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InP-CRS: an Intra-Platoon Cooperative Resource Selection Scheme for C-V2X Networks

Bingying Wang, Jun Zheng, *Senior Member, IEEE*, Nathalie Mitton, and Cheng Li, *Senior Member, IEEE*

Abstract—This letter proposes an Intra-Platoon Cooperative Resource Selection (InP-CRS) scheme for frequency-time resource selection to support reliable intra-platoon message delivery. The proposed InP-CRS scheme is based on the standardized sensing-based semi-persistent scheduling (SPS) scheme designed for C-V2X mode 4 and is intended to address the hidden-node problem in intra-platoon communication. Specifically, the InP-CRS scheme introduces an intra-platoon cooperative mechanism, in which the last member of a platoon needs to report the frequency-time resource occupation information of the platoon's hidden nodes to the platoon leader (PL) so that the PL can exclude those resources occupied by the hidden nodes of the platoon during its resource selection. In this way, potential packet collisions caused by the hidden nodes of a platoon can be largely reduced. Simulation results show that the proposed InP-CRS scheme can effectively improve the reliability of intra-platoon message delivery in terms of the successful broadcast probability of a PL as compared to the standardized sensing-based SPS scheme.

Index Terms—Intra-platoon cooperative, resource selection scheme, hidden-node, C-V2X network.

I. INTRODUCTION

PLATOONS of Connected and Automated Vehicles (CAVs) are considered as one of the most promising Intelligent Transportation System (ITS) applications [1]. Within a platoon, the platoon leader (PL) is responsible for delivering safety-related messages to its platoon members (PMs) [2], which can be implemented via one-hop broadcast. C-V2X (cellular vehicle-to-everything) is a new enabling networking technology for autonomous driving and ITSs [3]. The Third Generation Partnership Project (3GPP) specified two communication modes for C-V2X in Release 14, i.e., mode 3 and mode 4, which were specifically designed for V2V communications [4]. Mode 3 benefits from centralized frequency-time resource allocation, but can only operate within cellular coverage. Mode 4 can operate within or outside cellular coverage, and allows vehicles to autonomously select their frequency-time resources. Moreover, a sensing-based semi-persistent scheduling (SPS) scheme is designed for mode 4, in which a vehicle selects its frequency-time resources without the assistance of any cellular infrastructure in a distributed manner. Thus, mode 4 is more suitable for intra-platoon communication because message delivery in a platoon cannot depend on the availability of cellular infrastructure. However, mode 4 is

challenged by the hidden-node problem. If two vehicles cannot sense each other, they may select the same frequency-time resources and simultaneously transmit data packets using the selected same frequency-time resources, which would result in packet collisions. Therefore, it is necessary to enhance the sensing-based SPS scheme in order to address the hidden-node problem and implement highly reliable intra-platoon communication. However, existing related work did not consider this enhancement for reliable intra-platoon communication [5]–[8], which motivated this work.

In this letter, we propose an Intra-Platoon Cooperative Resource Selection (InP-CRS) scheme for frequency-time resource selection to support reliable intra-platoon message delivery. The proposed InP-CRS scheme is based on the standardized sensing-based SPS scheme designed for C-V2X mode 4 and is intended to address the hidden-node problem in intra-platoon communication. To reduce potential packet collisions caused by the hidden nodes of a platoon, the InP-CRS scheme introduces an intra-platoon cooperative mechanism, in which the last PM of a platoon needs to report the frequency-time resource occupation information of the platoon's hidden nodes to the PL and the PL can thus exclude those resources occupied by the hidden nodes during its resource selection. Moreover, the InP-CRS scheme makes use of the reserved field in a sidelink control information message defined in the SPS scheme to indicate the moving directions and relative positions of different vehicles, which are used by the PL in its resource selection. Simulation results are shown to evaluate the performance of the proposed InP-CRS scheme and investigate the impact of major system parameters on the performance of the scheme.

II. SENSING-BASED SEMI-PERSISTENT SCHEDULING SCHEME

A. Physical-layer specifications of C-V2X

According to 3GPP Release 14 [4], C-V2X uses SC-FDMA (single-carrier frequency-division multiple access) for channel access, and supports 10MHz and 20MHz channels. In SC-FDMA, the smallest unit of frequency-time resources for allocation is a resource block (RB), which has a width of 180 kHz in a frequency domain and a length of 0.5ms in a time domain. Moreover, a channel is divided into a sequence of 1ms-subframes in a time domain, and a subchannel is defined as a group of RBs in the same subframe, as shown in Fig. 1. The number of RBs contained in a subchannel can vary. The subchannels are used for transmissions of data packets and sidelink control information (SCI) messages. A data packet is transmitted over a physical sidelink shared channel (PSSCH)

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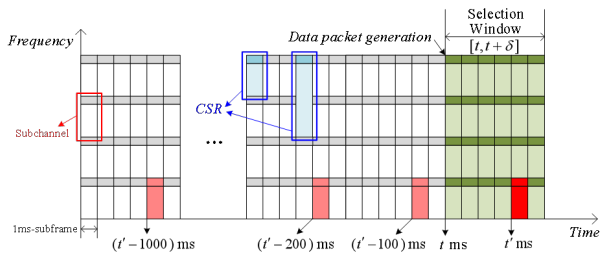


Fig. 1. Illustration of C-V2X mode 4 resource allocation.

on a transport block (TB), while an associated SCI message containing the sidelink control information on the transmission of the data packet is transmitted over a physical sidelink control channel (PSCCH). Thus, the successful reception of a data packet depends on the successful reception of the associated SCI message. The number of RBs contained in a TB depends on the size of a data packet to be transmitted.

B. Sensing-based semi-persistent scheduling scheme

In C-V2X mode 4, a vehicle needs to select frequency-time resources for data transmission in a distributed manner by performing the sensing-based SPS scheme. Thus, mode 4 does not require cellular coverage. In the sensing-based SPS scheme, when a vehicle has a data packet to transmit at time t , it needs to select and reserve candidate single-subframe resources (CSRs) within a selection window. A selection window is defined as the time period $[t, t + \delta]$, as shown in Fig. 1, where δ denotes the maximum latency for a data packet to be transmitted. According to [9], it is specified that $\delta = 100ms$, $\delta = 50ms$, and $\delta = 20ms$ when a vehicle transmits a data packet at a frequency of 10pps, 20pps, and 50pps, respectively. A CSR is defined as a group of adjacent subchannels in the same subframe. The number of subchannels that a CSR contains depends on the size of a data packet to be transmitted.

A vehicle selects and reserves a CSR for a random number of consecutive transmissions. This random number is referred to as reselection counter (RC), which depends on the frequency that a vehicle transmits a data packet. Let λ_m denote the packet transmission frequency of a vehicle and k_{RC} denote the value of an RC. According to Release 14, for $\lambda_m = 10pps$, $20pps$ and $50pps$, k_{RC} is randomly selected in $[5,15]$, $[10,30]$, and $[25,75]$, respectively. After each transmission, k_{RC} is decremented by 1. When k_{RC} reaches zero, a vehicle will continue to reserve the same CSR for its next transmission with probability P_0 , and select and reserve a new CSR with probability $(1 - P_0)$. According to [10], $P_0 \in [0, 0.8]$ and is usually set to 0 (i.e., $P_0 = 0$). A vehicle includes the information on λ_m and k_{RC} in its SCI messages, which is used by other vehicles to identify which CSRs are occupied, thus avoiding packet collisions due to simultaneous selection of the same CSR. Due to space limitation, readers are referred to [4] for more details on the sensing-based SPS scheme.

III. INP-CRS SCHEME

This section presents the proposed InP-CRS scheme for a C-V2X network.

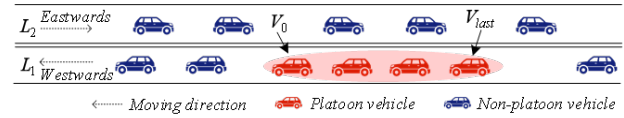


Fig. 2. Highway road scenario.

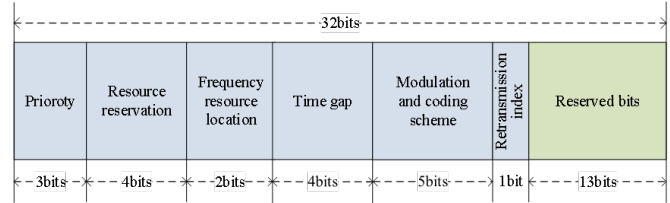


Fig. 3. Format of an SCI message.

A. Network model

Consider a two-way single-lane highway road scenario, where a platoon of CAVs as well as non-platoon vehicles move on lane L_1 while only non-platoon vehicles move on lane L_2 , as shown in Fig. 2. Assume that all the vehicles move on the centerline of each lane, and the distance between the two centerlines is denoted by d_L . The platoon consists of a platoon leader (PL) and several platoon members (PMs), and is denoted by Φ . Let V_0 denote the PL and V_{last} denote the last PM. All the PMs are covered by V_0 's one-hop broadcast. It is assumed that each vehicle is equipped with a global navigation satellite system (GNSS) device and a digital map, which provide the position of the vehicle itself and the positions of other vehicles, including V_0 and V_{last} . The carrier sensing range of each vehicle is denoted by R_S .

All vehicles on the road transmit messages via broadcast. The PL and all PMs use the InP-CRS scheme to select frequency-time resources for intra-platoon message delivery. All non-platoon vehicles use the sensing-based SPS scheme for resource selection.

B. The InP-CRS scheme

The InP-CRS scheme is intended to reduce packet collisions in intra-platoon message delivery by alleviating the effect of a platoon's hidden nodes. To implement this, the last PM (V_{last}) in a platoon needs to report its resource exclusion information to the PL (V_0), including the information on the CSRs occupied by the hidden nodes of the platoon. To this end, V_{last} will add the information in a data packet to be transmitted to V_0 so that V_0 can extract the information from the data packet, which will be used by V_0 to select an available CSR for its data transmission. In the InP-CRS scheme, only V_0 and V_{last} need to broadcast data packets, while other PMs only need to receive data packets.

The InP-CRS scheme makes use of the reserved field in an SCI message to indicate the relative positions between different vehicles, which will be used in subsequent resource exclusion. We first introduce the format of an SCI message specified for mode 4, as shown in Fig. 3. According to [9], an SCI message consists of 32bits, which are divided into seven fields. The frequency resource location field records information on the subchannels used for the transmission on

TABLE I
DEFINITION OF RF_1 - RF_5 FOR DIFFERENT VEHICLES.

RF_1	RF_2	RF_3	RF_4	RF_5
1 - The vehicle is a non-platoon vehicle;	1 - u_j is located within V_0 's carrier sensing range;	1 - u_j is located within V_{last} 's carrier sensing range;	1 - The CSR occupied by u_j is reselectable;	1 - The vehicle is moving westwards;
0 - The vehicle is V_0/V_{last} ;	0 - u_j is located outside V_0 's carrier sensing range;	0 - u_j is located outside V_{last} 's carrier sensing range;	1 - The CSR occupied by u_j is not reselectable;	0 - The vehicle is moving eastwards.

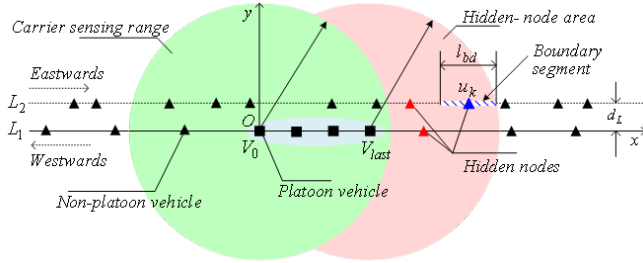


Fig. 4. Illustration of hidden nodes and boundary segment of platoon Φ .

the corresponding PSSCH, i.e., the transmission of the data packet associated with the SCI message. Moreover, there are 13 bits reserved for future extension and enhancement of the sensing-based SPS scheme. In the InP-CRS scheme, the first five bits (i.e., RF_1 - RF_5) of the reserved field are used to indicate the moving directions of different vehicles and the relative positions between different vehicles. The definition of the five bits is given in Table I.

A vehicle sets RF_1 - RF_5 according to the location information provided by its GNSS device. For instance, $RF_1 - RF_5 = 10111$ indicates that a non-platoon vehicle u_j moving westwards is located within V_{last} 's carrier sensing range while outside V_0 's, i.e., u_j is one of the hidden nodes of the platoon. The determination of RF_4 will be described later.

The InP-CRS scheme consists of two processes designed for V_0 and V_{last} , respectively. For ease of exposition, we use a rectangular coordinate system and set V_0 as its origin, as shown in Fig. 4. To further describe the processes of the InP-CRS scheme, we first define a set of notations:

N : the total number of CSRs in a selection window;

α : a pre-defined constant in $(0, 1)$;

$\mathcal{L}_A^0/\mathcal{L}_A^{last}$: a list of available CSRs that V_0/V_{last} can reserve within its selection window;

N_A^0/N_A^{last} : the number of CSRs in list $\mathcal{L}_A^0/\mathcal{L}_A^{last}$;

$\mathcal{L}_C^0/\mathcal{L}_C^{last}$: a list of CSRs including the first $(\alpha \cdot N)$ CSRs in sorted list $\mathcal{L}_A^0/\mathcal{L}_A^{last}$;

N_C^0/N_C^{last} : the number of CSRs in list $\mathcal{L}_C^0/\mathcal{L}_C^{last}$.

1) Process for the last PM

Within a platoon, the last PM V_{last} is responsible for reporting information on its resource exclusion because its carrier sensing range covers all hidden nodes of the platoon, as shown in Fig. 4. The main steps of the process for the last PM are described as follow:

Step 1: When V_{last} has a new data packet to transmit at time t and its k_{RC} reaches zero, V_{last} will first check the SCI message received from each of other vehicles, and meanwhile measure the average reference signal received power (RSRP) on the CSR used for transmitting the SCI message. If V_{last} detects a CSR that is "occupied" by a non-platoon vehicle

u_j whose SCI message contains $RF_1RF_2RF_3 = 101$ (i.e., u_j is one of the hidden nodes of the platoon), go to Step 2. Otherwise, go to Step 3. Here, a CSR is considered "occupied" when both the following conditions are satisfied:

- V_{last} receives an SCI message on the CSR from another vehicle during the last 1000 subframes;
- The average RSRP on the CSR used to receive the SCI message is larger than a given RSRP threshold θ_{th} .

Step 2: V_{last} adds the information on the CSR "occupied" by u_j , i.e., the information contained in the frequency resource location field of the SCI message received from u_j , to the next data packet to be transmitted.

Step 3: V_{last} excludes the CSRs that are "occupied" by vehicles within V_{last} 's carrier sensing range from all CSRs in the selection window $[t, t + \delta]$ and creates a list \mathcal{L}_A^{last} to include the available CSRs that V_{last} can reserve in the selection window for its data transmission. In the meantime, V_{last} adds the information on the CSRs excluded due to its half-duplex transmission (i.e., all CSRs in the subframe at time t' in the selection window ($t' \in [t_0, t_0 + \delta]$) if it has transmitted a data packet during any of the previous subframes at time $(t' - 1000/\lambda_m \cdot k)$ ($k = 1, 2, \dots, \lambda_m$)) to the next data packet to be transmitted.

Step 4: If $N_A^{last} \geq \alpha \cdot N$, go to Step 5. Otherwise, return to Step 3 with the RSRP threshold (θ_{th}) being increased by 3dB.

Step 5: V_{last} measures the average received signal strength indicator (RSSI) for each CSR in \mathcal{L}_A^{last} and sorts the CSRs in \mathcal{L}_A^{last} in an ascending order by the average RSSIs, and creates list \mathcal{L}_C^{last} to include the first $(\alpha \cdot N)$ CSRs in \mathcal{L}_A^{last} , i.e., the condition $N_C^{last} = \alpha \cdot N$ must be met.

Step 6: V_{last} randomly selects one CSR from \mathcal{L}_C^{last} , and reserves the CSR for its next k_{RC} transmissions.

2) Process for the PL

To prevent V_0 from over-excluding CSRs, instead of increasing the RSRP threshold like in the sensing-based SPS scheme [4], we introduce a new concept called "boundary segment" for V_0 . It is defined as a road segment that is on lane L_2 within V_{last} 's carrier sensing range and covers those vehicles with their occupied CSRs being reselectable. By introducing on the concept of "boundary segment", a vehicle moving on lane L_2 can make use of the location information provided by its GNSS device to determine whether it is located within the boundary segment, and if so will set appropriate values of $RF_1 - RF_5$ to indicate its occupied CSR is reselectable.

Fig. 4 shows an illustration of the "boundary segment". In this example, the boundary segment is located between the point at $((nd_v + \sqrt{R_S^2 - d_L^2} - l_{bd}), d_L)$ and the point at $((nd_v + \sqrt{R_S^2 - d_L^2}), d_L)$, where l_{bd} denotes the length of the "boundary segment", d_v denotes the intra-platoon

spacing, and n denotes the platoon size. A vehicle u_k is moving in the opposite direction to that of the platoon (or V_0/V_{last}) and is about to move out of V_{last} 's carrier sensing range. Thus, it can use its location information to determine that it is located within the boundary segment, and thus set $RF_1 - RF_5 = 10111$ to indicate that its occupied CSR is reselectable because it will no longer interfere with the intra-platoon message delivery in its future transmissions. The main steps of the process for the PL are described as follows:

Step 1: When V_0 has a new data packet to transmit at time t and its k_{RC} reaches zero, V_0 will first check each SCI message received from other vehicles, and meanwhile measure the RSRP on the CSR used for transmitting the SCI message.

Step 2: V_0 creates a list \mathcal{L}_A^0 to include the available CSRs that V_0 can reserve in the selection window for its data transmission, and excludes the following CSRs from all CSRs in the selection window $[t, t + \delta]$:

- The CSRs "occupied" by vehicles within V_0 's carrier sensing range according to checking results in Step 1;
- The CSRs that should be excluded due to V_0 's half-duplex transmission;
- The CSRs that are excluded by V_{last} according to the information contained in data packets received from V_{last} .

Step 3: If $N_A^0 \geq \alpha \cdot N$, go to Step 5. Otherwise, go to Step 4 with l_{bd} being increased by Δ (in meters).

Step 4: V_0 adds the reselectable CSRs to \mathcal{L}_A^0 , i.e., the CSRs "occupied" by non-platoon vehicles located within the boundary segment according to $RF_1 - RF_5$ contained in the received SCI messages. Return to Step 3.

Step 5: V_0 measures the average RSSI for each CSR in \mathcal{L}_A^0 and sorts the CSRs in \mathcal{L}_A^0 in an ascending order by the average RSSIs, and creates list \mathcal{L}_C^0 to include the first $(\alpha \cdot N)$ CSRs in \mathcal{L}_A^0 , i.e., the condition $N_C^0 = \alpha \cdot N$ must be met.

Step 6: V_0 randomly selects one CSR from \mathcal{L}_C^0 , and reserves the CSR for its next k_{RC} transmissions.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the InP-CRS scheme through simulation results. For evaluation, we compare the proposed InP-CRS scheme with the sensing-based SPS scheme, and introduce the successful broadcast probability of the PL in platoon Φ (P_Φ) as the performance metric, which is defined as the probability that a message broadcast by the PL is successfully received by all its PMs. The road scenarios considered in the evaluation were generated using SUMO-1.8 [11]. Moreover, it is assumed that non-platoon vehicles on both lanes follow Poisson distributions with the same traffic density. Vehicles in the platoon follows an equidistant distribution. Simulation experiments were carried on OMNeT++-5.6 with a C-V2X mode 4 related extension module, OpenCV2X [12]. Table II summarizes the system parameters.

Fig. 5 shows the impact of intra-platoon spacing (d_v) on the successful broadcast probability of the PL in platoon Φ (P_Φ) with the SPS scheme and the InP-CRS scheme, respectively. It is seen that P_Φ decreases with the increase of d_v . This is because as d_v increases, the distance between a receiving PM and the PL increases, and the received signal power at a receiving PM decreases, making the broadcast of the PL more

TABLE II
PARAMETER SETTINGS.

Parameter	Value	Parameter	Value
Carrier frequency	6GHz	Data packet size	190B
Channel bandwidth	10MHz	Transmission power	10, 20dBm
Number of subchannels	4	Platoon size	5
Vehicle speed	80km/h	δ	0.1m
Sensing threshold	-90.5dBm	d_L	8

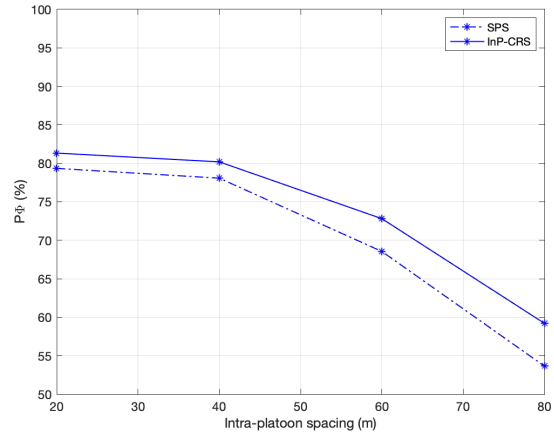


Fig. 5. P_Φ vs d_v ($\lambda_u = 0.02veh/s/m$, $P_t = 10dBm$, $\alpha = 0.2$, $\lambda_m = 10pps$).

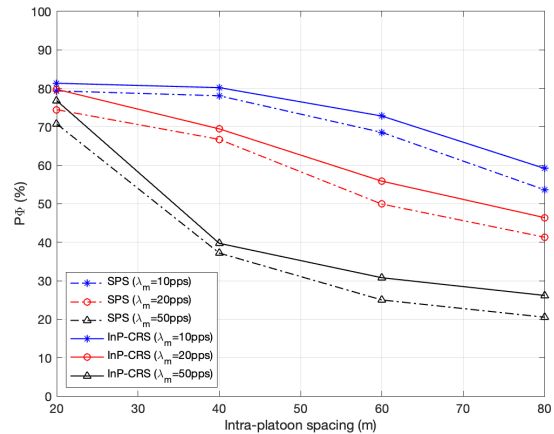


Fig. 6. Impact of λ_m on P_Φ ($\lambda_u = 0.02veh/s/m$, $P_t = 10dBm$, $\alpha = 0.2$).

likely to be interfered by other vehicles' broadcasts. On the other hand, the InP-CRS scheme outperforms the SPS scheme, i.e., with InP-CRS, P_Φ is improved by up to 6%.

Fig. 6 shows the impact of the packet transmission frequency of a vehicle (λ_m) on P_Φ . It is seen that as d_v increases, P_Φ with a larger λ_m decreases more quickly. This is because a larger λ_m leads to a smaller selection window with fewer CSRs available for each vehicle, which causes more packet collisions.

Fig. 7 shows the impact of transmission power (P_t) on P_Φ . It is seen that P_Φ with $P_t = 20dBm$ is always larger than that with $P_t = 10dBm$. This is because a larger P_t increases the received signal power at a receiving vehicle at the same distance and thus increases P_Φ .

Fig. 8 shows the impact of the non-platoon vehicle density (λ_u) on P_Φ . It is seen that as d_v increases, P_Φ with a larger

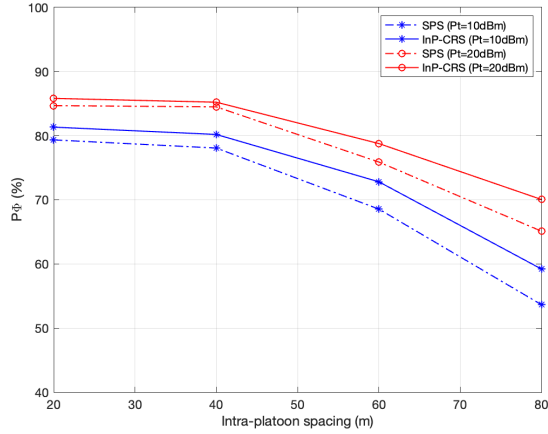


Fig. 7. Impact of P_t on P_Φ ($\lambda_u = 0.02\text{ vehs/m}$, $\alpha = 0.2$, $\lambda_m = 10\text{pps}$).

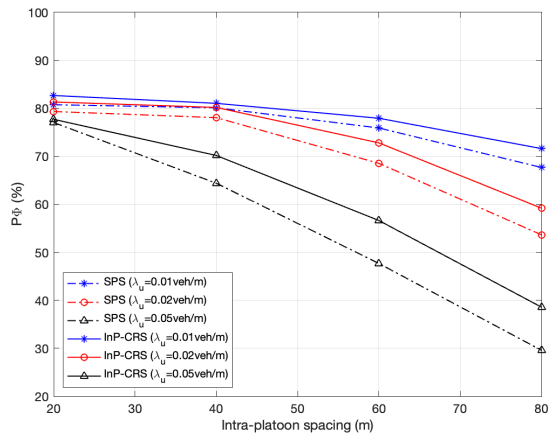


Fig. 8. Impact of λ_u on P_Φ ($P_t = 10\text{dBm}$, $\alpha = 0.2$, $\lambda_m = 10\text{pps}$).

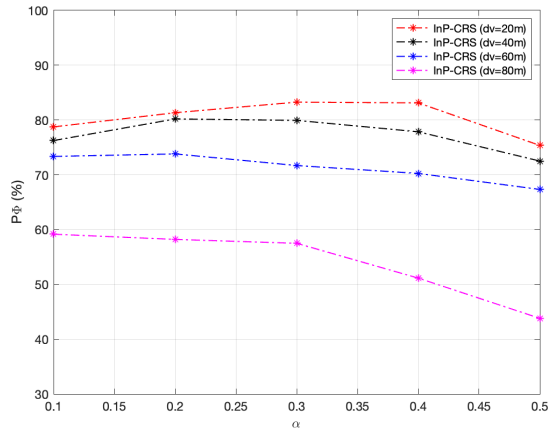


Fig. 9. Impact of α on P_Φ ($\lambda_u = 0.02\text{ vehs/m}$, $P_t = 10\text{dBm}$, $\lambda_m = 10\text{pps}$).

λ_u decreases more dramatically, and P_Φ with a larger λ_u is always larger than that with a smaller λ_u . This is because a larger λ_u leads to more interference vehicles for the platoon, which causes packet collisions.

Fig. 9 shows the impact of the coefficient α on P_Φ with the InP-CRS scheme. It is seen that as α increases, P_Φ with $d_v = 20\text{m}$, $d_v = 40\text{m}$ and $d_v = 60\text{m}$ first increase and then decrease, while P_Φ with $d_v = 60\text{m}$ increases the most slowly. P_Φ with $d_v = 80\text{m}$ decreases with the increase of α .

This is because when α is small (i.e., $\alpha \leq 0.3$), the number of available CSRs for V_0/V_{last} is small, which leads to a smaller probability that V_0/V_{last} selects the same CSR as that selected by other vehicles. As α continues to increase (i.e., $\alpha \geq 0.3$), however, the number of available CSRs for V_0/V_{last} becomes larger, which leads to the increase of the probability that V_0/V_{last} selects the same CSR as that selected by other vehicles, and thus the decrease of P_Φ . Note that the impact of α on P_Φ with the SPS scheme is not considered here because α is specified to 0.2 in the SPS scheme [4].

V. CONCLUSIONS

In this letter, we proposed an InP-CRS scheme to enhance the sensing-based SPS scheme for frequency-time resource selection in intra-platoon communication. The proposed InP-CRS scheme introduces an intra-platoon cooperative mechanism to reduce potential packet collisions caused by the hidden nodes of a platoon. The simulation results show that the proposed InP-CRS scheme can effectively improve the reliability of intra-platoon message delivery in terms of the successful broadcast probability of a PL as compared to the sensing-based SPS scheme. The proposed InP-CRS scheme is designed based on the standardized sensing-based SPS scheme and is compatible with the standard scheme. In future work, we will consider the extension of the proposed scheme in a road scenario with roadside units or cellular base stations.

REFERENCES

- [1] C. Campolo, A. Molinaro, G. Araniti and A. O. Berthet, "Better Platooning Control Toward Autonomous Driving: An LTE Device-to-Device Communications Strategy That Meets Ultralow Latency Requirements," *IEEE Veh. Technol. Mag.*, vol. 12, no. 1, pp. 30-38, Mar. 2017.
- [2] H. Peng et al., "Resource Allocation for Cellular-based Inter-Vehicle Communications in Autonomous Multiplatoons," *IEEE Trans. Veh. Technol.*, vol. 66, no. 12, pp. 11249-11263, Dec. 2017.
- [3] S. Chen, J. Hu, Y. Shi, L. Zhao and W. Li, "A Vision of C-V2X: Technologies, Field Testing, and Challenges With Chinese Development," *IEEE Internet of Things J.*, vol. 7, no. 5, pp. 3872-3881, May 2020.
- [4] 3GPP, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (v14.3.0, Release 14)," 3GPP, Tech. Rep. 36.300, Jun. 2017.
- [5] R. Molina-Masegosa, M. Sepulcre and J. Gozalvez, "Geo-Based Scheduling for C-V2X Networks," *IEEE Trans. Veh. Technol.*, vol. 68, no. 9, pp. 8397-8407, Sept. 2019.
- [6] S. shehata, Mohamed, C. Ciochina and J. Sibel. "On the Performance of Inter User Coordination for Resource Allocation Enhancement in NR V2X Mode 2," in *Proc. Int. Workshop Commun. Technol. Veh.*, Cham, France, Jan. 2022, pp. 3-14.
- [7] M. Ali, H. Hwang and Y. -T. Kim, "Performance Enhancement of C-V2X Mode 4 with Balanced Resource Allocation," in *Proc. IEEE Int. Conf. Commun.*, Seoul, Korea, May 2022, pp. 2750-2755.
- [8] X. He, J. Lv, J. Zhao, X. Hou and T. Luo, "Design and Analysis of a Short-Term Sensing-Based Resource Selection Scheme for C-V2X Networks," *IEEE Internet of Things J.*, vol. 7, no. 11, pp. 11209-11222, Nov. 2020.
- [9] 3GPP, "Evolved Universal Terrestrial Radio Access; Physical layer procedures (v14.3.0, Release 14)," 3GPP, Tech. Rep. 36.213, Jun. 2017.
- [10] M. Gonzalez-Martín, M. Sepulcre, R. Molina-Masegosa and J. Gozalvez, "Analytical Models of the Performance of C-V2X Mode 4 Vehicular Communications," *IEEE Trans. Veh. Technol.*, vol. 68, no. 2, pp. 1155-1166, Feb. 2019.
- [11] P. A. Lopez et al., "Microscopic Traffic Simulation using SUMO," in *Proc. of 21st Int. Conf. on Intelligent Transportation Systems (ITSC)*, Maui, HI, USA, Nov. 2018, pp. 2575-2582.
- [12] B. McCarthy and A. O'Driscoll, "OpenCV2X Mode 4: A Simulation Extension for Cellular Vehicular Communication Networks," in *Proc. 2019 IEEE 24th Int. Workshop Comput. Aided Model. Des. Commun. Links Networks*, Limassol, Cyprus, Sept. 2019, pp. 1-6.