A First Investigation of Congestion Control for LTE-V2X Mode 4

Adel Mansouri†, Vincent Martinez†, Jérôme Härri‡
† NXP, 134 Avenue du Général Eisenhower, 31023 Toulouse, France
‡EURECOM, 450 route des Chappes, 06904 Sophia Antipolis, France
E-mails: adel.mansouri@nxp.com, vincent.martinez@nxp.com, jerome.haerri@eurecom.fr

***Abstract*—3GPP LTE-V2X is a recent new cellular technology allowing direct communications between vehicles and any other stations. Its Sidelink mode 4 allows the scheduler to be fully distributed and not requiring any support from cellular infrastructures, thus making this mode well fitted for V2X safety-related communications. Based on a Listen-before-Talk (LBT) strategy, the scheduler, however, remains subject to performance degradation under increased channel load, and thus requires congestion control mechanisms. In this work, we focus on the interactions between the strategies used by the LTE-V2X Sidelink mode 4 for autonomous resource allocations - LBT and Semi-persistent scheduling (SPS) - and decentralized congestion control (DCC) mechanisms. Simulations under various scenarios showed counter-productive interactions leading to performance degradations, and strategies to mitigate them are suggested.**

I. Introduction

Cooperative intelligent transport systems (C-ITS) provides a framework for road users and traffic managers to share information, in the quest for a safer, greener and more comfortable travel. The term V2X defines the exchange of information between vehicles and any other type of stations, such as road-side units, infrastructure, pedestrians or other moving vehicles.

Today, two technologies are standardized for the V2X physical access layer, namely IEEE 802.11p[1] and 3GPP Long-Term-Evolution (LTE)-V2X. LTE-V2X uses the sidelink channel which is designed based on LTE uplink waveform. LTE-V2X made its debut in 3GPP Rel-14 specification, as an evolution of 3GPP Rel-12 Device-to-Device (D2D) functionalities.

Two sidelink modes dedicated to V2X were introduced in Rel-14: modes 3 and 4 support direct vehicular communications but differ on how stations' resources are allocated. In mode 3, vehicles are within the coverage of cellular network, and the stations' resources are selected, allocated and reserved by the eNodeB. In contrast, mode 4 was designed to work without the requirement of being under coverage of cellular network: resources are autonomously selected by the stations. Mode 4 defines an ad-hoc system, similar in concept to ITS-G5[2], and as such, one major challenge is to avoid collisions.

[1]Although widely known as "802.11p", "IEEE 802.11-OCB" is a more technically correct terminology. OCB stands for "Outside the Context of a BSS".

[2]ITS-G5 defines a protocol stack for vehicular communications in an ad-hoc network to be used in the 5,9 GHz frequency band allocated in Europe. Its access layer is based on IEEE 802.11p standard. The ITS-G5 standard adds features for decentralized congestion control (DCC) to control the network load and avoid unstable behaviour.

Wireless congestion control represents a family of mechanisms to mitigate such collisions by adjusting communication parameter to control the congestion level on the vehicular wireless channel and guarantee reliable V2X communications. Known in Europe under the name Decentralized Congestion Control (DCC), possible parameters are, among others, adjusting the transmission rate, the transmission power, the modulation or the offloading to alternative channels, as described by Smely et al. [1].

LTE-V2X defines a synchronous network, with all users having the same reference clock. Mode 4 resource scheduling uses a Listen-Before-Talk (LBT) type of algorithms, based on medium and long term measurements. In conjunction, a Semi-Persistent Scheduling (SPS) strategy has been proposed as a way to announce resources utilization, which is of critical importance in a synchronous network, and also based on the assumption of a periodic nature of safety-related transmissions. However, the benefit of SPS is not clear when LTE-V2X mode 4 is used in conjunction with wireless congestion control mechanism such as DCC.

In this paper, our focus is to analyze the impact of DCC mechanisms on the LTE-V2X mode 4. Our contributions are threefold: (i) we implement the LTE-V2X LBT-SPS scheduler on a network simulator (ns-3) and validate its performance, (ii) we evaluate its performance in conjunction with the ETSI DCC, (iii) we suggest modifications in the LTE-V2X mode 4 scheduler to better fit to safety-related traffic subject to DCC.

The rest of this paper is organized as follows. Section II proposes a brief overview of the state-of-art in LTE-V2X and DCC. Section III introduces the basic mechanisms of LTE-V2X mode 4, while Section IV describes the DCC and its application to LTE-V2X. Then, Section V introduces performance evaluation parameters and scenarios, while Section VI provides simulation results. Finally, Section VII discusses challenges of DCC and LTE-V2X, while Section IX concludes the paper and shed lights on future directions.

II. Brief State-of-Art Overview

A. Cellular Device-to-Device

In cellular networks, investigations on the potential capacity or resource allocations gains from Device-to-Device (D2D) communications have been observed since 2015 [2]–[5]. But these studies remained theoretical due to the lack of standards and protocols effectively describing D2D mechanisms for

LTE. Stemming from the early D2D protocol description from Rel.12, Gallo and Härri [6], [7] drew and evaluated the first sketches of what will later appear in the Rel-14 as LTE-V2X. With a full LTE-V2X specification published in the LTE Rel-14 in June 2017, several teams implemented and tested it via simulations [8]–[11]. And although Molina and Gozalvez [8] showed limitations of the LTE-V2X scheduler under increased load, and Bazzi *et al.* [11] illustrated the impact of PHY and MAC parameters to such limitation, efficient wireless congestion control mechanisms have so far not been investigated. This is the objective of this paper.

B. Wireless Congestion Control

A holistic view of wireless congestion control challenges and solutions may be found in [1]. Without loss of generalities, although some studies tried to adjust the transmission power (e.g. [12]), most studies focused on adjusting the transmission rate [13]–[15], a more controllable variable. Adjusting the transmission rate notably became the official DCC mechanism by the ETSI [16]. Yet, Huang et al. [17] investigated the possibility of jointly adjusting transmission rate and power, a mechanisms, which later became the SAE standard for wireless congestion control in the US [18]. At the time of this study, and to the best of the authors' knowledge, no LTE-V2X studies have explicitly tested congestion control mechanisms for a LTE-V2X mode 4 network. This study aims to fill this gap, by evaluating the impact of one congestion control mechanism on a LTE-V2X mode 4 network.

III. Basics of LTE-V2X

A. LTE-V2X waveform

The sidelink waveform design is fairly similar to the earlier developed LTE uplink, re-using the same principles for the subframe organization. LTE-V2X is a synchronous network, where all the users shall have the same time reference, typically obtained from GNSS. Time is divided into subframes. Each LTE subframe has a length of 1 ms and contains 14 OFDM symbols. One LTE-V2X subframe comprises 4 demodulation reference symbols (DMRS) and 9 data symbols conveying the user's payload. The last symbol is not transmitted, and acts as a time guard to allow transmitters to return to receiver state before the next subframe. The first data symbol may not be available for use by the receiver as it might be used for AGC calibration purposes.

Frequencywise, the LTE-V2X channel bandwidth is divided into a given number of subchannels. Each subchannel gathers a number of resource blocks (RB) (12 subcarriers). All subchannels have the same size. 3GPP LTE specification 36.213 [19] defines the following possible subchannel sizes: 4, 5, 6, 8, 9, 10, 12, 15, 16, 18, 20, 25, 30, 48, 50 RB, and the possible number of subchannels: 1, 3, 5, 10, 15 or 20 RB. One ITS station can use one or multiple subchannels to transmit its data. Two main physical channels are used in LTE-V2X:

- the physical sidelink shared channels (PSSCH) is used to transmit data packets, known as transport blocks (TB).

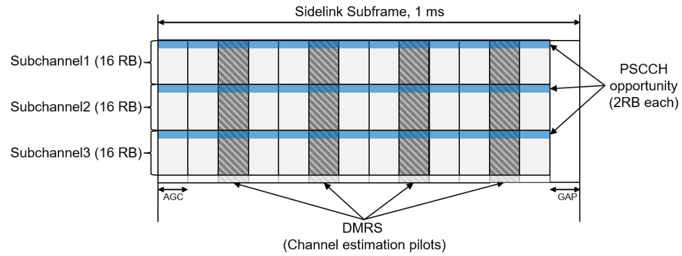


Fig. 1: Sidelink subframe, adjacent PSCCH-PSSCH, 3 subchannels

- the physical sidelink control channels (PSCCH) is used to transmit the associated control message, known as sidelink control information (SCI).

The PSCCH SCI and its associated PSSCH TB are transmitted in the same subframe. PSCCH always occupies two resource blocks. For PSSCH, the number of occupied RBs depends on the user's payload size, on the subchannels division, and on the modulation and coding scheme used (MCS). Two cases can be enabled for the location of PSCCH and PSSCH:

- **Adjacent PSCCH and PSSCH**: TB and its associated SCI are transmitted in adjacent RBs. PSCCH always uses the first two RBs of each subchannel. PSSCH uses the following RBs. If PSSCH occupy more than one subchannel, they will be overlapping with the next PSCCH opportunities (that might or might not contain actual PSCCH messages). The present study focuses on this configuration, as shown in Fig. 1.
- **Nonadjacent PSCCH and PSSCH**: Subchannels are only used for PSSCH. PSCCH opportunities are grouped in a pool at one edge of the channel, such that they cannot overlap with PSSCH. This configuration is less spectrally efficient in case of low number of users per subframe, as some PSCCH opportunities RBs will be unoccupied.

B. SCI messages

The SCI contains the scheduling information for the PSSCH. In mode 4, SCI format 1 is used. It has a length of 32 bits, as shown in Fig. 2 and the following structure:

- **Priority:** indicates the importance of message, such as high-priority DENM, normal CAM or relayed messages
- **Resource Reservation:** a field used only in mode 4, announcing resources to be used based on sensing decisions.
- **Frequency resource location:** a bit pattern used to define PSSCH physical RB resources
- **Time Gap:** the number of subframes gap between the first and the optional second PSSCH transmission
- **Modulation and Coding Scheme:** determines the MCS used for PSSCH
- **Retransmission Index:** indicates if the PSSCH refers to the first or the optional second transmission
- **Reserved bits:** zero-valued padding bits

C. Semi-Persistent Scheduling

Semi-Persistent Scheduling (SPS) was introduced in LTE-V2X to avoid the need for frequent resource selection or

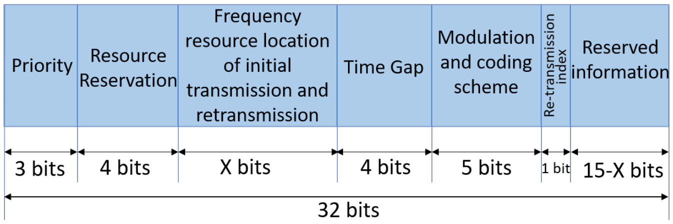


Fig. 2: SCI content

reselection, and also as a technique to reduce collisions of packets in a synchronous network. The time interval between packets can be selected among the possible values: 20, 50, 100, 200, 300 ... 1000 ms, respectively corresponding to the following transmission rates: 50, 20, 10, 5, ... 1 Hz. When a vehicle selects a new resource, it will be reserved for a number of upcoming consecutive transmissions, given by the re-selection counter. It is uniformly randomly selected between 5 and 15 when the new resource is selected. The re-selection counter is decremented by one after each transmission. When it reaches zero, the vehicle decides to keep the same resource with probability P or to select new resource using the sensing-based resource selection mechanism with probability (1-P). The standard does not specify a fixed value of P, it can be any value from the range [0, 0.2, 0.4, 0.6, 0.8]. Transmitters also need to select a new resource if the previously reserved resource is too small. This procedure is represented in Fig. 3.

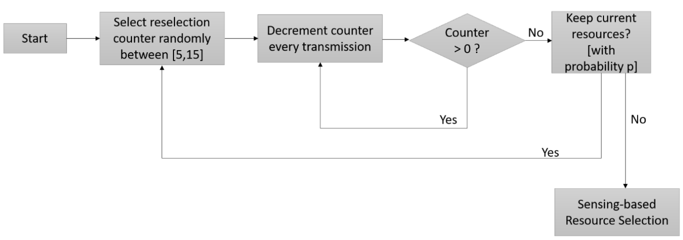


Fig. 3: LTE SPS flow chart

The station announces the reserved resource using the resource reservation field in the SCI. This field uses 4 bits to indicate the packet transmission interval. The SCI resource reservation field table (see Fig. 4) summarizes resource reservation field values and how it is interpreted by other vehicles.

Resource reservation field in SCI format 1	Corresponding value X	Indication
'0001', '0010', ..., '1010'	Decimal equivalent to the field [1, 2, ..., 10]	The same resource is reserved for the next transmission after (100 * X) ms
'1011'	0.5	The same resource is reserved for the next transmission after 50 ms
'1100'	0.2	The same resource is reserved for the next transmission after 20 ms
'0000'	0	This resource is not reserved for the next transmission
'1101', '1110', '1111'	Reserved	Reserved

Fig. 4: SCI resource reservation field

D. Sensing-based resource selection

When a station decides to select a new resource for its transmission, it uses the sensing-based resource selection algorithm. It estimates which resources are in-use by others, using the resource reservation field information included in the SCIs received. Decisions are also based on 2 measurements computed by the station itself:

- **Sidelink Reference Signal Received Power (S-RSRP)**: defined as the linear average over the power contributions (in [W]) of the resource elements that carry demodulation reference signals. The power per resource element is determined from the energy received during the useful part of the symbol, excluding the cyclic prefix.
- **Received Signal Strength Indicator (RSSI)**: comprises the linear average of the total received power (in [W]) observed only in the configured OFDM symbol and in the measurement bandwidth over N number of resource blocks, by the UE from all sources, including adjacent channel interference, thermal noise etc. To build this metric, a station considers the history in the last 1000 subframes, at the desired pace (for example 100 ms time interval).

In mode 4, radio resources are selected from a selection window, set between 20 ms and 100 ms, based on the above layers requirements. A shorter window provides a shorter latency but might increase the probability of collisions. The selection window is given by [n+T1, n+T2] where n is the time when the vehicle decides to select a new resource and T1 and T2 are selected by the vehicle with the limitation that T1 in [1,4] and T2 in [20,100]. Within the selection window, the vehicle identifies all the candidate resources. A candidate resource is a number of adjacent subchannels in which the packet to be transmitted can fit. When a message needs to be transmitted, the last 1000 ms of sensing history, referred to as the sensing window, are scanned to determine which resources are likely to be used by other stations. The sensing period and selection window are represented in Fig. 5.

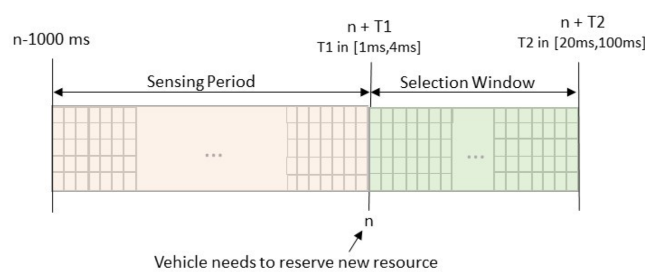


Fig. 5: Sensing period

The station excludes resources from the selection window that are going to be re-used by other users, and which measured RSRP is higher than a given threshold. After excluding these resources, the number of candidate resources must be at least 20% of the number of all candidate resources. If not, this step is re-iterated, with the RSRP threshold being increased by 3 dB. After that, the station extracts exactly the 20% candidate resources that have the lowest average RSSI measured in the sensing period. Finally, one resource is selected randomly from the resources considered in the previous step. Random selection is used to prevent situations where multiple stations select the same resource with the lowest RSSI. Once a resource is selected, it is reserved for the next n transmissions where n is given by the re-selection counter in the semi-persistent scheduling.

In LTE-V2X, stations have the possibility to send packets twice following the retransmission process to increase robustness, although at the expense of spectral efficiency. If retransmission is enabled, the station finds a second resource following the previously described procedure, in the time interval of [T-15ms, T+15ms] from the first resource. The vehicle indicates in the SCI if it is the first or second transmission using the retransmission index field, and the time interval between the original and the second transmissions in the time gap field.

IV. LTE-V2X Decentralized Congestion Control

A. Motivation for DCC

In some dense scenarios, a lot of ITS stations can be within a small geographical area, thus sharing resources is a challenge. To this end, Decentralized Congestion Control (DCC) is needed to coordinate the usage of the channel. All stations shall cooperate to keep the channel unsaturated, and resources are shared equally. The standard defines two metrics to characterize the channel state and allow the station to take necessary actions: the channel busy ratio (CBR) and the channel occupancy ratio (CR), shown in Fig. 6.

- **Channel busy ratio (CBR)**: defined as the portion of subchannels in the resource pool whose RSSI measured exceeds a pre-configured threshold. Such metric is sensed over the last 100 subframes. It provides an estimation on the total state of the channel.
- **Channel occupancy ratio (CR)**: calculated at subframe n, it is defined as the total number of subchannels used for its transmissions in subframes [n-a, n-1] and granted in subframes [n, n+b] divided by the total number of subchannels within [n-a, n+b]. a and b are determined by the station with the limitation of a+b+1 = 1000, a $\geq$ 500. The CR provides an indication on the channel utilization by the transmitter itself.

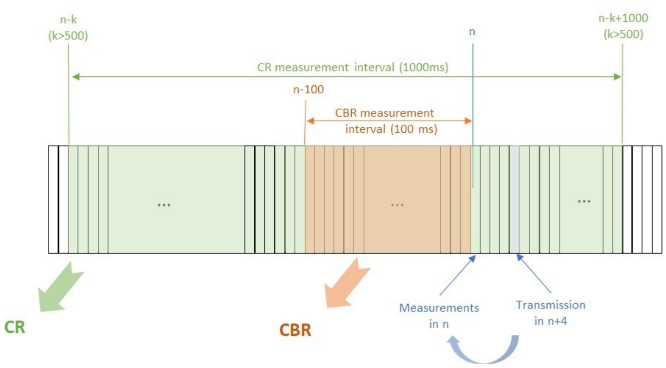


Fig. 6: CBR and CR calculations in DCC mechanisms

B. DCC application for LTE-V2X

CBR and CR measurements are updated after every subframe. The CBR range can be divided into up to 16 intervals. For each interval of CBR values, a CR limit is defined as a footprint that the transmitter should not exceed. When the station decides to transmit a packet, it maps its CBR value to the correct interval to get the corresponding CR limit value. If its CR is higher than the CR limit, the station has to decrease its CR below that limit. The standard does not specify a particular technique to reduce the CR, and it is up to each implementation to decide which technique(s) to use among the following options:

- **Drop packet retransmission**: if the retransmission feature is enabled, the station can disable it. Note: this technique is not considered in this study as we assume the retransmission feature to be disabled.
- **Drop packet transmission**: the station simply drops the packet transmission (including the retransmission if enabled). This is one of the simplest technique. As a reference, this technique is being used by 802.11p systems. Note: when doing such technique, from the LTE-V2X transmitter's perspective, the resource reservation for the subsequent transmissions is maintained even if one packet is dropped (as long as the re-selection counter has not reached 0).
- **Adapt the MCS**: the station can reduce its CR by augmenting the MCS index used. This can reduce the number of subchannels used for the transmission. However, increasing the MCS reduces the robustness of the message, and thus reduces the range of the message. Note: this technique is not considered in this study as we assume the MCS index to be fixed at 7.
- **Adapt transmission power**: the station can reduce its transmission power. Consequently, the overall CBR in the area will be reduced, and the value of CR limit might be increased. Note: this technique is not considered in this study as it notoriously complicated to fine-up (it can lead to oscillations), and would make sense only if all the stations are forced to use this technique.

V. Performance Evaluation

A. Simulation assumptions

We evaluate the performance of the LTE-V2X for a control safety ITS 10 MHz channel, considering ITS-G5 CAM messages. We assess the impact on DCC considering the communication parameters indicated on Table I. At the time of this study, there was no official "profile" set of physical layer parameters provided by regulators. For example, the ETSI ITS specification is still in a drafting stage [20]. Therefore, we have used the set of parameters that we think makes the most sense. This set of parameters is fully allowed and compliant to LTE-V2X Rel-14.

The CAM messages sizes are set approximately 190 Bytes, a value which is aligned with the published studies so far [8], [9]. Note: this scenario is arguably optimistic as CAM sizes are likely to be larger, and as set the of CAM sizes can be rather diverse. Nevertheless, such value was used as it allows comparison to other studies. Similarly, although this is not

Parameter	Value
Standard version	LTE-V2X Rel-14
Adjacency of PSSCH-PSCCH	enabled
Number of subchannels	3
Channel size	50 RB
Subchannel size	16 RB
MCS index	7 ($\approx$ IEEE 802.11p QPSK $\frac{1}{2}$)
HARQ retransmissions	disabled
transmission power	23 dBm
Noise Figure	5 dB
RSRP threshold (init)	-110 dBm
Message Size	1480 bits (190 bytes)
Message Tx rate	max 10Hz
Number of Subchannels/msg	1
PSSCH size	12 RB
Channel Throughput	4.5 Mbps

TABLE I: LTE-V2X communication parameters

the standard operational mode for ETSI, we fixed the CAM TX rate to 10Hz to ease comparison with other LTE-V2X studies[3]. For all the simulation results presented in this this study, the vehicles' movements have been simulated in SUMO (Simulation of Urban MObility), according to the mobility scenario described in Table II. Realistic traffic patterns were considered with the Krauss car following model, targeting a maximum speed yet adjusting its speed depending on the surrounding traffic state and its location. NS3 has been used as a simulation platform to perform the evaluations. The propagation path loss model is based on WINNER B1. In particular for the simulations of slow and fast highway, the LOS component has been used.

Scenario	Fast Highway	Slow Highway
Number of lanes	3 lanes x 2 directions	3 lanes x 2 directions
Length of the road	2000 m	600 m
Max vehicle speed	70, 140, 250 km/h	50 km/h
Min inter-vehicle spacing	2.5 sec	2.5 sec
Avg. number of vehicles	245, 123, 70	100, 200 250

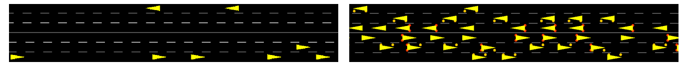
TABLE II: LTE-V2X mobility parameters

Finally, the DCC mechanism used in our simulations is "packet drop" (i.e. Tx Rate Control, TRC). At the time of this study, there was no official CR limit table provided by regulators. For example, the ETSI ITS specification is still in a drafting stage [21]. Therefore we used the CR limit table from 3GPP RAN1 working group contribution [22], as depicted in Table III.

CBR measured	CR limit
CBR $\leq$ 0.650	no limit
0.650 < CBR < 0.675	1.6e-3
0.675 < CBR < 0.700	1.5e-3
0.700 < CBR < 0.725	1.4e-3
0.725 < CBR < 0.750	1.3e-3
0.750 < CBR < 0.800	1.2e-3
0.800 < CBR < 0.825	1.1e-3
0.825 < CBR < 0.850	1.0e-3
0.850 < CBR < 0.875	0.9e-3
0.875 < CBR	0.8e-3

TABLE III: LTE-V2X DCC parameters

[3]The CAR2CAR is currently conducting a study to estimate the real size and Tx rate for CAM. It is expected that the selected values in this work will lead to better results than true ones due to predictable fixed values.



(a) fast highway (b) slow highway

Fig. 7: SUMO simulation examples

1) Fast highway scenario: We consider a highway of 6 lanes, with 3 lanes in each direction. The whole length of the highway is 2000 meters. All the cars move with the same speed. We considered 3 different speeds: 70 km/h, 140 km/h and 250 km/h, leading respectively to 245, 123 and 70 vehicles (based a constant inter-vehicle spacing of 2.5 seconds).

2) Slow highway scenario: This set of simulations is designed to test the performance of LTE-V2X mode 4 under heavy traffic load, where the DCC mechanism is stressed. To this end, the channel needs to be close to saturation. In this scenario, we simulate the vehicles' movements in a highway road of length 600 meters, composed of 3 lanes in each direction. To reach a dense network, the maximum speed is set low, to 50 km/h. Simulations were conducted for different number of vehicles in the road: 100, 200 and 250 vehicles. This scenario essentially tends to a simulate a traffic jam, when a high number of vehicle is used.

VI. Simulation results

1) Fast highway scenario: Figure 8 presents the packet delivery rate (PDR) against the transmitter-to-receiver distance (Distance Tx-Rx) in case of sensing-based resource selection, for 3 different speeds.

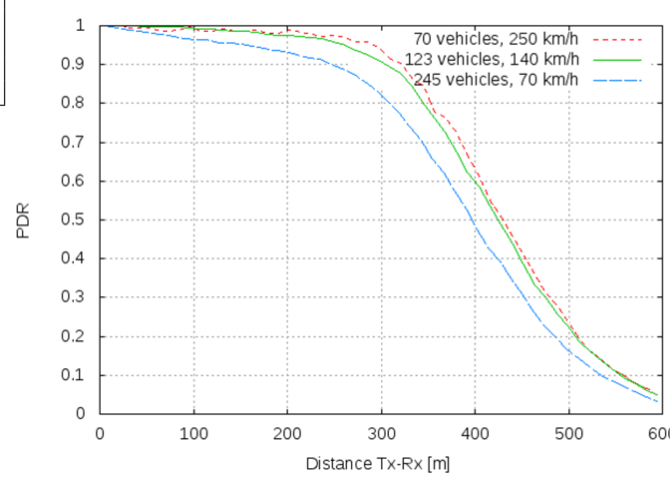


Fig. 8: PDR vs Distance Tx-Rx for 70, 123, 245 vehicles (speed = 250, 140, 70 km/h) in fast highway scenario

One can see that for 250 km/h and 140 km/h (when vehicles moving fast), PDR is over 90% for a range of 300 m. For distances bigger than 300 m, we start to have signal regression due to propagation path loss. This validates the choice of MCS 7 as an upper bound for the MCS index, to cover correctly all speeds type of situations. The PDR decreases progressively for distances bigger than 300 meters. In this scenario, the performance of LTE-V2X is more limited by the propagation path losses, rather than by the packets collisions. The channel is not heavily congested.

For a lower speed of 70 km/h, the system starts to undergo some impact of interference. Since vehicles are moving with a relatively slow speed, we will have a denser network. In this situation, we can observe the PDR starts to decrease noticeably already for small distances.

2) Slow highway scenario: Figure 9 presents the packet delivery rate (PDR) against the transmitter-to-receiver distance (Distance Tx-Rx) for respectively 100 and 200 vehicles transmitting at 10 Hz in case of sensing-based resource selection and random resource selection.

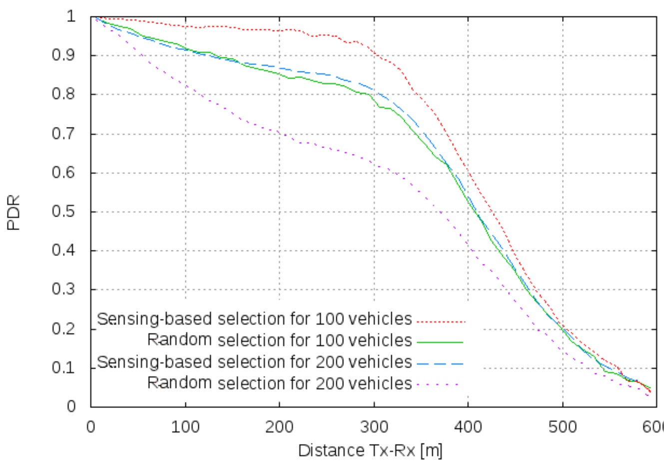


Fig. 9: PDR vs Distance Tx-Rx for 100 and 200 vehicles in slow highway scenario

We can see that sensing-based resource selection provides significant improvement in terms of packet reception rate. When the sensing-based resource selection is used, for 100 vehicles, the packet delivery rate is $\geq 90\%$ until approximately 300 meters of distance, then it starts to decrease steeply. For 200 vehicles, the packet delivery rate (PDR) is $\geq 90\%$ until approximately 125 meters of distance, and then it decreases progressively as the $\geq 80\%$ PDR mark is passed at approximately 300 meters, then starts to decrease more steeply. For both cases, when resources are selected randomly, the system is performing much worse: the packet delivery rate is decreasing fast even for small distances and this due to collisions since resources are selected randomly and no mechanisms of resource selection are used.

For the case of 200 vehicles and with the sensing-based approach enabled, we wanted to investigate the reasons of packet losses. Figure 10 shows the percentage of packets correctly received, packets lost due to collisions and packets lost due to propagation path loss. We can see that for small distances, the only reason of losing packets is collisions. At 300 meters, we start to have decoding errors due to the propagation path loss, until it becomes by far the main reason of packet lost for big distances. We can see that collisions still occur when sensing-based resource selection is used, and it can affect more than 10% of the messages if the number

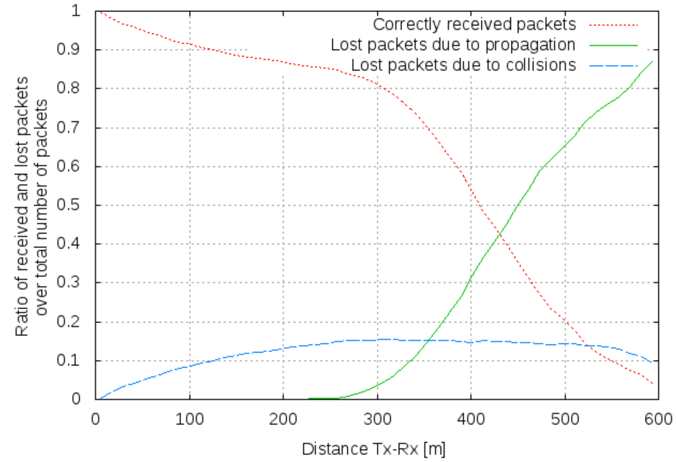


Fig. 10: Ratio of received and lost packets over number of sent packets for 200 vehicles in slow highway scenario

of stations in the area is significant. An explanation will be provided in the next section.

In our configuration, the channel bandwidth is divided into 3 subchannels and the selection window is 100 ms. When a station selects a new resource, it has to select 1 out of 300 available resources. We wanted to investigate the system's performance when 250 vehicles are in the same area, which is getting very close to the 300 resources. we are assessing the behavior of the following configurations:

- Resources are selected using sensing-based resource selection but without DCC algorithm
- Resources are selected using sensing-based resource selection and with DCC algorithm

Figure 11 shows the value of the CBR, as measured locally by a random vehicle over time. We can see that when the DCC is not applied, the measured CBR reaches up to 75% and the channel can be considered saturated. When the DCC is applied, the measured CBR is reduced and keeps oscillating around 60% $\pm$ 3%. This confirms that the DCC is functioning correctly.

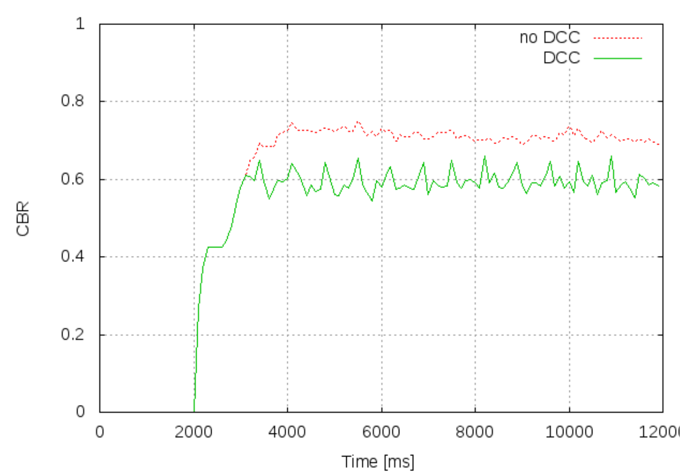


Fig. 11: CBR vs time for 250 vehicles in slow highway scenario

Figure 12 shows the PDR vs distance between transmitter

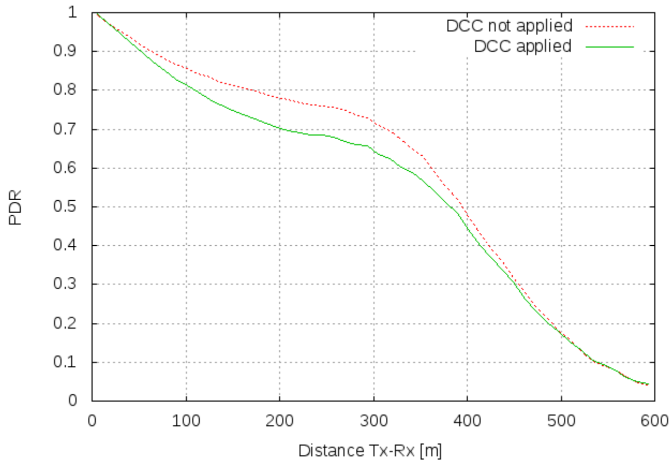


Fig. 12: PDR vs Distance Tx-Rx for 250 vehicles in slow highway scenario

and receiver for 250 vehicles for 2 usecases: with and without DCC. We can see that there is a drop in PDR when DCC is enabled, compared to DCC disabled, even though DCC reduces the number of transmitted packets (a packet dropped is considered not transmitted). In this configuration, vehicles will have to select one resource from the 20% of available resources (20% of 300 resources) that experienced the lowest RSSI. Since the number of vehicles is high in a small geographical area, one vehicle is more likely to select an already reserved resource by another vehicles. Once a collision takes place, it occurs for a number of transmissions given by the re-selection counter.

VII. Challenges of DCC on LTE-V2X

In the previous part, we showed the performance of LTE-V2X algorithms under slow and fast highway. Using the sensing-based resource selection algorithm, always provided better packet delivery rate compared to when resources are selected randomly.

When the channel is congested, with many users in the same area, the DCC is applied. Dropping packet transmission will decrease the packet delivery rate and the total number of transmitted and received packets will be decreased, which is good from a pure CBR and CR limit compliance perspective. However, we noticed that when the DCC starts to be heavily triggered by demanding use cases, the overall performance of the system is degraded. We investigate this phenomenon in this section.

When a first vehicle decides to select a new resource, it sets a selection window. The sensing-based resource selection selects one resource from this selection window. The other vehicles will not know about the selected resource until the packet is transmitted and decoded correctly. In the meantime, if a second vehicle decides to select a new resource, it can unfortunately select the same resource already selected by the first vehicle. This is depicted on Fig. 13.

When such kind of collision occurs, it cannot be detected by transmitters due to half duplex. Such collisions can last for a large number of consecutive transmissions. As the re-selection

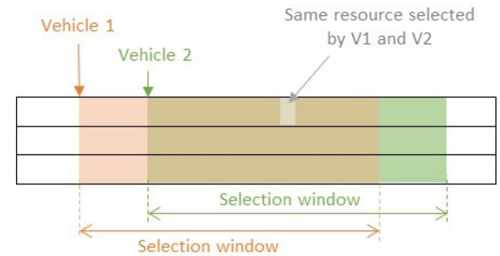


Fig. 13: Same resources selected by two vehicles

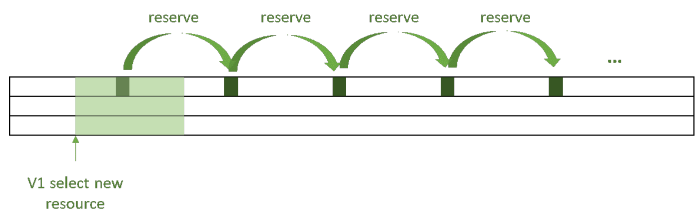


Fig. 14: Resource reservation in LTE-V2X SPS

counter is uniformly selected between 5 and 15, this means that such collisions last in average 1 second (if transmitting at 10 Hz), which is a relatively long time for safety related messages.

The LTE-V2X standard does not specify a particular DCC technique. It is up to the implementation to decide what to do in order to reduce its CR. In our simulations we adopted as a technique packet dropping. Results have showed that using this technique will reduce the CBR and thus, the channel is not saturated. However, this technique will also cause a decrease in the PDR even if the total number of transmitted packets has dropped, which is indeed not desired. A reason might be due to the way LTE stations treat the reservation field, placed in their SCI messages. The reservation field indicates to other vehicles when the resource will be used for next time. If the vehicle decides not to reserve the resource for the next time, this field is set to zero. The important point to notice is that the reservation of the resource is in fact done only for the next transmission, as depicted in Fig. 14.

When the packet is dropped due to DCC mechanism, the reservation series continues at the transmitter's side, but the message is not sent. On the other hand, the receiving stations will not find a reservation being placed, and might decide to start using the same resource, unfortunately. The incompatibility of a semi-persistent scheduling scheme with a packet-drop DCC mechanism becomes clear. If the DCC allows the vehicle to transmit packets again for the next message, it might collide with other messages, as shown in Fig. 15.

Furthermore, applying packet drop can cause a waste of resources. When a station decides to drop a packet, if its resource was already reserved, the other stations will not consider this resource as a free candidate resource, and no other transmission will occur on the same resource, during the subframe when packet drop is performed.

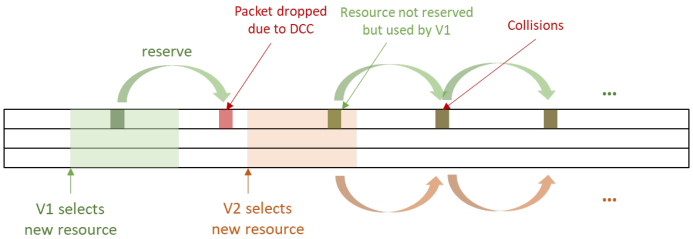


Fig. 15: Collisions due to packet drop (DCC mechanism)

VIII. LTE-V2X Enhancements for Congestion Control

In this section, we provide some ideas for potential improvement proposals of the LTE-V2X system. Such proposed enhancements will be assessed in a future paper.

Our first suggestion is related to the CBR intervals table that we have been using. We have seen in above figure 16 some CBR oscillations. This phenomenon might be due to the abrupt changes in CR limit that kick-in when CBR exceeds a threshold.It might be interesting to have a CR limit table with more entries and an additional rule that would sure that the CR limit can only change by one row at a time.

Secondly, we have clearly shown that packet-drop is not a suitable technique for LTE-V2X mode 4 congestion control, due to the semi-persistent scheduling with reservations. Dropping the packet problematically causes the resource to be sensed free and thus available for use by the surrounding nodes, leading to collisions when the station resumes its series of reserved transmissions. Therefore one suggestion would be to force a station to perform a new resource reservation process whenever a packet is dropped, by resetting its re-selection counter to zero.

Thirdly, it would be also interesting to study different techniques for congestion control, since packet drop was not satisfactory. Such other techniques can be transmission power reduction, or MCS adaptation.

IX. Conclusion

We presented in this paper a study on the impact of wireless congestion control on LTE-V2X sidelink Rel-14 mode 4. It included a detailed analysis of semi-persistent scheduling (SPS), sensing-based resource selection used as a distributed resource scheduling, as well as ETSI Decentralized Congestion control (DCC) as wireless congestion control mechanism. We first showed that the sensing-based resource selection helps to increase the system performances compared to a random scheduling. However, degradations can be observed in case of channel congestion, which requires congestion control mechanisms to mitigate them. Yet, our study showed that DCC led to worse performance than no congestion control at all.

References

[1] D. Smely, S. Rührup, Schmidt Robert, J. Kenney, and K. Sjöberg, *Decentralized Congestion Control Techniques for VANETs*. Book Chapter N°6 in "Vehicular Ad Hoc Networks: Standards, Solutions and Research", *Molinaro, Campoli, Riccardo Scopigno Eds*,, 2015.

[2] W. Sun, E. Strom, F. Brännström, K. Sou, and Y. Sui, "Radio Resource Management for D2D-based V2V Communication," *IEEE Transactions on Vehicular Technology*, pp. 1–1.

[3] M. Botsov, M. Klugel, W. Kellerer, and P. Fertl, "Location-based Resource Allocation for mobile D2D communications in multicell deployments," in *Communication Workshop (ICCW), 2015 IEEE International Conference on*. IEEE, 2015, pp. 2444–2450.

[4] ——, "Location dependent resource allocation for mobile device-to-device communications," in *2014 IEEE Wireless Communications and Networking Conference (WCNC)*. IEEE, pp. 1679–1684.

[5] Y. Ren, C. Wang, D. Liu, F. Liu, and E. Liu, "Applying LTE-D2D to Support V2V Communication Using Local Geographic Knowledge," in *Vehicular Technology Conference (VTC Fall), 2015 IEEE 82nd*. IEEE, 2015, pp. 1–5.

[6] L. Gallo and J. Härri, "Short paper: A LTE-direct broadcast mechanism for periodic vehicular safety communications," in *VNC 2013, IEEE Vehicular Networking Conference, December 16-18, 2013, Boston, USA*, 2013.

[7] ——, "Unsupervised LTE D2D - Case study for safety - Critical V2X communications," *IEEE Vehicular Technology Magazine, Special Issue on Emerging Technologies, Applications, and Standardizations for Connecting Vehicles, Vol.: PP, Issue: 99, June 2017*, 02 2017.

[8] R. Molina-Masegosa and J. Gozalvez, "Lte-v for sidelink 5g v2x vehicular communications: A new 5g technology for short-range vehicle-to-everything communications," *IEEE Vehicular Technology Magazine*, vol. 12, no. 4, pp. 30–39, Dec 2017.

[9] ——, "System level evaluation of lte-v2v mode 4 communications and its distributed scheduling," in *2017 IEEE 85th Vehicular Technology Conference (VTC Spring)*, 2017, pp. 1–5.

[10] G. Cecchini, A. Bazzi, B. M. Masini, and A. Zanella, "Performance comparison between ieee 802.11p and lte-v2v in-coverage and out-of-coverage for cooperative awareness," in *2017 IEEE Vehicular Networking Conference (VNC)*, Nov 2017, pp. 109–114.

[11] A. Bazzi, G. Cecchini, B. M. Masini, and A. Zanella, "Performance comparison between ieee 802.11p and lte-v2v in-coverage and out-of-coverage for cooperative awareness," 3GPP, Tech. Rep., July 2018. [Online]. Available: https://arxiv.org/pdf/1807.10699.pdf

[12] B. Kloiber, J. Härri, T. Strang, and C. Rico Garcìa, "Random transmit power control for DSRC and its application to cooperative safety," *IEEE Transaction of Dependable and Secured Communication, 25 June 2015, Volume PP, N°99*, 2015.

[13] J. B. Kenney, G. Bansal, and C. E. Rohrs, "Limeric: a linear message rate control algorithm for vehicular dsrc systems," in *8th ACM Workshop on Vehicular inter-networking (VANET), 2011.*

[14] M. Sepulcre, J. Gozalvez, O. Altintas, and H. Kremo, "Integration of congestion and awareness control in vehicular networks," *Ad Hoc Networks*, vol. 37, 2016.

[15] A. Vesco, R. Scopigno, C. Casetti, and C.-F. Chiasserini, "Investigating the effectiveness of decentralized congestion control in vehicular networks," in *Globecom Workshops (GC Wkshps), 2013 IEEE.*

[16] ETSI, "TS 102 687 (v1.2.1) - Intelligent Transport Systems (ITS); Decentralized congestion control mechanisms for intelligent transport systems operating in the 5 ghz range; access layer part."

[17] C. Huang, Y. P. Fallah, R. Sengupta, and H. Krishnan, "Intervehicle transmission rate control for cooperative active safety system," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 645–658, Sept 2011.

[18] SAE, "J2945/1 (2016) - On-board system requirements for v2v safety communications."

[19] 3GPP, "TS 36.213 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Layer procedures (Release 13) v14.2.0," 3GPP, Tech. Rep., April 2014.

[20] ETSI, "TS 103 613 - Intelligent Transport Systems (ITS); Access layer specification for intelligent transport systems using lte vehicle to everything communication in the 5,9 ghz frequency band."

[21] ——, "TS 103 574 - Intelligent Transport Systems (ITS); Congestion control mechanisms for c-v2x pc5 interface; access layer part."

[22] Qualcomm, "R1-1611594 congestion control for v2v," 3GPP TSG RAN1-87, Tech. Rep., November 2016. [Online]. Available: http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_87/Docs/R1-1611594.zip