How vehicles' speeds influence the optimal configuration and performance of the C-V2X

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ABSTRACT

V2X (vehicle to everything communication) is an indispensable part of the future cooperative traffic. C-V2X mode-4 has become the focuses of a lot of researches due to its high reliability, scalability and low latency without the need for support from cellular network infrastructures. SPS (Semi-Persistent Scheduling scheme) is the reason that C-V2X mode-4 is such powerful and worth much more researches. In this research, the performance of C-V2X is firstly compared between vehicles with different velocities. Then, the impacts of some SPS parameters are tested under different scenarios to try to figure out why vehicle speeds influence the performance of C-V2X. Lastly, the performance of vehicles with different speeds and corresponding packet frequencies is analyzed. PDR (Packet Delivery Ratio) is used as the measurement standard among all experiments. The results of each experiment are presented and discussed. Conclusions and possible suggestions about the improvement of the performance of C-V2x mode-4 are given based on the analysis of the results.

Keywords

C-V2X mode-4, SPS, Performance, Speeds, Packets Frequency.

1. INTRODUCTION

1.1 Background

Vehicle communication is an essential part of future cooperative traffic safety and management and receives more and more attention nowadays. Ideally, vehicles on roads can reliably share information gathered from their sensors with each other in a very low delay. With data from other cars, cars with safety applications can make proper decisions, improving traffic safety. For example, by sharing the location data extracted from the GPS, vehicles can immediately realize the presence of other nearby vehicles, lowering the risk of traffic accidents. As a result, V2X, vehicles to everything communication, has become a hot research topic. Currently, there exist two types of V2X, WLAN-based V2X and cellular-based V2X (C-V2X). WLAN-based V2X is based on the technology which is part of the IEEE 802.11 family of standards and has been equipped by some brands in their cars due to its low latency. C-V2X is more recent and uses cellular networks. Since it has several advantages over WLAN-based V2X, especially in reliability[1], C-V2X is considered as the future of the V2X. Thus, this research focuses on C-V2X.

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1.2 State of art

In release 14, 3PGG introduced C-V2X mode-3 and mode-4, which support vehicle communication by cellular network technology. With the support of C-V2X, vehicles can directly communicate with each other through the PC5 interface. The significant difference between mode-3 and mode-4 is that mode-4 supports transmission when vehicles are out of the coverage of cellular infrastructures. Because traffic safety should not entirely rely on the availability of cellular networks, thus, mode-4 worth more researches. In mode-4, vehicles should select resources by themselves with limited information. However, when two adjacent vehicles choose the same resource, messages may lose because of the interference between messages sent by these vehicles. The reliability of communication is critical to traffic applications. Therefore, in mode-4, a sensing-based Semi-Persistent Scheduling (SPS) scheme, which supports the subchannel selecting, is introduced and standardized (details will be introduced in section 2). Although [3] has proved that SPS can handle the worst case in the urban (Manhaton) scenario, SPS still has a significant potential to be improved. So far, there are many inspiring and valuable researches finding that SPS can have different optimal configurations in different contexts. [6] finds that parameters of SPS such as Resource Reservation Period and Reselection Probability can have different effects on the performance of C-V2X under various scenarios in which different numbers of vehicles are assigned to equal size areas. Besides, the configurations of SPS are also analyzed from two aspects (PHY and MAC layers) under three scenarios(Cologne, Bologna and Highway) in [2]. Also, [7]tries to figure out the best configuration of SPS in highly congested roads. The density of the vehicles and packets is the main focus of most research. At the same time, few studies have compared the influence of SPS configurations and packet frequency on the performance of C-V2X mode-4 between vehicles at different speeds.

1.3 Motivations

If vehicle velocity does have an obvious impact on the performance of C-V2X mode-4, configuration parameters should be analyzed to figure out affecting factors. Then the configuration can be optimized based on the vehicle speeds to counteract the negative influence caused by speeds.

Vehicles regularly broadcast information to inform their status. Cars with different speeds need corresponding frequencies of packets to keep the accuracy of transmitted data. However, vehicle velocity and packets rate probably have opposite effects on the performance. For instance, a fast vehicle requires a high packets rate. High velocity supposes to have positive impacts, while high packet rate compromises the performance.

1.4 Research questions

This research focuses on three problems. Vehicles with different speeds may perform differently with the same settings of SPS. This difference in performance may be caused by some SPS parameters. Therefore, the impacts of two critical parameters of SPS (Sensing Window and Resource Keep Probability) are compared between vehicles at different speeds. Furthermore, the packet frequency together with vehicle speed may have unpredictable influences on the performance. In general, this research tries to answer the following three research questions:

- How the speeds of vehicles affect the performance of C-V2X.
- How the speeds of vehicles affect the function of the Sensing Window and Resource Keep Probability.
- What is the performance if corresponding packet frequencies are used by vehicles with different speeds.

1.5 Paper structure

In section two, relevant technical details of C-V2X mode-4 and SPS will be introduced. Section three will talk about the tools and metrics used in research as well as detailed settings of simulation and different traffic scenarios. The expected experiment results will be introduced and explained in section four. In section five, simulation results will be analyzed and compared with the expected results. Section six will talk about the limitation and deficiencies of this research. Section seven is the conclusion of the study.

2. C-V2X MODE 4

Figure 1 presents a simple model of C-V2X. C-V2X uses Single-Carrier Frequency-Division Multiple Access (SC-FDMA) and supports both 10MHz and 20MHz channels. The channel is divided into 180KHz Resources Blocks (RBs) in terms of frequency and 1ms subframes in terms of time. Several RBs in the same subframe can constitute a subchannel that is used to transmit messages. Two types of messages are used in transmissions, which are Transport Blocks (TB) and Sidelink Control Information (SCI). TB, which usually occupies several subchannels, contains data and is transmitted over Physical Sidelink Shared Channels (PSSCH), while SCI, which occupies 2 RBs, contains crucial control information and is spread over Physical Sidelink Control Channels (PSCCH). Each TB has a corresponding SCI. TB and its SCI should be transmitted in the same subframe. TB and SCI can use adjacent or non-adjacent subchannels. In the latter case, SCI can only use reserved specific resources rather than subchannels.

2.1 Semi-Persistent Scheduling scheme (SPS)

To efficiently allocate transmission resources and minimize interference, SPS is used when vehicles are out of coverage of cellular infrastructures. The whole process of SPS is divided into three steps.

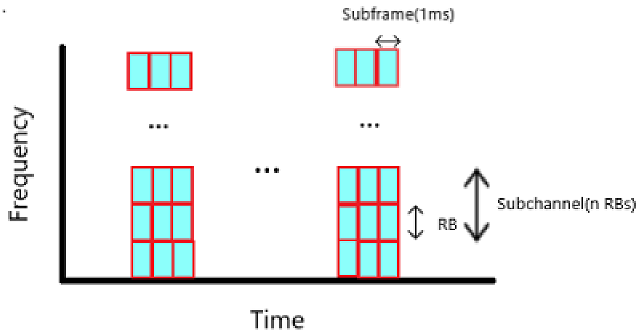

Figure 1. C-V2X

1. When a vehicle V needs to find new resources. It has to find Candidate Single-Subframe Resources (CSRs) within Selecting Window. A CSR is a group of subchannels in the same subframe
2. During Sensing Window, which usually includes the last 1000 subframes before Selecting Window, vehicle V senses the status of the channel. V forms a list *L1* of CSRs, and some CSRs should be excluded if they fulfill one of the following two conditions.
   - Within Sensing Window, if an SCI from another vehicle indicates that that vehicle will use this CSR to transmit its packets.
   - Based on SCI, the average Reference Signal Received Power (RSRP) over this CSR is measured. The calculated RSRP of this CSR is higher than a given threshold.

   L1 should contain at least 20% of all found CSRs in Step 1. If *L1* is smaller than required, Step 2 will be iterated until 20% CSRs are selected. In each iteration, the RSRP threshold will be increased by 3dB.
3. Vehicle V creates a new list *L2*, which chooses CSRs with the lowest Received Signal Strength Indicator (RSSI) from list *L1*. The size of *L2* should equal 20% of the number of CSRs in Step 1. Then V randomly chooses a resource from *L2*. The chosen resource will be reserved to transmit several packets. The number of packets to be transmitted through this resource is arbitrary (usually between 5 and 15), and is indicated by Reselection Counter.

When Reselection Counter reaches zero, V has the possibility P (Resource Keep Probability) to reserve a new resource by going through the above three steps again and the possibility *1-P* to keep using the previous resource.

3. SIMULATIONS

3.1 Evaluation metrics

The evaluation metrics used in this research is the Packet Delivery Ratio (PDR).

Packet Delivery Ratio: the ratio of the number of packets received by the receiver to the number of packets transmitted by the transmitter.

3.2 Simulator

SUMO, OMNET++ and VEINS are used in this research. SUMO is a software that can build different models of traffic, including roads and vehicles. OMNET++ is a simulator of network transmission. VEINS is a framework that

Table 1. Software versions

Software	Version
SUMO	1.2.0
OMNET++	5.5.1
VEINS	5.0

Table 2. Simulation configuration parameters

Parameters	Value
Sensing Window	100ms
Subchannel Size	16
Number of Subchannels	3
Packet Size	190 Bytes
Packets frequency	10Hz
RSRP Threshold	-110 dBm
Transmission Power	23 dBm
Resource Keep Probability	0.4

integrates SUMO and OMNET++. Table 1 shows the version of the software used in this research. Due to the limitation of time, an open-sourced C-V2X mode-4 simulator implemented over SUMO, OMNET++ and VEINs is used in this research[5]. Table 2 describes the default simulation configuration. To simplify the simulation, it is assumed that all vehicles in each simulation have identical settings.

3.3 Scenarios

Sumo is used to build models of traffic. Figure 2 presents the model of the road used in all simulations. It is a 2km bi-direction road with three lanes in each direction. Each lane is 4m width. Vehicles are evenly distributed in six edges. It is a simplified model of the highway. Table 3 shows three scenarios designed for the first two research questions.

3.4 Particular scenarios designed for the third research question

Corresponding packet frequencies are tested under scenarios with different vehicle speeds. The packet frequencies are calculated based on vehicle speeds following the below formula. Table 4 presents the four different scenarios and their corresponding packet frequencies to evaluate. These scenarios are specifically for the third research question. The packet frequencies are calculated based on the assumption that vehicles should keep one-meter accuracy. One-meter accuracy is that at least one packet should be broadcast whenever a vehicle moves one meter. Therefore, higher velocity requires higher packet frequency.

$$PacketSendingPeriod(s) = \frac{1}{VehicleVelocity(m/s)}$$

4. EXPECTED RESULTS

The expected experiment results will be discussed based on the analysis and understanding of C-V2X mode-4.

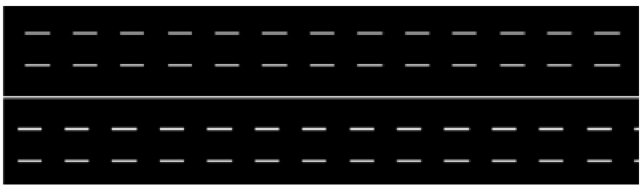

Figure 2. Road model in simulation

Table 3. Settings of Scenarios

Scenarios	A	B	C
Number of Vehicles	120, 240	120,240	120,240
Vehicle speeds	200km/h	50km/h	15km/h

4.1 How the speeds of vehicles affect the performance of C-V2X.

Both [4] and [5] have presented that C-V2X mode-4 performs worse in scenarios where vehicles have lower speeds. Although they did not keep the density of vehicles constant in each scenario, vehicle speed alone, in principle, should have an impact on the performance of C-V2X mode-4. Furthermore, low vehicle velocity supposes to compromise the performance because of some SPS parameters. For example, a small Sensing Window has a negative influence on slow vehicles, and the default value of the Sensing Window of the simulator used in research is quite low (100ms). Resource Keep Probability is also affected by speeds. The influences on these two parameters are explained in detail in the next subsection. As a result, scenario A should have the best performance among the three scenarios, followed by B and C.

4.2 How the speeds of vehicles affect the function of Sensing window and Resource Keep Probability.

In this research, Sensing Window and Resource Keep Probability P are tested in scenarios A, B and C. There are 240 vehicles in each scenario.

4.2.1 Sensing Window

During Sensing Window, control information is collected by vehicles to prepare for resource selection. Larger Sensing Window means vehicles have more time to sense the status of the channel.

High velocity: Collecting more control information also means a higher probability of gathering outdated information because older information is collected. In fast scenarios, valid data become outdated fast because vehicles change their locations quickly. Therefore, When vehicles are very fast, the probability of acquiring outdated information can be quite high. As a result, vehicles with high speed should perform worse while having larger Sensing windows.

Low velocity: Slower vehicles are less sensitive to the aging of information because they change their location slower. Control information thus remain valid longer. Therefore, large Sensing Window should have a small influence on vehicles with low velocity. However, if Sensing Window is too short, vehicles probably cannot collect enough control information to choose suitable sources. With short Sensing Window, a slow vehicle may not be able to get all useful information. Therefore, short Sensing Window can have a negative influence on slow vehicles.

4.2.2 Resource Keep Probability P

When Reselection Counter reaches zero, vehicle V has the possibility P (Resource Keep Probability) to reselect resources and the possibility *1-P* to keep using the previous resource.

High velocity: Fast vehicles with low P may not be able to reselect proper resources in time while encountering other vehicles. For example, once two vehicles come into each other's transmission range, they need to reselect resources based on the new context. However, due to the

Table 4. Settings of Scenarios

Scenarios	D	E	F	G
Number of Vehicles	240	240	240	240
Vehicle speeds	120km/h	60km/h	45km/h	25km/h
Packets Period	0.03s	0.06s	0.08s	0.15s

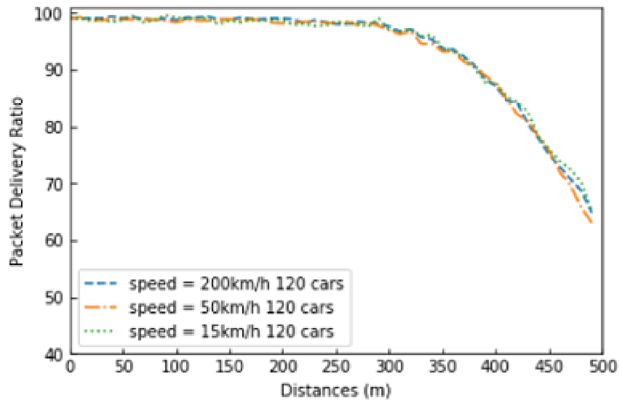

Figure 3. Speeds influence with low density

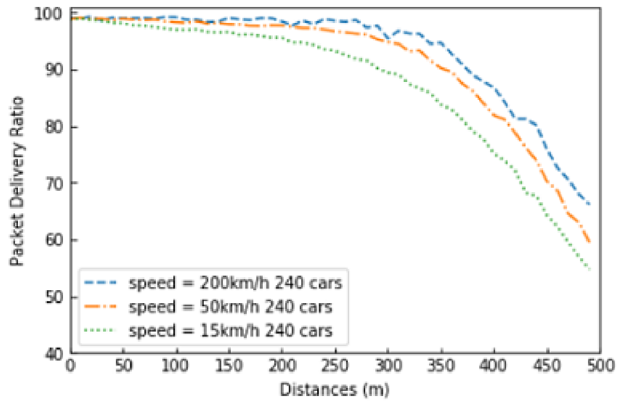

Figure 4. Speeds influence with high density

low P, these two vehicles tend to keep the same resource. Besides, the transmission environment changes fast in the fast scenario. Therefore, low Resource Keep Probability supposes to have negative impacts on vehicles with high velocities. Nevertheless, high Resource Keep Probability will not have a big influence on fast vehicles.

Low velocity: Slow vehicles with high P usually reselect resources more frequently than enough. Therefore, the possibility of selecting the subchannels with interference should be higher. As a result, high Resource Keep Probability supposes to have negative impacts on vehicles with low velocity. However, low Resource Keep Probability should have a tiny influence on slow vehicles.

4.3 What is the performance if corresponding packets frequencies are used by vehicles with different speeds.

Although vehicles with higher velocity should have better performances, they have much higher packets density because they require higher packet rate to keep accurate. [6] shows that packets density can influence the performance of C-V2X dramatically. Therefore, the influence of packets density should outweigh the impact of speed. Vehicles with higher velocity and packets frequency suppose to perform worse.

5. EXPERIMENT RESULTS

The simulation results are analyzed with the help of Python. Some packages of Python, such as NumPy, Pandas and Matplotlib, are compatible with OMNET++ and very powerful in the data analysis. PDR, Packet Delivery Ratio, is presented as a function of distances between transmitter and receiver.

5.1 Influence of Velocity

Figure 3 and 4 compares the influence of vehicle velocity on the performance of C-V2X mode-4. In figure 3, vehicle density is low. Thus transmission load is low enough, and the channel is stable enough. Vehicle speeds do not influence the performance because vehicles in scenarios A, B and C can all have their best performance without the worry of interference. When it comes to high vehicle density(figure 4), the impacts of vehicle velocity become more obvious because the channel, in this case, has a higher load, thus the interference in channel is more often. This result is similar to the expected results. However, the cause of the influences of vehicle speeds is different from what is expected because the speeds' effects on the functions of Sensing Window and Resource Keep Probability are unexpected (will discuss in the next subsection). Given a scenario that two slow vehicles choose the same resource, they experience the interference much longer while compared to faster vehicles because it takes a longer time for slower ones to leave each other. Therefore, lower velocity can also increase the load of the channel and compromise the performance of C-V2X mode-4.

5.2 Sensing Window and Resource Keep Probability

Only the results from scenarios with high vehicle density (240 vehicles) are presented because the performance difference is too small to be noticed in scenarios with low vehicle density(120 vehicles).

5.2.1 Sensing Window

Figure 5,6 and 7 indicate the influence of Sensing Window on C-V2X performance in scenarios with different vehicle speeds. SW represents the Sensing Window. The simulation results are different from expectations. The impact of the Sensing Window becomes more obvious while vehicles are slower. This result is also caused by the changing of the channel load. When cars are fast, the channel is stable and has a low possibility of interference. The changing of the Sensing Window is not able to make a difference in the performance of C-V2X mode-4. While cars have lower velocity, the load of the channel is higher, as explained in the previous section. Therefore, the performance changes with the modification of the sensing window. Besides, the result also indicates that a 100ms Sensing Window is large enough for the research model. When the Sensing Window is larger than 100ms, the performance becomes worse because more outdated information is collected.

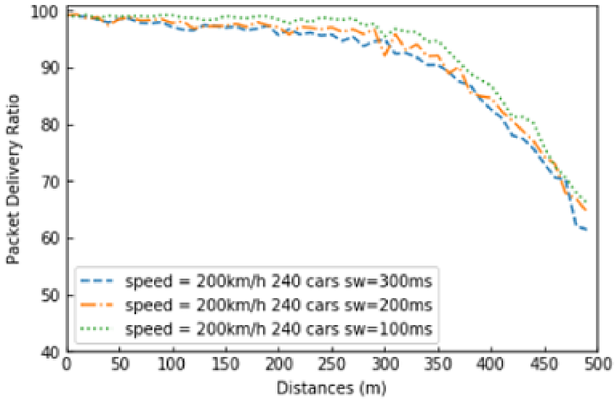

Figure 5. Sensing Window impact with 200km/h

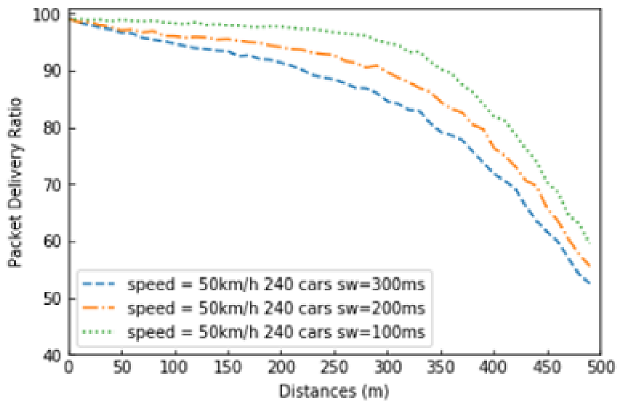

Figure 6. Sensing Window impact with 50km/h

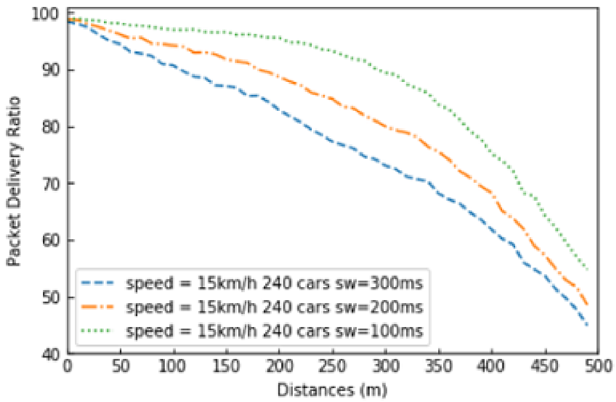

Figure 7. Sensing Window impact with 15km/h

5.2.2 Resource Keep Probability P

Figure 8,9 and 10 describe the influence of Resource Keep Probability on C-V2X performance in scenarios with different vehicle speeds. *RKP* represents the Resource Keep Probability. The simulation results are also different from the expected results. Similar to the Sensing Window, the impact of Resource Keep Probability is minimal on vehicles with speeds of 200km/h while maximum on vehicles with speeds of 15km/h. The lower probability of reserving new resources (lower Resource Keep Probability) is, the lower performance of C-V2X mode-4. If two vehicles with small Resource Keep Probability choose the same reservation, they are likely to keep using the same resource with interference continually occurring. This aspect was

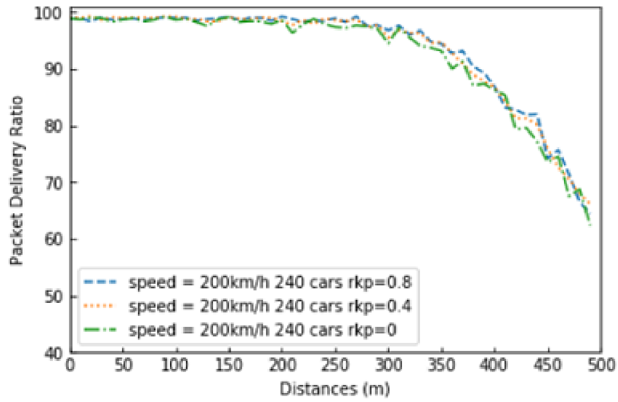

Figure 8. Resource Keep Probability impact with 200km/h

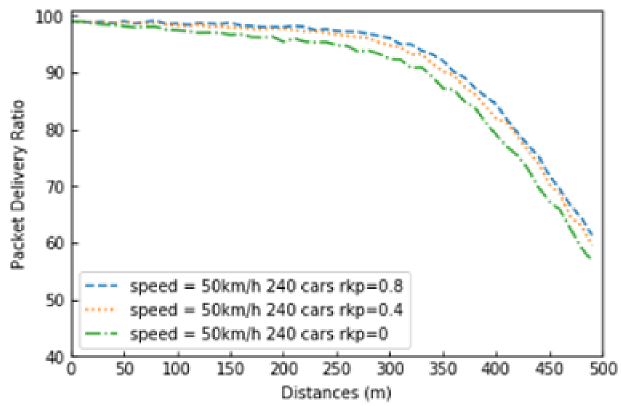

Figure 9. Resource Keep Probability impact with 50km/h

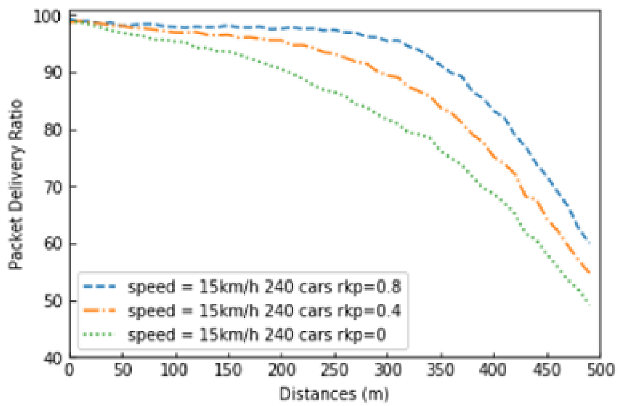

Figure 10. Resource Keep Probability impact with 15km/h

ignored in the expected results.

5.3 Vehicle speeds and Packets Frequency

Figure 11 shows the performances of C-V2X mode-4 on vehicles with different speeds and corresponding packets frequencies. *Period* determines the time interval of broadcasting packets. The impacts of packet frequency are counteracted by the effects of vehicle velocity. This result is gratifying since it indicates that vehicles with higher speed are more able to bear the negative influence of higher packet frequency. Therefore, the sacrifice of performance to maintain the accuracy of the information in fast scenarios is smaller than expected.

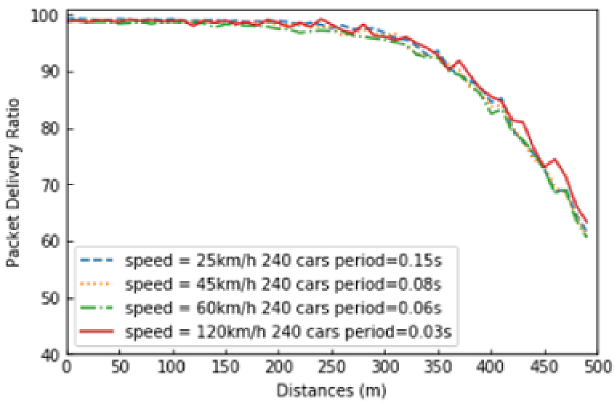

Figure 11. Performance with different velocity and packets frequency

6. DISCUSSION

This research still has many deficiencies. First of all, the experiments do not cover all main SPS parameters such as Selecting Window and RSRP threshold. Their functions should more or less be influenced by vehicle speeds as well. Secondly, the simulation does not go through all possible values of Sensing Window and Resource Keep Probability. Thus, the simulation may ignore some values which have distinctive impacts. Thirdly, due to the limitation of hardware, more congested scenarios have not experimented. Besides, only the highway scenarios are studied in the research, more complex and common scenarios such as urban areas should be studied in the future. Last but not least, to simplify the simulation, all vehicles are assumed to have an identical configuration. However, the real world is much more complicated. Different vehicles can have different speeds as well as V2X configurations. Consequently, the influence of velocity can be different in reality. Therefore, real world application testing is needed to verify the research results.

7. CONCLUSION

In this paper, the impacts of vehicle velocity on the performance of C-V2X mode-4 are investigated based on an open-source simulator. Speeds' influence on the functions of Sensing Window and Resource Keep Probability are also analyzed, respectively. Based on the test results and analysis, research questions introduced before can be answered:

- *How the speeds of vehicles affect the performance of C-V2X.*

  Low velocity has a negative impact on the performance of C-V2X mode-4, and the performance is more stable at higher speeds.

- *How the speeds of vehicles affect the function of the Sensing Window and Resource Keep Probability.*

  Sensing Window and Resource Keep Probability only have visible effects on slow vehicles. Vehicles with Sensing Window larger than an optimal value have worse performances of C-V2X mode-4. The larger the Resource Keep Probability is, the better performance of C-V2X mode-4.

- *What is the performance if corresponding packets frequencies are used by vehicles with different speeds.*

  Faster vehicles can withstand higher packet frequencies because the influence of speeds can cancel out the impact of packets density to some extend.

This research is valuable for the community since it looks into an area (influence of velocity) few studies have focused on before. Further studies should be done to have a better understanding of the influence of velocity.

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