Performance Evaluation of DSRC and C-V2X Coexistence in the 5.895–5.925 GHz Spectrum

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Abstract—**Two competing radio access technologies (RATs) are presently available for intelligent transportation systems: Dedicated short-range communication (DSRC) and cellular vehicle-to-everything (C-V2X). Recent FCC rulings allocate 30 MHz worth of spectrum (5.895–5.925 GHz) for both RATs, recommending 20 MHz (2 channels) for C-V2X and 10 MHz (one channel) for DSRC. However, significant debate has ensued on the optimality of such a split, not to mention the fact that it does not consider the possibility of both DSRC and C-V2X coexisting over the same channel. In this paper, we study various performance metrics related to the coexistence of DSRC and C-V2X, considering different configuration parameters under both highway and urban scenarios. Extensive simulations are conducted using WiLabV2XSim, a discrete-event simulation tool for modeling vehicular networks. Our results reveal that, contrary to common wisdom, in highway scenarios it is more efficient to assign two channels for DSRC and one channel for C-V2X. Conversely, in urban scenarios, allocating one channel for DSRC and two channels for C-V2X leads to superior performance. The paper also discusses various challenges for coexistence between DSRC and C-V2X, including interference and differences in the MAC layer designs. Overall, the study provides insights into optimizing the allocation of channels between DSRC and C-V2X to mitigate the effects of coexistence and improve the performance of vehicular communication systems.**

Index Terms—**DSRC, C-V2X, ITS Services, Shared Spectrum.**

I. INTRODUCTION

Rapid technological advances in wireless and sensing technologies, combined with widespread adoption of cloud/edge computing platforms, have fueled global interest in intelligent transportation systems (ITS) and connected and autonomous vehicles (CAVs). In 2021, there were about 237 million Internet-connected vehicles worldwide. This number is expected to exceed 400 million by Year 2025 [1]. ITS involves various modes of vehicular communications, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), vehicle-to-pedestrian (V2P), etc.; collectively, referred to as vehicular-to-everything (V2X). Augmented with sensing modalities (e.g., cameras, radar, etc.), V2X increases a vehicle's situational awareness, facilitating beyond line of sight (BLOS) safety applications, such as congestion/merge alerts, as well as non-safety applications, such as cooperative adaptive cruise control, infotainment, and self-parking, among others.

Both dedicated short-range communication (DSRC) and cellular vehicle-to-everything (C-V2X) have emerged as promising radio access technologies (RATs) for V2X. DSRC is a contention-based RAT based on the IEEE 802.11p standard. It supports V2V and V2I. C-V2X was first specified in 3GPP Rel. 14. Built on LTE-Advanced (LTE-A), C-V2X supports more diverse forms of V2X than DSRC, achieves higher throughput, improves resilience to interference, and guarantees low latency for time-critical V2X.

Although C-V2X seems to be winning the race in the US, it is quite likely that DSRC and C-V2X (and its 5G sequel, known as NR V2X) will both be used in the foreseeable future. This is attributed to three factors. First, many existing vehicles are already retrofitted with DSRC radios, which will be hard or costly to replace with a new technology. Second, DSRC is still favored in some regions outside the US, particularly Europe and Japan. Third, enhancements to DSRC are currently underway, making the next-generation DSRC a serious contender to C-V2X. It is, therefore, imperative to investigate the coexistence of these two heterogeneous RATs (one is contention based while the other is schedule based).

Seven channels of 10 MHz each, reserved around 5.9 GHz were allocated for ITS in 1999, as shown in Figure 1. A similar allocation was issued in Europe in 2008. In both cases, the allocations were implicitly addressing DSRC. A technology like V2X only works if a substantial percentage of the vehicles on the road use it. But the failure of automakers to actually build DSRC into their cars means there is no user base to benefit from the technology, even after two decades. In 2020, the Federal Communications Commission (FCC), responsible for regulating and overseeing spectrum allocation in the US, made a decision to reallocate 45 MHz from V2X to Wi-Fi [2].The upper 30 MHz of the band (5.895-5.925 GHz) is still reserved for ITS as shown in Figure 1. Both DSRC and C-V2X share these 30 MHz of band which means they both have to co-exist in a way that achieves the best performance.

To the best of our knowledge, there is currently no literature available that specifically tackles the challenge of channel allocation to attain optimal performance while considering the coexistence of DSRC and C-V2X technologies. To thoroughly investigate the comparative performance of DSRC and C-V2X technologies, a simulation-based approach was employed using the WiLabV2XSim simulator [3]–[6]. This simulator, developed in MATLAB, is specifically designed for modeling vehicular networks with a primary focus on the cooperative awareness service. We evaluated the performance of both technologies in highway and urban environments. Surprisingly, the findings of this investigation revealed that employing dif-

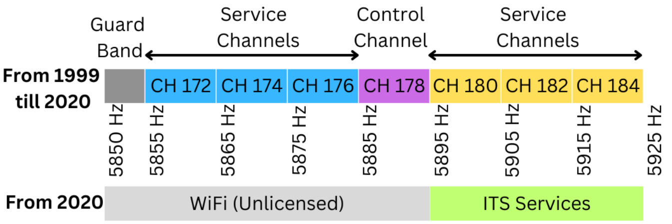


Fig. 1. Frequency and channel allocation of the 5.9 GHz band reserved for ITS before and after 2020.

ferent channel allocations for DSRC and C-V2X technologies yields better results in different scenarios. Specifically, using two channels for DSRC and one channel for C-V2X proves advantageous in the highway scenario, while utilizing one channel for DSRC and two channels for C-V2X demonstrates superior performance in urban environments.

The rest of this paper is as follows. In Section II, we introduce two vehicular RATs: DSRC and C-V2X. Then, we summarize related work in Section III. We address coexistence challenges in Section IV and introduce the WiLabV2XSim simulator and its settings in Section V. We summarize our results in Section VI, following by conclusions in Section VII.

II. OVERVIEW OF V2X RADIO ACCESS TECHNOLOGIES

Dedicated Short Range Communication (DSRC): The DSRC amendment was released in 2010, as part of the wireless access in vehicular environment (WAVE) protocol suite in the US. A slightly modified version, denoted by ITS-G5, was included in the cooperative-intelligent transport systems in Europe [7]. DSRC makes use of CSMA/CA at the MAC layer. This leads to allowing a fully distributed and uncoordinated access to the wireless channel, with no need for a resource allocation procedure. A node that needs to transmit senses the medium to check if it is idle, and random back-off mechanism is performed to reduce the probability of collisions. For vehicular networks, acknowledgements and retransmissions are not used [4], [7], [8]. The physical layer is based on OFDM with 48 subcarriers for user payload and 4 pilot subcarriers. The OFDM symbol lasts 8 µs and the subcarrier spacing is 156.25 kHz with a bandwidth of 10 MHz. The packet is preceded by a preamble for synchronization. 8 modulations and coding schemes (MCS) are possible. Depending on the adopted MCS, the data rate varies between 3 and 27 Mbps [4], [7], [8].

Cellular Vehicle-to-Everything (C-V2X): C-V2X was defined in Release 14, based on the device-to-device (D2D) of Release 12 [7]. It is also called sidelink and its communication interface is named PC5. It relies on single carrier frequency division multiple access (SC-FDMA). The subcarrier spacing is fixed to 15 kHz and subcarriers are used in groups of 12. The subframe of 1 ms consists of 14 symbols. C-V2X has a high number of MCSs, with 4-QAM and 16-QAM modulations and an almost continuous coding rate [4], [7], [8]. C-V2X is designed to enable the cooperative awareness service which has periodic transmissions of messages to inform about the vehicle status and movements. The resource allocation is normally performed with a semi-persistent scheduling (SPS) mechanism. In SPS mechanism, certain radio resources are pre-allocated to specific UEs for a predefined period of time, usually longer than a single transmission time interval. This provides a level of continuity for the UEs, allowing them to efficiently communicate without needing constant resource allocation in every transmission interval. However, it's not as rigid as full persistent scheduling, which assigns resources for an extended period without flexibility.Two different approaches are defined by 3GPP for the resource allocation, namely Mode 3 and Mode 4, depending on the entity in charge of allocation [4], [7], [8].

In Mode 3, the resources allocated to each vehicle are defined by the network. This requires that the vehicles are within the coverage of a base station and that some information is exchanged between the vehicles and the base station. It takes advantage of the large processing capabilities and more detailed view of the state of the network, and so it is expected to enable improved performance [4], [7], [8]. In Mode 4, also known as autonomous mode, each node selects the resources to use based on a sensing procedure and an SPS mechanism. The algorithm is defined in details by 3GPP [5], [9]. Figure 2 illustrates how the SPS works. At the MAC layer, a resource is randomly selected within a set received from the physical for a period of time between 5 to 15 times the packet generation interval. After that, the same resource is kept for another random interval with probability p_k (set by the operator within 0 and 0.8) and changed otherwise. At the physical layer, the resources are monitored for a window $TSense = 1$ s, comparing the received signal strength with a given threshold and reading sidelink control information (SCI) messages that advertise future reservations. From the resources that are assumed not used in the next packet interval, the 20% with the highest received signal strength are selected and passed to the MAC. If less than 20% resources are estimated free, the threshold is increased by 3 dB and the process is repeated.

III. RELATED WORK

Since the first experiments with DSRC, studies to compare its performance to that of C-V2X have been carried out [10], [11]. Jellid et al. [10] presented a comparative study between DSRC and C-V2X based on several criteria as well as a simulation to evaluate the performance of packet delivery in which either DSRC or C-V2X is solely used in the environment. Moreover, Hu et al. [11] conducted link level simulations of C-V2X and DSRC for several types of scenarios. Simulation results showed that C-V2X can achieve the same Block Error Ratio with a lower Signal Noise Ratio than DSRC.

The coexistence of the two technologies were discussed in multiple papers [12]–[15]. Naik et al. [12] provided a comprehensive theoretical overview of the various coexistence scenarios in the 5 GHz bands. In this paper, they discussed coexistence issues between a number of important wireless technologies— LTE and Wi-Fi, radar and Wi-Fi, dedicated short range communication (DSRC) and Wi-Fi, and coexistence among various 802.11 protocols operating in the 5 GHz bands. Additionally, they identified and provided brief discussions on the coexistence issue between Cellular V2X and DSRC/Wi-Fi. Ansari et al. [13] discussed hybrid V2X environments supporting concurrent and simultaneous operations of DSRC and C-V2X. Either a single transmitter system containing only DSRC or C-V2x is used or a dual transmitter system where a combination of DSRC and C-V2X transmitters is used. Ghafoor et al. [14] present a QoS-aware relaying algorithm that incorporates multi-metric to prioritize dual interface vehicles and provides robust communications among vehicles that are equipped with different RATs.

In [15], Elbal et al. used idle users to boost the signal coming from the Base Station (BS) and therefore to improve the coverage of the overall network. Furthermore, the authors analyze a scenario where both standards coexist: the cellular users enhance the signal from the BS while DSRC users act as interferes in the relay-assisted link. To model the interference of the DSRC users, they considered both perfect and imperfect Carrier Sense Multiple Access (CSMA). King et al. [16] proposed a cognitive protocol translator capable of translating between LTE Sidelink device-to-device (D2D) and DSRC packets, allowing interoperability of the two technologies. They propose this hybrid architecture as a potential solution to address the challenge of interoperability. They demonstrated through simulations the feasibility of their solution and show how the protocol converter has no adverse effect on packet delivery performance of the DSRC and LTE-V2X technologies. In [17], Shen et al. proposed a service-aware RAT selection algorithm that enables a heterogeneous LTE/DSRC solution. Each vehicle is equipped with both LTE and DSRC interfaces. The heterogeneous solution selects RAT based on the services requirements with consideration of the networks performance. To the best of our knowledge, no existing literature addressed the allocation of the three ITS channels to achieve optimal performance for DSRC/C-V2X technologies.

IV. COEXISTENCE CHALLENGES

The coexistence of these two technologies presents several challenges. One of the main challenges is the interference caused by the simultaneous use of the same frequency band. Since both DSRC and C-V2X operate in the same frequency band, they can potentially interfere with each other. This concern has been previously addressed in related studies, where interference models were introduced to mitigate the problem [13]–[15].This can result in degraded performance and reduced reliability of both systems, leading to communication breakdowns and unsafe driving conditions. This effect can be increased after the FCC reallocated 45 MHz from the ITS 5.9 GHz band to be used for Wi-Fi and unlicensed use.

Another challenge is the differences in the design of the two systems. The DSRC MAC layer uses CSMA/CA like mechanism for sensing the channel while C-V2X MAC layer uses SPS for transmission scheduling. This increases the probability of collisions and further degrades the overall performance. This can also lead to unfair allocation of resources and inefficient use of the available bandwidth. Fig. 2 shows how both SPS and CSMA/CA interacts. During the sensing time, SPS can sense the existence of DSRC transmissions within the resource blocks where DSRC is transmitting. SPS can also sense the existence of C-V2X transmissions in different resource blocks. Then SPS avoid these resource blocks while scheduling to decrease collisions probabilities. The problem occurs when the SPS schedule transmission in a resource block. A collision takes place when both the C-V2X vehicle and the DSRC vehicle begin transmitting traffic simultaneously on the same resource block time.

In short, the coexistence of DSRC and C-V2X presents several challenges that must be addressed to ensure safe and efficient vehicular communication. Ongoing research and development are needed to overcome these challenges and to enable the widespread adoption of these technologies for safer and more connected driving experiences. Solutions for coexistence challenges should be devised to optimize the coexistence by minimizing interference and ensuring fair resource allocation.This paper aims to estimate the optimal allocation of the three available channels between DSRC and C-V2X technologies in order to minimize the impact of coexistence and achieve superior overall performance. We can either use the three channels shared for both DSRC and C-V2X or have two channels dedicated to one technology and the third channel for the other technology, taking into consideration that in the future, the use of C-V2X will be the dominant.

V. SIMULATION TOOL AND SETTINGS

In this section, we delve into the details of the WiLabV2XSim simulator, the settings we used for our simulations and the output parameters used to evaluate the performance. WiLabV2XSim is a discrete-event simulation tool, developed in MATLAB, that tries to model vehicular networks, with a focus on the cooperative awareness service. The position and movements of vehicles can be produced following mobility models or reading the information from external traffic traces. It is designed to simulate both C-V2X and DSRC [4]. Our main settings are summarized in Table I. The application in question is the cooperative awareness service. Each vehicle broadcasts periodic messages informing of its status and movements. This service is the basis of most applications, especially the safety applications. The messages are transmitted at regular intervals of 100 ms, and each message is assumed to be 350 bytes in size. The channel bandwidth is set at 10 MHz. All nodes transmit with the same transmission power of 23 dBm, using antennas with 3 dB gain. The propagation is modelled following the WINNER+ model, with a path loss exponent of 4. The log-normal shadowing has a standard deviation of 3 dB in LOS and 4 dB in NLOS. WINNER+ is a European research project focused on creating advanced radio channel models for wireless communication systems like 5G [18]. The simulation time adopted is 30 seconds. We simulated coexistence between DSRC and C-V2X with and without interference. We consider both highway and urban scenarios in our simulations. For the highway scenario, we

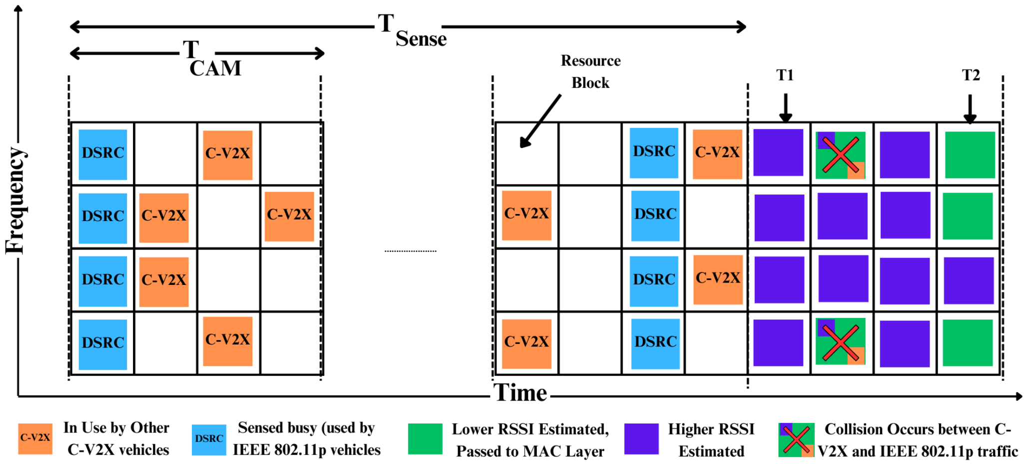


Fig. 2. An Allocation Example for C-V2X sensing-based on SPS in the presence of DSRC traffic showing when collisions occur between C-V2X and DSRC.

TABLE I
MAIN SIMULATION PARAMETERS AND SETTINGS

Settings	
Beacon periodicity	10 Hz
Beacon size	350 B
PHY Layer	
Channel bandwidth	10 MHz
Transmission power	23 dBm
Antenna gain (both tx and rx)	3 dB
Noise figure	9 dB
Propagation model	WINNER+
Shadowing variance	LOS 3 dB, NLOS 4 dB
Related to DSRC	
Carrier sensing sensitivity	-85 dBm
contention window	15
Related to C-V2X	
Probability to maintain the allocation (p_k)	0 or 0.8
Sensing threshold to assume the channel busy	-110 dBm

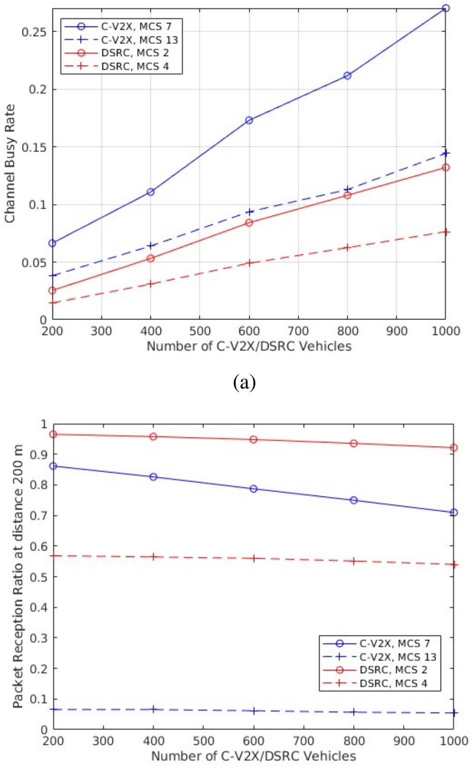
used mean speed of 120km/h with standard deviation of 20 km/h. The highway road length is 10000 meters with lane width of 4m. The traffic flow is bidirectional, with four lanes in each direction. For the urban scenario, we used mean speed of 30km/h and standard deviation of 15 km/h. The number of blocks in the urban scenario is 9 blocks in a 3×3 grid . The number of vertical and horizontal lanes per block is 4. The width and length of each block is 250m.

The positioning update resolution is 0.05 second. Both the resource allocation period and the packet generation interval are 0.1 second. The DSRC uses modulation and coding index of 2 which is QPSK with coding rate of 1/2. The C-V2X uses modulation and coding index of 7 which is QPSK with coding rate of 0.57. We also tried with DSRC using modulation and coding index of 4 which 16QAM with coding rate of 1/2 and C-V2X using modulation and coding index of 13 which is equivalent to 16QAM with coding rate of 0.52. The number of vehicles per Km changes according to the simulations.

We evaluated multiple output parameters including: packet reception rate (PRR), packet age, inter-packet gap and channel busy rate (CBR). The PRR is the average ratio between the number of significant neighbours correctly decoding a beacon and the total number of significant neighbours. Inter-packet gap is defined as the time interval between two consecutive successfully received beacons from the same node within the selected awareness range. Packet age is defined as the time interval between the generation of the packet and its effective transmission. The metric is computed for each successful reception within the selected awareness range. For DSRC, The CBR is then calculated every $T_{CBR} = 100$ ms as the ratio between the time the channel was sensed busy T_{Busy} and the T_{CBR}. T_{Busy} is reset every time a new CBR is calculated. For C-V2X, The CBR is then calculated every $T_{CBR} = 100$ ms as the ratio between N_{Busy} and N_{CBR} where N_{Busy} is the number of suchannels sensed as busy in T_{CBR} and N_{CBR} is the overall number of suchannels in T_{CBR}.

VI. SIMULATION RESULTS

C-V2X or DSRC Performance Evaluation: We ran simulations for the case when C-V2X and DSRC vehicles are assigned separate channels. We varied the number of vehicles in both the C-V2X and the DSRC cases. We also changed the MCS index and re-ran the simulations for few MCS indices. Refering to Figure 3, we have both channel busy rate and packet reception ratio vs. the number of C-V2X or DSRC vehicles at two different MCS settings. We tried different MCS index settings, but we are only showing two MCS settings with different modulation types. We found that DSRC MCS index 2 combined with C-V2X MCS index 7 has better performance in terms of channel busy rate and packet reception ratio compared with DSRC MCS index 4 combined with C-V2X MCS index 13. We also found that for the given MCS settings and at an awareness distance of 200 m, DSRC has a better performance compared to C-V2X in terms of channel busy rate and packet reception ratio. This is due to the fact that we are simulating C-V2X mode 4 which depends on SPS while the DSRC uses the listen-before-send method without the scheduling overhead.



(a)

(b)

Fig. 3. (a) Channel busy rate and (b) packet reception ratio vs. the number of C-V2X and DSRC vehicles varying independently without any channel coexistence at two different modulation and coding schemes settings.

Coexistence of C-V2X and DSRC in Highway Scenario: For the highway scenario, we have three modes of operation. We assumed that the number of C-V2X vehicles is double the number of DSRC vehicles since the direction is moving to using C-V2X instead of DSRC. We kept the total number of C-V2X vehicles in the three channels the same for the three modes of operation. We attempted various combinations of C-V2X vehicles, considering different total numbers from the set {600, 1200, 1800, 2400, 3000}.

The first mode of operation is to allocate the whole three channels available for ITS to both DSRC and C-V2X simultaneously. This means that both will suffer from interference and collisions. The number of vehicles is divided equally among the three channels. The second mode of operation is to allocate 2 channels for C-V2X solely and the third channel for DSRC. Again, for the C-V2X, the number of vehicles is divided equally between both channels. The third mode of operation is to allocate only one channel for all the C-V2X traffic and the other two channels for DSRC. The number of vehicles is divided equally between the DSRC two channels. Table II summarizes the three modes of operation used when allocating the spectrum for C-V2X and DSRC.

TABLE II
THREE MODES OF OPERATIONS FOR C-V2X AND DSRC SHARED SPECTRUM ALLOCATION

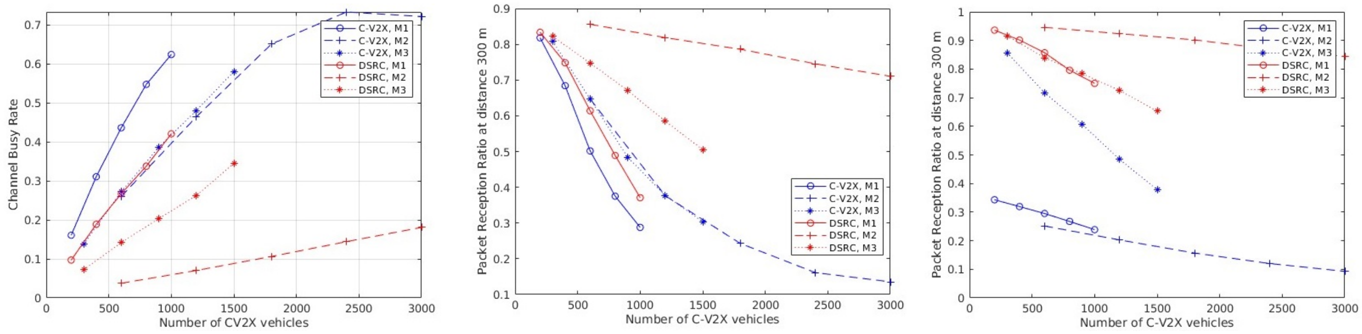
Mode	Channel Allocation
M1	All the three channels are shared between DSRC and C-V2X
M2	One channel used for C-V2X solely and the other two channels for DSRC
M3	Two channels used for C-V2X and the other channel used for DSRC

Figures 4a and 4b refers to the CBR and the PRR of both DSRC and C-V2X vs the number of C-V2X vehicles in only one channel. We can see that CBR of C-V2X traffic is the lowest when only on channel is allocated for C-V2X traffic and that the CBR when one or two channels are allocated to C-V2X are really similar. We also can see that CBR is the lowest with a big margin for DSRC traffic when two channels are allocated to DSRC traffic. For PRR, we can find from the figure a similar behavior where the highest PRR for DSRC traffic is when we allocates two channels to DSRC traffic. Moreover, PRR for both one or two channels allocated to C-V2X is really similar and outperforming the PRR of C-V2X when all the channels are shared. This is due to the fact that, in highway scenarios, all the vehicles are in line of sight of each other. This means that DSRC vehicles that listens before talk suffer from more collisions than C-V2X vehicles and hence needs more bandwidth to overcome the collisions effects.

Coexistence of C-V2X and DSRC in Urban Scenario: For the Urban scenario, we have the same three modes of operation as in the highway scenario. Figure 4c refers to the PRR of both DSRC and C-V2X vs the number of C-V2X vehicles in one channel. As we observe, the highest PRR for DSRC traffic is when two channels are allocated to DSRC traffic. However, PRR for C-V2X traffic is the highest when Mode 3 is in operation and two channels allocated to the C-V2X while one channel allocated to the DSRC. A similar conclusion is observed for CBR in urban scenario. This is due to the fact that in urban scenarios, the area under investigation is divided into different LOS area. This leads to C-V2X vehicles having more lost packets and needing more bandwidth. Figure 5 shows the PRR for C-V2X taffic vs the awareness range with different number of vehicles. We can see that PRR decreases with distance and also decreases with the increase of the number of vehicles. We also can see a dip in the PRR at distance 250 meters corresponding to the length of the blocks of the Manhattan model. At length of 250 meters, the LOS among vehicles is obstructed due to reaching an intersection and taking turns. Similar results are observed for DSRC traffic.

VII. CONCLUSIONS AND FUTURE WORK

In this paper, we conducted a comprehensive analysis and performance evaluation of the coexistence between DSRC and C-V2X in shared spectrum for vehicular communication systems. We compared their performance in different channel coexistence conditions for both highway and urban scenarios using the WiLabV2XSim simulator. Our study aimed to optimize the allocation of channels between DSRC and C-V2X to



(a) (b) (c)

Fig. 4. (a) Channel busy rate and (b) packet reception ratio vs. the number of C-V2X and DSRC vehicles in only one channel for the three modes of operation in highway. (c) Packet reception ratio vs. the number of C-V2X and DSRC vehicles in only one channel for the three modes of operation for urban scenario.

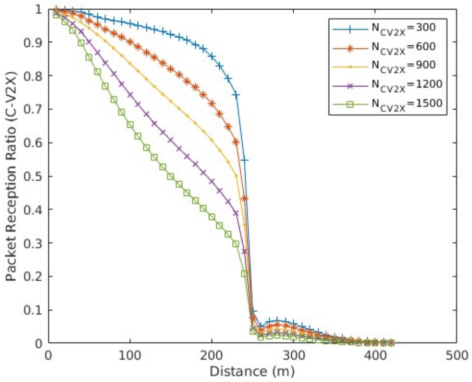


Fig. 5. Packet reception ratio vs. awareness range for C-V2X traffic with different number of vehicles for urban scenario.

mitigate the effects of coexistence and improve overall system performance. The results of our simulations indicated that for highway scenarios, allocating two channels for DSRC and one channel for C-V2X yields better performance, while for urban scenarios, allocating one channel for DSRC and two channels for C-V2X proves to be more effective. These findings provide valuable insights into optimizing channel allocation strategies based on the specific environment and traffic conditions.

To the best of our knowledge, no existing literature has addressed the channel allocation challenge to achieve optimal performance with coexistence of DSRC and C-V2X. Future research and development efforts should focus on devising solutions to optimize this coexistence, aiming to minimize interference, ensure fair resource allocation, and improve overall system performance.

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