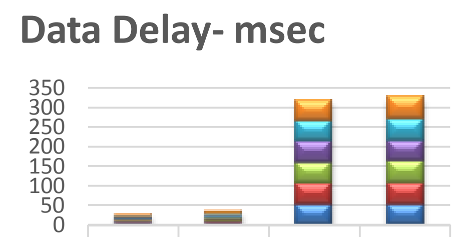
	low density, single channel	high density, single channel	low density,multi channel	high density, multi channel
Q=5,B=400, P=1000	3.39	4.509	3.7013	4.5453
Q=2,B=400, P=1000	3.2405	4.348	4.868	4.265
Q=1,B=400, P=1000	3.23	4.006	4.925	4.261
Q=5, ,B=100,P=800	3.316	4.275	4.584	4.368
Q=2,B=100,P=800	3.399	4.095	4.761	4.121
Q=1,B=100,P=800	3.23	3.987	4.681	4.066

Figure 6. Beacon delay (non-safety Application)

Regarding the queue size and beacon length, the difference of beacon and packet length has no impact on the delay. Moreover, the varied values of queue size have too little impact and queue size equal 1 has the lower delay values than others in the gathered results. The difference of data delay in non-safety application between single and multi-channel case is clear in "Fig. 7". This clear difference come from the long waiting time for a vehicle to the service channel interval in order to send its data in multi-channel case. While in single-channel protocol no switching accrued and the vehicle stay all the time in the channel.

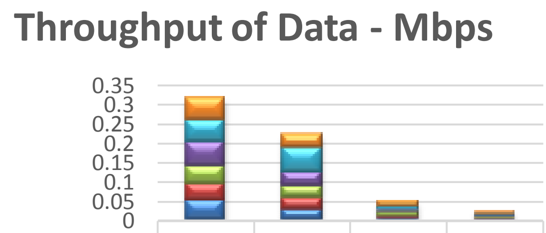
B. Packet Loss

As presented in "Fig. 9", for safety application (as expected) the multi-channel scenario suffer from higher lost packets than single channel scenario due to the implemented multi-channel mechanism which has a number of drawbacks as explained in this paper. Moreover, for non-safety application in "Fig. 10" the opposite result found where the single channel has higher delay than multi-channel. The intuitive reason for this unlikely situation is due to both packets and beacons are transmitted on the same channel at the same time and this leads to collisions at any traffic load. Naturally, the packet loss probability due to collisions increases with the increase of traffic load, so the high density traffic has higher lost packet than the low density for both scenarios due to queue overflow. As a results, it can be concluded that the single channel is not suitable to transmit both safety and non-safety messages.



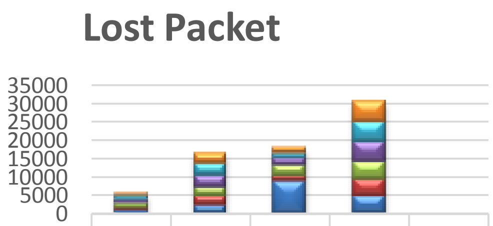
	low density, single channel	high density, single channel	low density, multi channel	high density, multi channel
Q=5,B=400, P=1000	5.462	7.4603	53.579	58.181
Q=2,B=400, P=1000	4.316	5.3594	52.98	53.83
Q=1,B=400, P=1000	4.128	4.347	51.879	51.6
Q=5, ,B=100,P=800	4.69	6.897	55.08	57.37
Q=2,B=100,P=800	4.128	4.927	52.928	53.7
Q=1,B=100,P=800	3.814	4.174	51.531	51.28

Figure 7. Data Delay (non-safety Application)



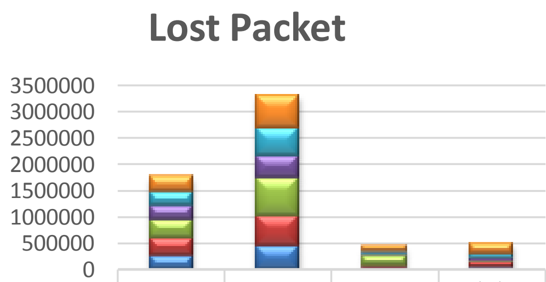
	low density, single channel	high density, single channel	low density,multi channel	high density, multi channel
Q=5,B=400, P=1000	0.0559	0.03265	0.0144	0.006415
Q=2,B=400, P=1000	0.055	0.06511	0.008599	0.00435
Q=1,B=400, P=1000	0.0626	0.0369	0.005599	0.003005
Q=5, ,B=100,P=800	0.0462	0.0291	0.01085	0.00537
Q=2,B=100,P=800	0.0454	0.02928	0.00627	0.00349
Q=1,B=100,P=800	0.05131	0.02905	0.00505	0.00236

Figure 8. Throughput of Data (non-safety Application)



	low density, single channel	high density, single channel	low density,multi channel	high density, multi channel
Q=5,Beacon=400byte	540	2579	1298	5486
Q=2,Beacon=400byte	1095	3228.9	1298	5486
Q=1,Beacon=400byte	742.3	3228.9	1987	5486
Q=5, ,Beacon=100byte	1204.7	2579	3079	4689
Q=2,Beacon=100byte	832.2	2483	1306	4820
Q=1,Beacon=100byte	900	2272	8908	4689

Figure 9. Lost Packet (safety Application)

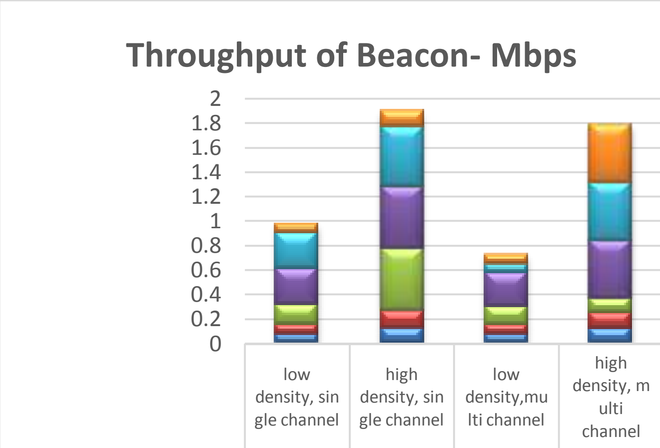


	low density, single channel	high density, single channel	low density,multi channel	high density, multi channel
Q=5,B=400, P=1000	289075	629671	104445	205710
Q=2,B=400, P=1000	258173	535779	46743	85325
Q=1,B=400, P=1000	270792	412153	21503	45313
Q=5, ,B=100,P=800	360661	707406	183571	20568
Q=2,B=100,P=800	322750	579715	49288	93207
Q=1,B=100,P=800	263108.9	449010	21361	42883

Figure 10. Lost Packet (non-safety Application)

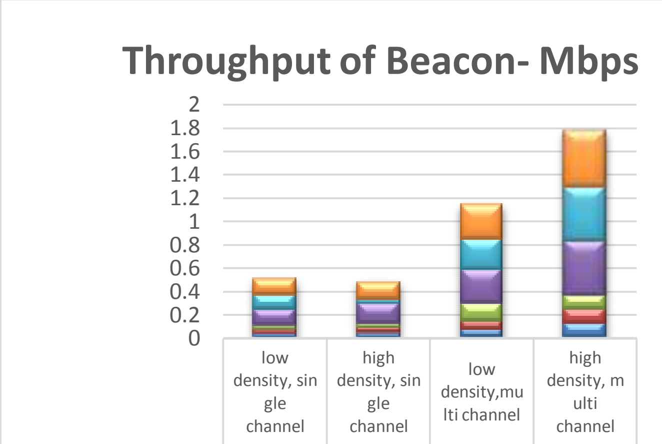
C. Throughput:

Throughput is the average number of successfully delivered data packets on a communication network or network node. As shown in “Fig. 11”, for safety application the beacons have higher throughput in single-channel than the multi-channel protocol. That was predictable, since it has lower delays and loss ratio. Also,the result shows that the beaconnig throughput has higher range at high density for both multi and single channel scenarios, this is due tolarge number of nodes in the network then large number of beacons will be broadcasted. Moreover, it can be notice that the throughput of beacons has higher values in the case of beacon length=400 byte than the lower length beacon case. When considering the effect of queue size values, the larger value of queue size has negative effect on beaconnig throughput except in the high density multi-channel scenario whereno differences is noticed with varied values. In general, q=1 is the best value that have acceptable throughput amongest all cases because it has a lower delay than other queue size values.



	low density, single channel	high density, single channel	low density,multi channel	high density, multi channel
Q=5,Beacon=400byte	0.074	0.127	0.0716	0.47006
Q=2,Beacon=400byte	0.289	0.4985	0.0716	0.47
Q=1,Beacon=400byte	0.296	0.4985	0.2741	0.47
Q=5, ,Beacon=100byte	0.159	0.511	0.1514	0.12084
Q=2,Beacon=100byte	0.082	0.138	0.0809	0.13
Q=1,Beacon=100byte	0.0728	0.126	0.073319	0.1203

Figure 11. Throughput of Beacon (Safety Application)



	low density, single channel	high density, single channel	low density,multi channel	high density, multi channel
Q=5,B=400, P=1000	0.1259	0.142	0.2871	0.475
Q=2,B=400, P=1000	0.128	0.0383	0.2689	0.463
Q=1,B=400, P=1000	0.1339	0.171	0.285	0.466
Q=5, ,B=100,P=800	0.0349	0.0394	0.147	0.1186
Q=2,B=100,P=800	0.036	0.041429	0.0798	0.128
Q=1,B=100,P=800	0.0386	0.0437	0.06923	0.122

Figure 12. Throughput of Beacon (non-safety Application)

For non-safety application,the result in “Fig. 12”shows an opposite performance to the first application since the throughput at single-channel is very small compared to the multi-chnnel scenario. Moreover, the throughput in high traffic density is higher than that in low traffic density for the same reason we mentioned above. Opposite situation found in“Fig. 8”, the throughput of data in high density is lower than that in low density scenario for both single and multi-channel. The reason is that the network will be busier with the unicast transmission of communicated vehicles.

Conclusion and Future Work

This paper investigated the drawbacks of the developed IEEE 1609.4 WAVE standard that might negatively affects the practical realization of vehicular application with strict delay requirements. By making a comparison between single-channel and multi-channel protocols for safety and non-safety messages dissemination with varied number of queue size and packet length. A detailed description of the simulation setup is given, which includes a network and road traffic simulator chosen with real-world maps, and a list of the network, traffic parameters and metrics used. From obtained results, it is found that IEEE 802.11p decreases the average beacon delay by 36% and 26%for low and high traffic density respectively for safety application. Also, decreased by 28% for low densityfor non-safety application. Therefore, the average throughput in single-channel protocol is improved for safety application by 25% and 6% for low and high density respectively. Regarding the number of packet loss, the results showed that when the density of vehicles increase, the packet loss increase due to the impact of higher number of collisions. In particular, for safety application scenario the number of lost packet decreases about 70% and 46% for single-channel protocol in low and high traffic density respectively. Based on throughput metric, it is concluded that for safety application the legacy IEEE 802.11p single-channel protocol is better than the IEEE 1609.4 multi-channel protocol. While for non-safety application, the multi-channel protocol is better than single-channel protocol. With respect to the queue size value, it is found that the queue size equal 1 case has better throughput in general.

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