Enhanced Semi-persistent scheduling (e-SPS) for Aperiodic Traffic in NR-V2X

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***Abstract*—In cellular vehicle-to-everything (C-V2X) mode 4 and New Radio V2X (NR-V2X) mode 2 based on local observations resources are scheduled by the vehicles themselves. For resource scheduling operation third generation partnership project (3GPP) defined semi-persistent scheduling (SPS). Vehicles rely on the sensing information received in sidelink control information (SCI) over physical sidelink control channel (PSCCH). Based on the sensing information vehicle select the resources for its transmission and reserve the resources for its successive future transmissions. For periodic transmission, SPS works fine comparatively to aperiodic messages. Because aperiodic messages compelled the vehicle to select new resources for its transmission based on the latency associated with the generated packet. In turn, it results in unutilized resources which were reserved before. This would also increase resource contention. To overcome this, we have proposed the enhanced semi-persistent scheduling (e-SPS) method for resource reservation for aperiodic traffic. The proposed scheme utilizes the reinforcement learning mechanism where each vehicle act as an agent. Based on the traffic density and speed of the vehicle, the size of the sensing window is dynamically adjusted and re-evaluation mechanism is also introduced to confirm the available resources by performing the sensing again while selecting the resources. The performance of the proposed scheme is evaluated in ns-3 and compared with the naïve sensing mechanism. Results show that the e-SPS scheme outperforms the others.**

***Index Terms*—C-V2X, NR-V2X, Vehicular Communications, Aperiodic traffic, Semi-Persistent Scheduling (SPS), Cooperative Awareness Messages (CAMs)**

I. Introduction

The next-generation safety and management applications in vehicular environments are enabled by Long Term Evolution-Vehicle to Everything (LTE-V2X) communications. The awareness range of the autonomous and connected vehicle is extended in LTE-V2X utilizing the information received from neighboring vehicles, the infrastructure, and other users in the vicinity [1]. The 802.11p protocol is replaced by the Cellular-V2X (C-V2X) to enable enhanced applications owing to its scalability and flexibility. The C-V2X, proposed in Release 14 by the 3rd generation partnership project (3GPP), includes two transmission modes for direct communication, i.e., mode 3 over the Uu interface and mode 4 over the PC5 interface. In mode 3, the resources are allocated by the eNodeB (eNB) under its coverage region whereas, in mode 4, the vehicles autonomously reserve the resources in out of coverage regions [2], [3]. To evaluate the performance of C-V2X mode 4 in the worst-case scenario, [4] presents an open-source simulator based on the network simulator ns-3.

These standardization efforts were continued by 3GPP for V2X communications in Release 16 and 17 towards new radio (NR) access. NR-V2X holds several enhancements to enable a wide range of V2X applications in order to increase the data rate, minimize the latency, and enhance the spectral efficiency of V2X communications [5]. Similar to C-V2X, NR-V2X includes two transmission modes: mode 1 (centralized) and mode 2 (decentralized). In mode 1, the resources are scheduled by the enB when the vehicles are within the coverage region, whereas, in mode 2, the vehicles carry out the resource reservation by themselves using semi-persistence scheduling (SPS) algorithm in out of coverage region. The sensing-based SPS or SB-SPS assumes the exchange of periodic messages on the physical layer. These messages are called cooperative awareness messages (CAMs) in Europe, defined by the ETSI, and basic safety messages (BSMs) in the US, defined by the Society of Automotive Engineers (SAE). Using these awareness messages, the occupied resources in the last time interval are estimated and then the future usage of resources is predicted. Finally, the reservation of identified resources is carried out using the semi-persistent method for a given period of time [6]. In addition, although, according to the current 3GPP standard, the awareness messages (CAM and BSM) are not periodic, and several studies have shown that the interval between these messages as well as their size has a significant effect on the performance of medium access control (MAC) in distributed environments such as CV2X mode 4 or NR-V2X mode 2 [1].

Machine learning has opened a significant number of ways to find solutions in all domains. Similarly, in vehicular communications, the advanced tools of machine learning have been extremely beneficial in finding optimal solutions. Numerous studies have been carried out to tackle the problems in V2X communications using the advanced machine learning tools and algorithms such as the issues in resource allocation method in C-V2X mode 4 where vehicles are vulnerable to make selfish decisions based on the limited available knowledge leading to contention in the network or the problem of excessive signaling overhead in C-V2X mode3 and so on. In this paper, we propose a solution for the distributed resource scheduling. The proposed scheme utilizes reinforcement learning and revaluation mechanism (also a potential technique drafted in 3GPP Rel.17 meetings) to reduce the resource contention in NR-V2X mode 2.

In the remainder of this paper section II presents the naive SPS method. Section III and section IV present the European Telecommunication Standard Institute (ETSI) standards related to CAM generation process and impact of aperiodic traffic generation on resource reservations respectively. Section V introduces the enhanced semi-persistent scheduling (e-SPS) that is proposed to address resource contention in NR-V2X. Performance results are evaluated in in Section VI. Finally the conclusion is drawn in section VII.

II. Semi-persistent Scheduling

In this section a short overview of naive schedulling mechaism in NR-V2X mode 2 and C-V2X mode 4 is discussed.

In C-V2X mode 4 and NR-V2X mode 2, resources are scheduled by the vehicles using SPS. Based on SPS sensing vehicle user equipment (V-UE) reserved the number of subchannels for periodic and aperiodic transmission. In C-V2X vehicles sense for 1 sec, which is beneficial for periodic message transmission. Fig. 1. shows the illustration of sensing based SPS mechanism. The transmit V-UE will sense for 100 ms equivalent to 1000 subframes and then after 1 sec at time n select the resources in a resource selection window.

From Fig. 1 the lower bound of selection window $t1$ is in between $(1, 4)$ and upper bound $t2$ is in between $(20, 100)$. $t1$ is defined by V-UE configuration, whereas $t2$ depends upon the maximum inter reception time interval of packets. Based on probability of resource reselection, the resources are scheduled for the UE. If in a case, all the resources are occupied then vehicles will defer the channel access or transmit on occupied resources of low received power.

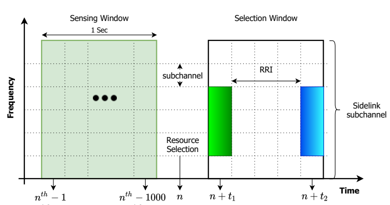

Fig. 1. Semi-Persistent Scheduling based Sensing Mechanism

III. ETSI Standard for CAM Generation

The CAM generation depends on the following conditions as follows.

- **Speed:** A change in position by more than 4 m.
- **Heading:** A change of direction of $\geq +/-4^o$
- **Change of speed:** A change of speed equal to or larger than $0.5\ msec^{-1}$.

In general the time of generation between CAM is not fixed and it varies [7].In particular, the time between CAMs depends on the mobility of vehicles and the vehicles will generate more CAMs per second when their acceleration is higher. Moreover, the size of CAM is also not fixed and it depends on the intelligent transportation system (ITS) packet datagram unit header (PDU), basic container, low frequency container and special vehicle container. Fig. 2 shows the CAM PDU. Basic container and high frequency containers are mandatory fields where former includes the position information of the vehicle and latter includes the velocity information of the vehicle. However, the size of CAM depends on the optional containers which include the low frequency container and special vehicle container. Optional containers include the information regarding the change of lane and to inform any accident to the neighboring vehicles.

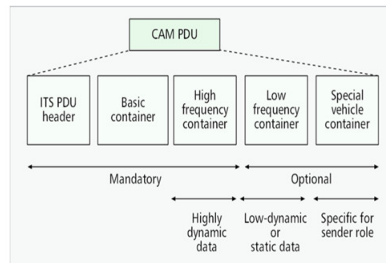

Fig. 2. Cooperative awareness message (CAM) packet format

IV. Impact of Aperiodic Message Generation on the Resource Reservation

According to the ETSI standards, the generation of CAMs is no more periodic that can adversely affect the performance of resource scheduling in V2X. Since SPS based mechanism relies on the local observations, the vehicles made the announcement of their reserved resources in its SCI over PSCCH. The SCI includes RRI and RC value. The vehicle that wants to transmit its packet at time t, makes the reservation for its successive transmissions at $(t + RRI)$ for RC times as shown in Fig. 1. The vehicle transmits the RRI and RC information in its SCI, so the neighboring vehicles get information about the already reserved resources. However, this might work in the case of ideally periodic traffic generation, wherein in the case of aperiodic traffic, this will result in unutilized resources. The following three cases are discussed which would result in unutilized resources and adversely affect the performance of resource scheduling in V2X.

A. Resource reselection due to variation in message size

As shown in Fig. 3, the vehicle has selected the resource for its packet transmission of bytes N at time t and reserves its resources for future transmissions at a time $(t + RRI)$. If the next packet of size $N' > N$ is generated at $Tgen_2$ that does not fit into the already reserved resource at $(t+RRI)$, then the vehicle should reserve the new resource for its transmission. In turn, the already reserved resources would result in unutilized resources.

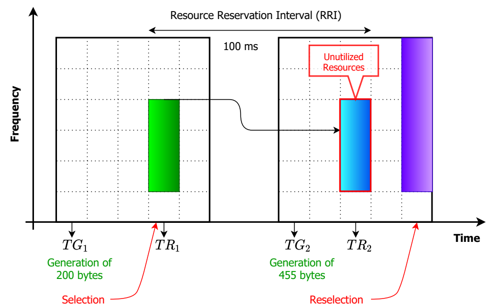

Fig. 3. Resource reselection due to Variation in Message Size

B. Resource reselection due to the latency associated with the generated packet

Similarly, in this case, as shown in Fig. 4, if the next packet is generated at $Tgen_2$ and the latency associated with the generated packet is let suppose 100 ms whereas the reserved resource is at $(t+RRI) \geq 200$ ms. The vehicle should reserve the new resource at time t' for its transmission which should meet the latency of the generated packet. This would also result in unutilized resources which were already reserved at $(t+RRI)$.

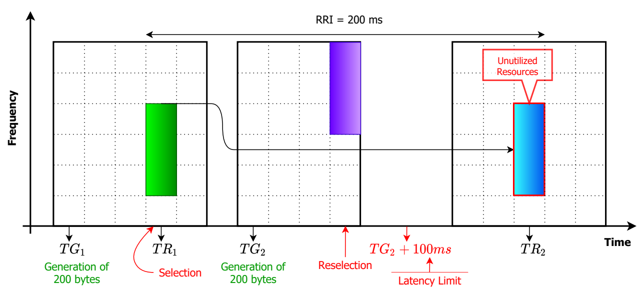

Fig. 4. Resource reselection due to latency associated with packet

C. Resource reselection due to time interval between generations of packets

Likewise, in this case, as shown in Fig. 5, if the next packet is generated at $Tgen_2$ such that $Tgen_2 > (t+RRI)$, this would also result in unutilized resources at the time $(t+RRI)$.

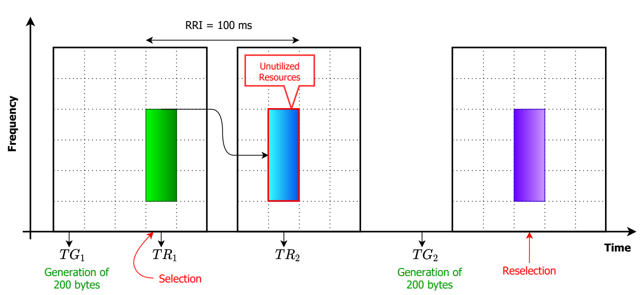

Fig. 5. Resource reselection due to variation in Message interval time

In order to address the resource scheduling for the aperiodic generation of messages, we proposed the e-SPS based scheme as discussed in Section V.

V. Enhanced Semi-Persistent Schedulling (e-SPS)

In C-V2X mode 4, 3GPP defined a fixed sensing window size of 1 sec also known as Long-term sensing (LTS). The sensing window with a 1 sec duration includes 1000 subframes and 1000 slots with subcarrier spacing of 15 kHz. Where, NR-V2X with subcarrier spacing of 15 kHz, 30 kHz, 60 kHz includes 1000, 2000 and 4000 slots respectively. However, for both NR-V2X mode 2 and C-V2X mode 4 SPS is defined by the 3GPP and the sensing window size of 1 sec is considered. The current LTS mechanism can add delay in communication, in order to fulfil the ultra-low latency for future applications short-term sensing (STS) window is a potential solution proposed by the 3GPP in unlicensed channels. However, in LTS the sensing results become quickly obsolete due to the highly dynamic vehicular environment, wherein STS can add delay and increases resource contention if the vehicles could not find the available resources in a short duration. To complement the mode 2 operation of NR-V2X we proposed the enhanced-SPS (e-SPS) mechanism as explained following.

The sensing window size is adjusted dynamically based on the machine learning outcome. Deep reinforcement Q-learning is proposed to predict the sensing window size between 0.1 second to 1 second i.e., $[0.1, 0.2, 0.3, 0.8, \ldots, 1]$ sec. The subframes that the vehicle needs to observe include the last $[100, 200, 300, 800, \ldots, 1000]$ subframes respectively corresponding to the sensing window size. Each vehicle act as an agent, that observes the environment. The state-space includes the density of the vehicles, the current vehicle speed, the last 20 temporal sequences of CAM generation intervals. The state space is shown in equation 1.

$$S_t = \{V, d, [it-20, i_{t-19}, \ldots, i_{t-1}]\} \tag{1}$$

The action space set consists of sensing window size duration between $(0.1, 1)$ seconds, resource reservation interval (RRI) between $[0-99, 100, 200, \ldots, 1000]$ ms, and resource reselection counter (RC) between $(1-15)$. In the proposed e-SPS mechanism the RC and RRI are selected based on the vehicle current speed and temporal sequence of CAM generation intervals. This would assist in scheduling resources for aperiodic traffic.

The reward is designed based on the packet delivery ratio (PDR) as the goal is to reduce the resource contention and fair resource scheduling in V2X that lead to an increased in overall PDR and improved network performance.

Based on the machine learning outcome the e-SPS mechanism is summarized in the following three steps. In step 1, the vehicle observes the last subframes from the sensing window as selected based on the machine learning outcome. The vehicle based on the SCI information selects the sidelink resources for its transmission from the selection window. The length of the selection window is from $[n+T_1, n+T_2]$, where T1 is between $(0ms - 4ms)$, n is the time at which the packet is generated and T2 depends on the latency of the generated packet.

In step 2, the vehicle identifies the available resources that can be selected from the list of available resources (L_A). The list is identified based on the sensing and the information received by the neighboring vehicles in SCI over PSCCH. The resources from the list L_A will be excluded based on the following conditions.

- The resources would be excluded if the RSSI received is higher than the threshold.
- Those resources would also be excluded based on the RRI received in SCI indicating other vehicles already reserved those slots for successive transmissions in future.

One more process is added in step 2 which is called a re-evaluation mechanism. In this process, while identifying the L_A the UE can again execute the sensing mechanism to make sure that the resources that have been added in the L_A are still available or not. This can also address the resource scheduling for the aperiodic generation of traffic. The length of the selection window is set between $[(n' + T_1'), (n' + T_2')$. Where n' is the slot at which the UE again executes the sensing mechanism and $T_2' = (n' - n)$. T_2' shows the time elapsed since the generation of the initial sensing window at time n. During the re-evaluation mechanism if the resources that were identified before if still available the UE will not execute the step 2. If not then the UE will again execute the step 2 to identifies the L_A and then select the resource as explained in step 3.

In step 3, a vehicle will select the resources randomly from the candidate subframe resources list (L_C). LC includes the least RSSI which constitutes 20% of L_A. If the 20% target is not met the RSSI threshold is iteratively increased by 3 dB. For successive transmissions, the value of the RC depends on the output of machine learning and semi persistently resources are scheduled for future transmissions for RC times after each RRI interval.

VI. Simulation Results

A. WINNER+ B1 Channel

The WINNER + B1 channel is considered as used by 3GPP [8]. The B1 channel model is considered for 5.9 GHz band and the antenna height set for vehicles is 1.5m. The path loss model is calculated for non -line of sight (NLOS) and line of sight model from WINNER+ B1 model [9]. Table I shows the simulation parameters.

TABLE I
Simulation Parameters

Vehicular Speed	20-130 kmh^{-1}
Number of Vehicles	(100...300)
$T1$, $T2$	4 ms, $[100, 200, \ldots, 1000]$ ms
Resource Blocks per Subchannels	10
Channel Model	WINNER+ B1
Transmission Power	23 dBm
Antenna Height	1.5 m

B. Simulation

We consider a Manhattan grid scenario of $500x500$ m^2. The proposed scheme is evaluated in sparse and dense traffic conditions. Vehicles that are considered are from 100-to-300 in numbers. The simulator is built in compliance with the 3GPP standards defined for C-V2X and NR-V2X. The enhanced semi-persistent scheduler is implemented to complement C-V2X mode 4 and NR-V2X mode 2.

Fig. 6, shows the impact of the increase in the number of vehicles on the PDR. The proposed scheme is compared with the naïve SPS mechanism. From the Fig. 6, with the increase in the number of vehicles the PDR degrades. The PDR degrades because of resource contention. However, the performance is better in the case of NR-V2X 30 kHz and 60 kHz subcarrier spacing as compared to C-V2X 15 kHz subcarrier spacing. This is due to the increase in number of slots as 2000 and 400 in NR-V2X with 30 kHz and 60 kHz subcarrier spacing. The subcarrier spacing with 30 kHz and 60 kHz can accommodate more number of vehicles in terms of resource assignment. This in turn reduces the probability of resource collisions such as by $\lambda/2000$ and $\lambda/4000$. In order to improve the reliability and to reduce the packet dropped ratio the -SPS scheme works effectively. Because of the re-evaluation mechanism, the e-SPS outperforms the others in each case. The e-SPS scheme helps vehicles to identify the available resources and in turn reduces the resource contention.

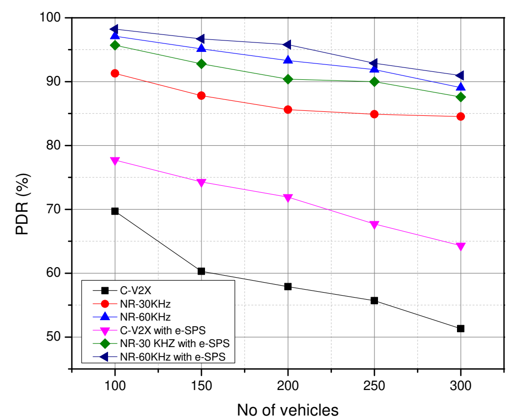

Fig. 6. Impact of number of vehicles

Fig. 7, shows the impact of the number of available sidelink subchannels on PDR. With the increase in the sidelink sub-channels, the PDR gets better. This is because the increase in the number of sidelink channels results in more resources that vehicles can select for their transmission. From Fig. 7, it is shown even with less number of available sidelink subchannels the PDR is better with e-SPS based resource selection as compared to naïve SPS based scheme.

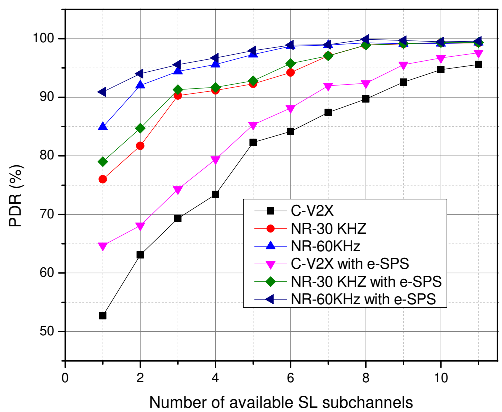

Fig. 7. Impact of number of avaialable sidelink (SL) subchannels

VII. Conclusions

In this paper, we have proposed the e-SPS method to complement NR-V2X mode 2 in order to schedule resources for aperiodic CAMs. If the resources are scheduled using the naive mechanism lead to the unutilized resources because of aperiodic CAMs. This also increased resource contention and degrades the overall network performance. The re-evaluation mechanism introduced in the e-SPS assists in the resource scheduling for aperiodic traffic. Also, each vehicle is modeled as an agent, and based on machine learning outcome the size of the sensing window is dynamically adjusted and the other parameters of the SPS are adjusted. This reduces resource contention and assists in conflict-free resource assignment for aperiodic message transmission. The performance results show the overall increase in network performance in terms of PDR.

VIII. Acknowledgment

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