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Cooperative Resource Allocation and Scheduling for 5G eV2X Services

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ABSTRACT In this paper, a cooperative solution for vehicle-to-everything (V2X) communications is proposed and presented, which can guarantee reliability and latency requirements for 5G enhanced V2X (eV2X) services. Cooperation is useful for both in-coverage and out-of-coverage vehicular communications scenarios. The proposed solution relies on the sidelink (SL) device-to-device (D2D) communications for V2X communications. In this work, we first provide a performance evaluation of SL D2D V2X communications in terms of resource allocation and scheduling. The resource allocation is known as mode 3 and 4 SL D2D communications and the scheduling is using a semi-persistent scheduling (SPS) approach. Simulation results are obtained in order to identify and highlight the reliability trade-offs considering different payload sizes and SPS parameters. In the sequel, a cooperative solution that decreases transmission collision probability is devised and presented, which is able to significantly improve the reliability of future 5G enhanced vehicle-to-everything (eV2X) communications. Different application scenarios are simulated to obtain results that can guarantee the latency also requirements per 5G eV2X use case as specified in 3GPP Rel.16 towards ultra reliable and low latency communications (URLLC).

INDEX TERMS Sidelink device-to-devic, 5G enhanced V2X (eV2X) services, V2V communications, resource allocation, scheduling, cooperative ultra reliable and low latency communications.

I. INTRODUCTION

Vehicular communications are considered as one of the big challenges towards 5G networks. Thus, several 5G vehicular-to-everything (V2X) use cases have already been included in 3GPP Rel.15 initially that can be found now in Rel.16 such as vehicle platooning, remote and autonomous driving and cooperative collision avoidance [1][2]. Such emerging technologies are driven from the industry that aims to enhanced V2X (eV2X) 5G communication services in terms of reliability and latency [3-7].

In particular, the authors in [3] provided an overview of the open challenges towards supporting vehicle-to-everything (V2X) services in high mobility environments and dense locations of User Equipments (UEs). The authors focused on different design requirements such as the air interface, cost-effective network deployment and the support of different communication types. They also referred to the channel structure of the sidelink (SL) device-to-device (D2D) communications as a candidate for future 5G V2X communications. D2D communications has been extensively developed within 3GPP for different type of applications [8]. More recently, in [4], the author focused on the PC5 interface, where the SL D2D communications rely on, and the recently introduced modes 3 and 4. A discussion about the new resource allocation technique that takes into account the near-far effect is also provided.

Further to the PC5 interface, the authors in [5] mentioned the open challenges to provide efficient resource allocation, reliable and prioritized message type, and power control and communication range enhancements. In [6], the authors also mentioned the need for an extension of the PC5 interface for V2X communications provided by the LTE D2D proximity service (ProSe). In [7], the authors proposed a V2X communications solution to support better vehicle platooning towards the 5G V2X communications. The proposed solution relies on the LTE D2D technology, addressing the low latency requirement of messaging within the platoon. Nevertheless, they pointed out that resource management is required to provide ultra-reliability to extend of an almost error free communication channel. Such a management solution is relative to the new modes 3 and 4, which can provide centralized and distributed resource allocation respectively, as pointed out in [9].

In this work, we address the challenge of ultra-reliable low latency communications (URLLC) for 5G enhanced V2X (eV2X) as proposed in 3GPP 16 [1][2]. Given that the SL D2D are considered the air interface for V2X communications [7], we first provide an overview of the different SL D2D modes, including details about the resource allocation and scheduling. The resource allocation aims at dealing with the latency, and the scheduling is employed using a sensing-based semi-persistent scheduling (SPS) algorithm aiming at lowering collision probability that is related to reliability. Simulations are carried out and results are obtained highlighting the performance in terms of Block Error Rate (BLER) and collision probability assuming different parameters of the system. We observed that the collision probability is affected by different configuration parameters of the standardized SPS.

Given the identified performance tradeoffs, we devise a solution that provides enhanced performance for V2X communications satisfying the design requirements of 5G eV2X use cases. To this end, we first describe the design requirements as introduced within the Rel.16 of 3GPP for enhanced 5G V2X communications. Next, we propose the cooperative solution, which reduces packet collision probability, i.e. improves the system reliability, while guaranteeing the low latency constraint. Different type of performance results are obtained, which prove the concept of cooperative resource allocation and scheduling for the emerging 5G V2X communications.

Summarizing, our contribution is considered twofold: a) the performance evaluation of SL D2D V2X communications in terms of BLER and collision probability, identifying the reliability performance requirements respectively, b) the proposed cooperative solution that can provide URLLC for 5G eV2X services, which rely on counter reselection learning process.

There are a few related works on this topic such as the cooperative small cell solution in [8], the UE autonomous resource selection in [10], and the TTI-based low latency solution in [11]. However, none of them addressed the reliability requirement for in and out of coverage application scenario to deal with 5G V2X use cases according to the 3GPP Rel.15. A recently published work in [12] provides an overview about the SL D2D mode 3 and 4 proposing also a distributed solution, which relies on the resource reservation procedure of the SPS algorithm. Instead, our solution relies on a counter reselection procedure that is useful for 5G V2X use cases with high number of vehicles requesting for cooperation to guarantee the reliability. Finally, our preliminary work on this topic that can be found in [13], it pointed out the benefit of counter reselection learning procedure over the standardized SPS approach. However, it was not deployed assuming more complicated 5G application scenarios with many users and different type of eV2X performance requirements. Moreover, potential solution of how to implement the proposed solution within 3GPP system and towards 5G was not also discussed.

II. Sidelink D2D communications for V2X services

In this work, we focus on the communication part of the channel structure. Some 3GPP terminology is given below. The SL D2D channel structure consists also of logical, transport and physical channels. The data is transmitted over the physical SL shared channel (PSSCH), and the SL control information (SCI) message is transmitted over the physical SL control channel (PSCCH) [6].

A. Sidelink D2D communications for V2X services

D2D communications was first introduced in modes 1 and 2 form [7]. The resource allocation for modes 1 and 2 is carried out at the eNodeB (eNB) or autonomously by the UEs respectively. Mode 2 can be used by the UEs both in out-of-coverage and in-coverage scenarios while mode 1 can only be used when the UE is under the coverage of the eNB. Both modes share the same resource allocation structure, in which the transmission and reception of data is scheduled within the PSCCH period [14]. Within this period, a set of subframes are determined for the PSCCH transmission (ocean blue region in Fig.1a) and a different set of subframes are determined for the PSSCH (yellow part in Fig.1a). The corresponding PSCCH data for a given PSSCH is always sent before the PSSCH data, where the PSCCH contains the SCI, also called Scheduling Assignment (SA). The SCI is used by the receiver to know the occupation of the PSSCH radio resources. In both modes, the SCI is configured in format 0 and is transmitted identically in two different subframes in order to provide reliability due to the lack of feedback channel in SL communications. The receiver blindly detects the SCI by trying out all possible PSCCH resources. Once the correct SCI is decoded (indicated by the Group ID field of the SCI), the receiver UE extracts the relevant information to know where the resources of the actual data are allocated. The PSSCH transport block can be transmitted up to four times in four consecutive subframes within the subframe pool, allowing the receiver UE to implement open loop HARQ by combining the four redundancy versions of the PSSCH transport block.

SL modes 3 and 4 provide a different structure than modes 1 and 2. In particular, PSCCH period does not exist, where the PSCCH and PSSCH channels are separated in the frequency domain. The resource grid is divided into sub-bands, or sub-channels, in which the first two resource blocks of each sub-channel form the PSCCH pool (ocean blue region in Fig.1b) and the other resource blocks form the PSSCH pool (yellow region in Fig.1b). PSCCH and PSSCH data can be transmitted on non-adjacent resource blocks. However, we

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assume an adjacent configuration in our example. Two identical SCIs (format 1) and their corresponding PSSCH transport block are sent out in the same subframe. If the PSSCH data occupies more resource blocks than available in one subchannel it also uses the PSCCH and PSSCH pool of the next subchannels (Fig.1b for P3). In modes 3 and 4, a transport block can be sent out one or two times. In case of two transmissions, another subframe is used with the same structure with two SCIs and the corresponding PSSCH transport block. In this case, all four SCIs provide information of the allocation of both PSSCH transport blocks. The receiver also detects the SCIs blindly. In case of two transmissions of the same PSSCH transport block, the receiver also implements HARQ [15].

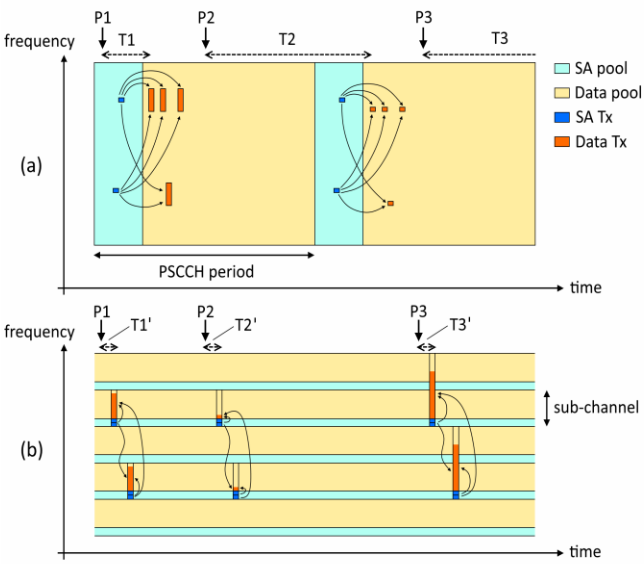

FIGURE 1. Resource allocation: a) modes 1 and 2, b) modes 3 and 4.

Obviously, in modes 1 and 2, a packet can be delayed till the next PSCCH period, e.g. P2 (Fig.1a) arrives at lower layers during the data pool that should wait for the next PSCCH period to begin. Modes 3 and 4 were proposed in order to overcome such a latency restriction. Fig.1b depicts that for modes 3 and 4 any packet can be scheduled almost immediately no matter when it arrives at lower layers.

In order to evaluate the performance of modes 3 and 4, we developed a customized simulator using Matlab. Simulation was carried out in order to develop the SL D2D baseband processing. Fig.2 depicts the BLER vs SNR (in dB) while transmitting 500 packets. We plot the BLER for packets with payload sizes of 3240 bits (QPSK) and 12960 bits (16QAM), with and without retransmission, using a code rate of 1/3. For the channel configuration, different Doppler shifts (100 and 300 Hz) are considered, which correspond to different relative velocities (18 km/h and 55 km/h, respectively1) between UEs. The considered SNR range (from -10 dB to 16 dB) corresponds to distances between vehicles of 2000 m to 100 m approximately, according to the D2D path loss model presented in [7]. We consider a SIMO (single-input-multiple-output) configuration with 1 TX antenna and 2 RX antennas, and we assume that there is no interference of other UEs transmissions.

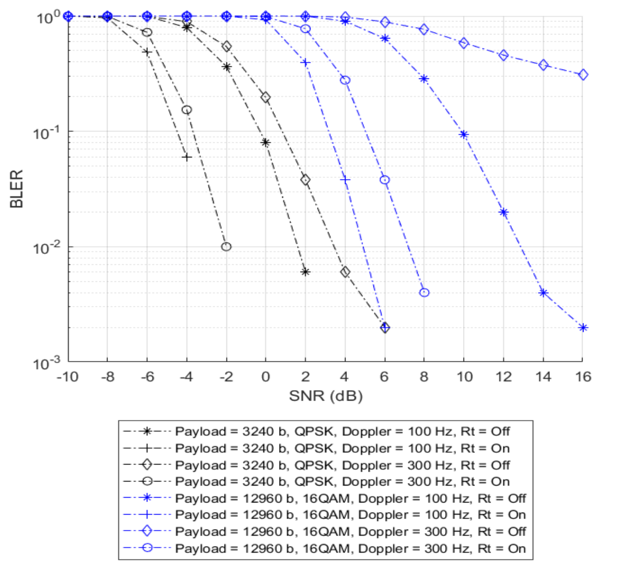

FIGURE 2. Achievable BLER vs SNR for different payload sizes, modulations, Doppler shifts and transmissions.

Fig.2 shows that both the modulation type (QPSK or 16QAM) and the retransmissions have a big impact in the BLER results. The packet transmission using 16QAM implies a higher BLER than the QPSK transmission, and the use of retransmission implies a smaller BLER than transmitting the packet only once. There is a smaller impact when assuming different Doppler shifts; however, as we expected, a higher Doppler shift implies a higher BLER due to mobility increase. We can figure out that in case of QPSK transmissions with HARQ there is no error above 0 dB. Without using HARQ this takes place from an SNR of 8 dB. Using 16QAM transmission the BLER is getting 0 above 10 dB when using HARQ, but without retransmission it only gets below 10 % within the considered SNR range in case of a Doppler shift of 100 Hz. Considering that the distance between vehicles could be lower than 100m, especially for V2V communications services, reliability constraints of 99 %, or higher, can be satisfied in most cases. Nevertheless, system level design specification should be provided for particular use cases with high number of vehicles and this is what follows next in this paper.

B. Sidelink D2D scheduling for V2X services

[1] $\Delta f = \frac{\Delta v}{c} f_0$, where Δf is the Doppler frequency, Δv the relative velocity, c the wave speed ($3 * 10^8 \frac{m}{s}$), and f_0 the wave carrier frequency ($5.9\ GHz$).

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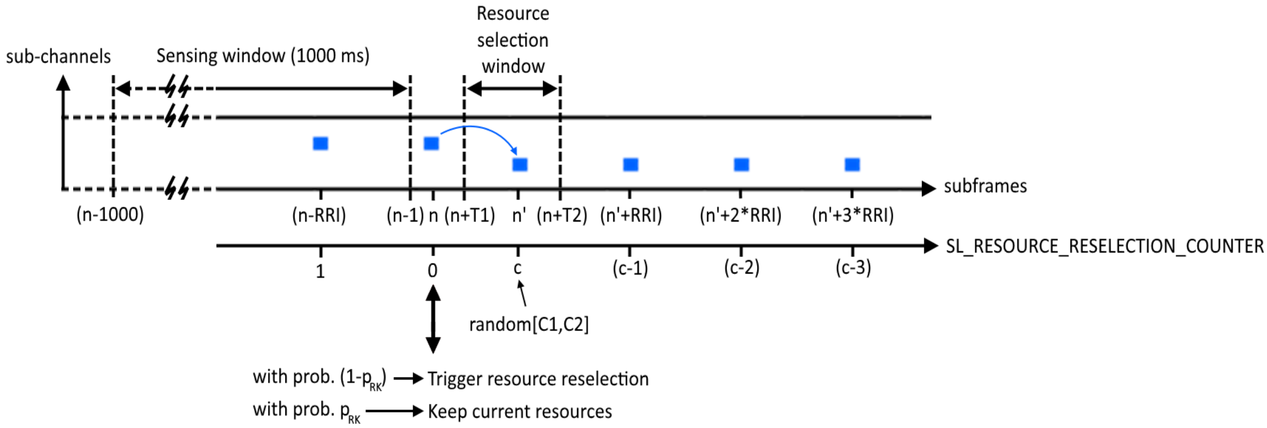

FIGURE 3. Resource reselection triggering in standardized sensing-based SPS procedure

Due to the periodic nature and predictable size of packets in V2X transmissions, a sensing-based semi-persistent scheduling (SPS) was standardized by 3GPP in order to optimize the use of the resource grid and minimize the transmission collisions between different UEs. The SPS procedure is illustrated in Fig.3, where the UE transmits in a certain resource every resource reservation interval (RRI). The value of a counter named SL_RESOURCE_RESELECTION_COUNTER is decreased by one per transmission, where if this counter reaches zero, the UE either keeps transmitting in the same resources or triggers resource reselection with a specific probability. To keep transmitting or not is specified by a reselection probability p_{RK} (probResourceKeep) [2]. In any case, the UE randomly selects a new integer value for the counter within a the range [C1,C2] that depends on the RRI value (see Table 1) [16]. If a resource reselection is triggered, the UE is going to select within a resource selection window, which is within the range [n+T1, n+T2], where n is the current subframe, T1 depends on the process delay of the UE ($T1 \leq 4$) and T2 on the latency requirements ($20 \leq T2 \leq 100$). The actual resource selection is related to the sensing results sensed for a period of the sensing window (1000ms). Details about the spectrum sensing procedure can be found in [12].

TABLE I
SL_RESOURCE_RESELECTION_COUNTER RANGE DEPENDING ON RRI VALUE [15]

RRI (ms)	[C1,C2]
100	[5,15]
50	[10,30]
20	[25,75]

[2] The reselection probability p_{RK} can take the values 0, 0.2, 0.4, 0.6 and 0.8 [12].

In order to evaluate the standardized SPS, we developed a system-level simulator using Python programming language for rapid prototyping We focused on the transmission collisions and thus, we simulated an abstraction of a time-frequency grid divided in subframes and subchannels. We first simulated the grid with values of '0' for no transmission, where the transmissions were indicated by '1' into the simulated resource grid. This allows a fast calculation of collisions without decoding real messages. The considered simulation parameters are summarized in Table 2 for the evaluation of the SPS in the first place. The simulation example consists of a group of 10 UEs that communicate to each other using SL D2D mode 4. At the beginning of the simulation, the resources used by each of the UEs are randomly initialized and the current value of their counters. In order to simulate a dynamic scenario, we add a new UE into the system every 10 secs occupying resources randomly. In parallel, one of the existing UEs leave the group randomly and simultaneously keeping the total number of users equal to ten.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Number of vehicles	10
Retransmission	Off
Bandwidth	10 MHz
Message payload size	3240 bits
Modulation	QPSK
Allocated RBs	45
Number of subchannels	1
Allocated subchannels	1
RRI	20 ms
[T1,T2]	[2,20] ms
[C1,C2]	[25,75]
p_{RK}	0

We also assume that all the UEs transmit periodically with the same rate, i.e., they use the same RRI value and they send packets of equal size. Moreover, we assume that if a transmission is not colliding with another transmission, it will be correctly decoded by the other vehicles. Likewise, if two or more transmissions are colliding, we consider that all of them will be incorrectly decoded at the receivers. Finally, we assume that the resources used by other UEs are occupied regardless of a received power threshold. The simulation runs for one million subframes, which represent 1000 secs in the system. The average collision rate from the beginning of the simulation is calculated every 1 sec and thus, the last obtained collision rate value represents the average collision probability along all the simulation.

Fig.4 depicts simulation results of the average (i.e. over the different simulation samples) collision probability with the 5 possible p_{RK} values. We can observe that the lowest average collision probability is obtained with $p_{RK} = 0.4$ while the highest average collision probability is obtained with $p_{RK} = 0.8$. With $p_{RK} = 0.4$, reselection is performed when the counter expires with a probability of 60%, whereas the resources are kept with a probability of 40%. For the following simulations $p_{RK} = 0.4$ is assumed.

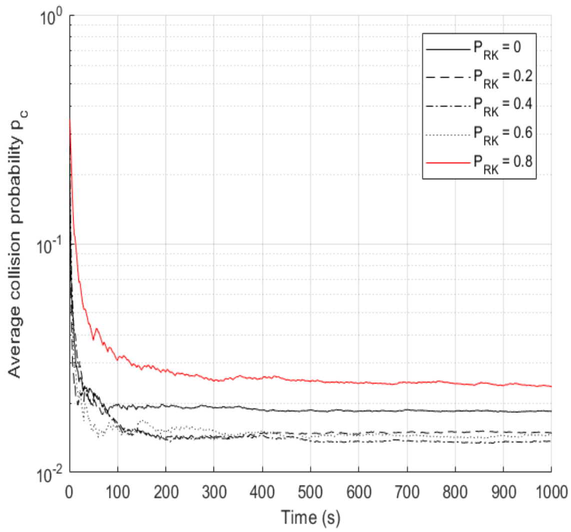

FIGURE 4. ***Average collision probability p_c with different reselection probability p_{RK} values.***

The rest of configurable parameters within the standardized SPS approach are RRI and T2, which depend on the specific application requirements. While RRI can take the values 20, 50 and 100 (also other higher values that are not considered in this work), T2 can take any value between 20 and 100 [14][15]. In order to observe the system's performance for different combinations of RRI and T2, we perform nine different simulations using all the combinations within the numbers 20, 50 and 100. We depict all these results in Fig.5. We observe that the lowest average collision probability is obtained with RRI = 100 ms and T2 = 20 ms. In fact, given a specific RRI the lowest collision probability always seems to be given by a low T2 value. On the other hand, a higher RRI number gives also a lower collision probability due to a lower UEs transmission density. Nevertheless, the combination of RRI = 100 ms and T2 = 20 ms can only be used if the maximum end-to-end delay requirement is 100 ms or higher. If the latency requirement is 20 ms, only the combination RRI = 20 ms and T2 = 20 ms could be used from all considered cases

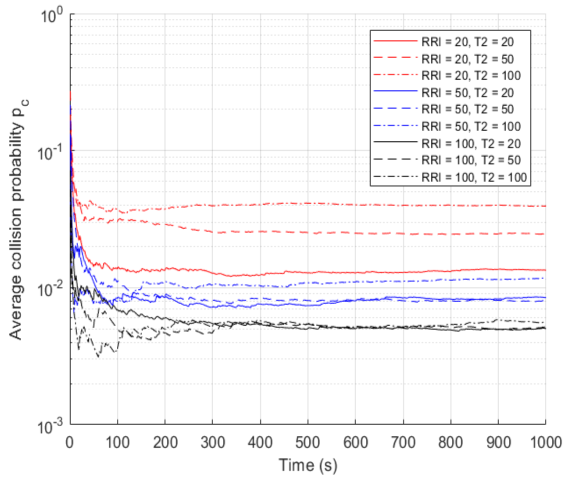

Figure 5. Average collision probability p_c with different combinations of RRI and T2.

III. Cooperative resource allocation and scheduling for 5G eV2X services

A. 5G eV2X services requirements

3GPP has provided a long list of 5G use cases for eV2X communication services [1][2]. In particular, design requirements for 25 different 5G eV2X use cases are presented in Rel.15 and now in Rel.16. This is a quite extensive list aiming to provide different type of serviced to the automotive industry. Most of those requirements are going to affect the system design to fulfil the requirements. We summarize below some of the most important 5G eV2X use cases as specified in 3GPP Rel.16 [1]:

- eV2X support for vehicle platooning: information exchange such as join/leave, announcement warning, etc.

- eV2X support for remote driving: remote driving where differently from autonomous driving, the vehicle is controlled remotely.
- Automated cooperative driving for short distance grouping: automated cooperative driving is a combination of vehicle platooning with high-demanding communication between the vehicles.
- Collective perception of the environment: vehicles can exchange real time information collected by vehicle sensors.
- Cooperative collision avoidance: vehicles should be able to know the probability of an accident using cooperative aware messages and data from sensors.

Table 3 summarizes the different 5G eV2X use cases with the corresponding key performance indicators (KPIs) such as message payload size, reliability and latency. We assume that the 5G eV2X use cases should be provided also in an "out of 5G coverage" application scenario. On the other hand, cooperation among the UEs can provide solutions to this problem as described above.

TABLE III
PAYLOAD MESSAGE SIZE, RELIABILITY AND LATENCY 5G EV2X REQUIREMENTS [1]

5G use cases	Size (bytes)	Reliability (%)	Latency ms)
Vehicle platooning	300-400	90	25
Remote driving	300-400	99.99	5
Aut. Coop. driving	1200	99	10
Coll. Perc. Env.	1600	99	100
Coop. Coll. Avoid.	2000	99.99	10

B. Cooperative resource allocation and scheduling

In the standardized SPS resource allocation approach described above, it can be observed that transmission collisions among different UEs may occur in case of reselection window overlapping. In fact, such overlapping is a source of collisions to the proposed SPS mechanism, In order to overcome this source of collisions, we propose a cooperative solution to avoid a concurrent reselection. The proposed solution comes with the idea of transmitting the counter values in each packet transmission that can provide the UEs with the information about future concurrent reselection. The UEs will trigger counter reselection as long as the received counters in the last RRI coincide with their own current counter. In this way, the system will not allow the UEs to perform resource reselection that can result progressively in time to a collision within the reselection window.

Therefore, the proposed solution relies on the counter learning and reselection (CLR) mechanism that is explained below in detail. First, the counters considered for counter reselection (set A) consists of the counters lower than the current counter. We choose among the lower counters in order to not introduce extra delays into the resource reselection triggering process. For example, if the transmission of the UE involved in the counter reselection is colliding with another transmission, we do not prolong the collision time. Next, considering the received counter values during the last RRI as $\mathrm{C_{RX}} = [\mathrm{c_0}, \mathrm{c_1}, \ldots, \mathrm{c_{N-1}}]$, where $\mathrm{c_i}$ is the i-th received counter value and *N* is the number of received counters, the non-available counters (set B) consists of $C_{RX} \cup (C_{RX} - 1)$, where $(C_{RX} - 1) = [c_0 - 1, c_1 - 1, \ldots, c_{N-1} - 1]$. $(C_{RX} - 1)$ are also considered in set B because in case one of them was chosen, it would coincide with some surrounding UE counter when such a surrounding UE has gone through another RRI. Finally, the UEs will randomly choose, with equal probability, one of the counters in the set $Z = A\backslash B$ while performing counter reselection.

Our proposed solutions differs also to the standardized SPS approach in terms of counter value while the current counter reaches 0 value. As presented above for the standardized approach, a counter range is randomly chosen, with equal probability, in the counter range [C1,C2]. In our solution, we choose the counter equal to 63 for both C1=C2=63. We devised this option in case that the counter values among close UEs are already separated by the counter reselection approach, they should continue separately in case they choose a fixed counter when the current counter expires. However, they might collide once again as long as they choose a new counter randomly within a specific range. Further, the reselection probability p_{RK} is not considered into the system (or set to 0) since it does not have an impact to the performance of the algorithm. The algorithmic procedure of the proposed cooperative solution is depicted in Fig.6. The parameter C denotes the current counter value of the UE, where C_{RX} denotes the received counters from the surrounding UEs during the last RRI period.

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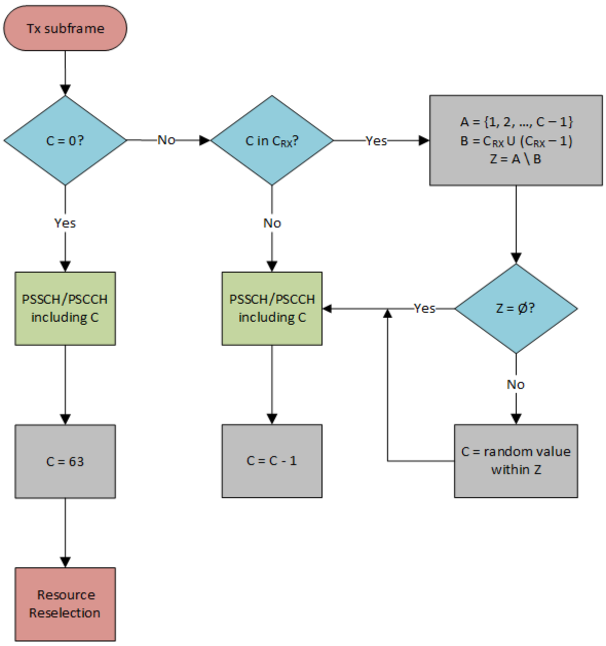

Figure 6. **CLR scheduling mechanism for eV2X services.**

The proposed CLR scheduling mechanism is also simulated by modifying the standardized system-level simulator. Fig.7 depicts simulation results of the proposed cooperative solution using the parameter values from Table 2 (apart from C1 and C2) compared to the simulation results obtained by the simulated standardized approach (in this case, using $p_{RK} = 0.4$). It is observed that the proposed approach clearly achieves lower collision probability (0.34 % after 1000 secs in the simulated scenario) than the standardized approach (1.43 %) in the dynamic scenario. Considering a static scenario, i.e., without a UE join and leave, it is observed that the difference is even higher between these two approaches. More specific, it is observed that in the static scenario the average collision probability decrease throughout the simulation time. It is actually expected to have some collisions at the beginning of the simulation (caused by a random initialization of the UEs resources in the simulator), where they are going to be minimized afterwards thanks to the CLR mechanism. This means that in the dynamic scenario, the collisions are only introduced by the new UEs that enter into the system for the sake of simulation examples.

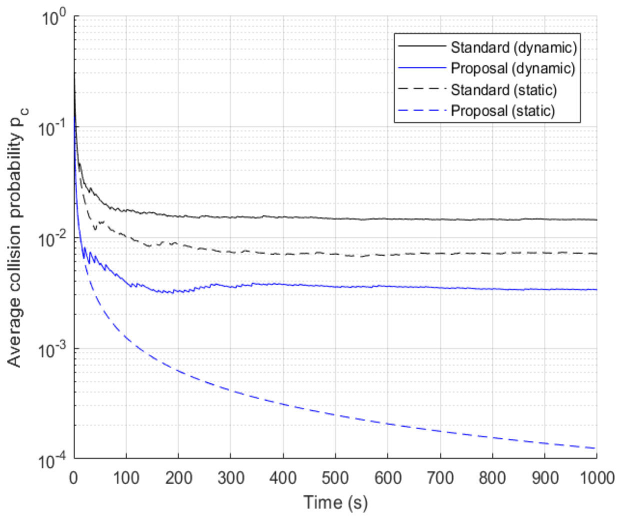

Figure 7. Average collision probability of standardized SPS and proposed scheduling for dynamic and static applications scenario

In order to see the impact of the number of UEs into the system, we depict in Fig.8 the average collision probability for different number of UEs in a dynamic scenario. In our proposal, we can see that for 5, 10 and 15 number of UEs the results are quite similar, whereas in the case of 20 UEs we have a collision probability clearly higher. In fact, 20 is the ideal number of UEs that could be allocated in the proposed scenario since each UE transmits periodically every 20ms and, thus, only one packet per subframe can be sent without colliding. However, even if 20 UEs could be ideally allocated, the proposed approach only works properly when the number of UEs is lower than the maximum that can be allocated. In the standard, we can see that having a lower number of UEs clearly gives better results than having more UEs. In summary, our proposal performs better than the standard for 5, 10 and 15 UEs, and similar in the limit of 20 UEs.

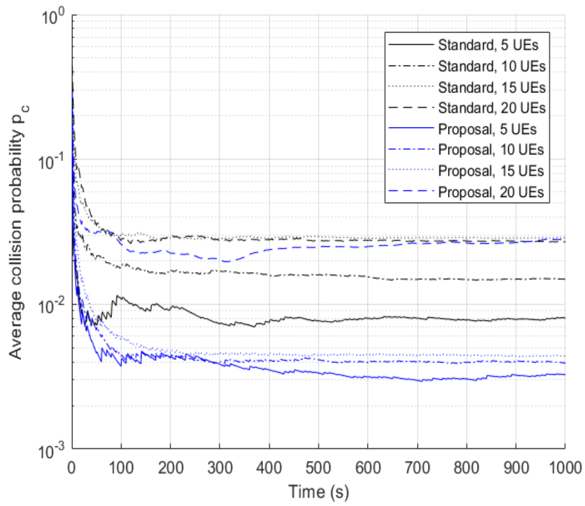

Figure 8. Average collision probability of the proposed CLR mechanism for different number of UEs in a dynamic scenario.

We assume now two application scenarios (ASs), which can accommodate some of the features listed in the 5G use cases in Table 3. A 20MHz grid dedicated to mode 4 is assumed for both ASs. In the first application scenario (AS1), *we consider a use case similar to "vehicle platooning*, where some UEs periodically transmit packets with a payload of 3240 bits (about 400 bytes) while fulfilling a 25 ms latency requirement. In order to guarantee this latency requirement, we choose *RRI=20ms* and *T2=20ms*. QPSK is employed for AS1 due to the better BLER performance compared to 16QAM. We simulate two grid configurations with two different N_{subCH} values (5 and 2) to test the impact of this parameter into the system, even though $N_{subCH} = 2$ is not a standardized value [12]. Using $N_{subCH} = 5$ (AS1a), the packet occupies 3 subchannels ($L_{subCH} = 3$), which limits the number of possible allocated UEs to ten in case they perform packet retransmission. This is because the UEs transmit two packets every 20 ms and only one packet per subframe can be transmitted without collision. Five UEs are assumed for AS1a since, as seen in Fig.8, the number of UEs must be lower than the limit. In case of $N_{subCH} = 2$ (AS1b), the packet occupies 1 subchannel ($L_{subCH} = 1$). This enables twice as many UEs to be allocated compared to the previous case for the fact that two packets can be transmitted per subframe instead of one. In this case, 15 UEs are assumed. As depicted in Fig.9, the comparison between AS1a and AS1b shows that by using $N_{subCH} = 2$ the collision probability is clearly lower than by using $N_{subCH} = 5$, even though the number of UEs is three times higher. This demonstrates the importance of the grid configuration as well as that $N_{subCH} = 2$ can be a useful value for this configuration even if not standardized.

In the second application scenario (AS2*), we assume a use case similar to "collective perception of the environment"*, where the latency requirement is 100 ms and packets with a payload size of 12960 bits (about 1600 bytes) are transmitted. We choose *RRI=100ms* and *T2=100ms* in order to guarantee the latency requirement. Due to the size of the packet, only 16QAM modulation can be considered in this case so that the packets fit into the 20MHz grid. Packet transmission is carried out in one subframe occupying more than half of the frequency axis of the grid. Thus, only one packet can be transmitted per subframe whichever the grid configuration. $N_{subCH} = 2$ is chosen in order to match with AS1b configuration. In this case, the packet occupies two subchannels ($L_{subCH} = 2$). Due to the less-stringent latency requirement, more UEs can be allocated in this AS; however, we also simulate 15 UEs for comparison purposes.

As depicted in Fig.9, the comparison between AS1b and AS2 shows that the less-stringent latency requirement does not make the collision probability to be lower for AS2. In fact, the results show that the collision probability for AS2 is higher than for AS1b. This is because each packet in AS2 occupies all the subchannels in the grid, whereas in AS1b only half of them. More generally, it can also be seen that the collision probability is higher when using retransmission (Rt = On); however, it is below 1 % in in the long term for all simulated scenarios, which guarantees a reliability of 99 % in good channel conditions according also to Fig.2. In this way, the 5G eV2X requirements presented in Table 3 for "vehicle platooning" and "collective perception of the environment" use cases are guaranteed.

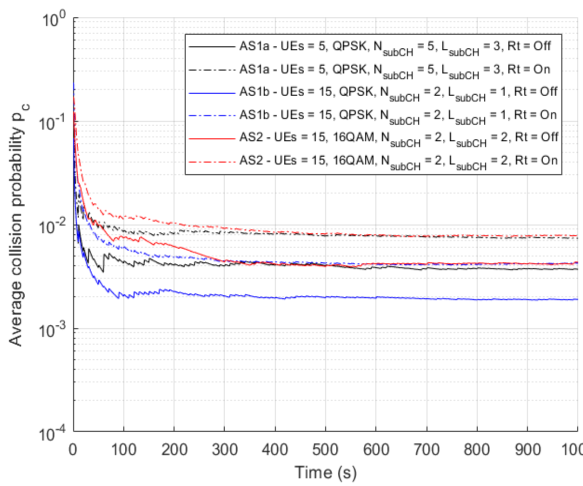

Figure 9. Average collision probability for different application scenarios (ASs)

C. 3GPP implementation details

Given our approach above, a trade-off can be assumed related to whether an increase in signalling information among the cooperative vehicles exists. In particular, the collision probability is improved because the UEs exchange more information about their state by sending the SL_RESOURCE_RESELECTION_COUNTER to nearby UEs. This section deals with the signalling issue revealing that no extra signalling overhead is required since our solution can be integrated within the SCI message.

Fig.10 depicts the structure of the SCI format 1 message, transmitted in modes 3 and 4 in PSCCH and used for the scheduling of PSSCH [17]. The SCI format 1 consists of the fields shown in Fig.10, where “RIV”, which stands for Resource Indication Value, represents the “Frequency resource location of initial transmission and retransmission” field, “Time gap” represents the “Time gap between initial transmission and retransmission” field, and “Rt. idx” represents the “Retransmission Index” field. According to [17], all the SCI format 1 fields but “RIV” occupy a fixed number of bits, which sum 17 bits in total. The number of bits required for “RIV” depends on the number of subchannels in the resource grid and it might range from 0 to 8 bits. Reserved information bits are added (and set to zero) until the size of SCI format 1 is equal to 32 bits. Obviously, at least 7 bits are not used (set to zero) in each SCI format 1 transmission.

Priority	Resource reservation	RIV	Time gap	Modulation and coding scheme	Rt. idx	Reserved information bits	
3	4	0 - 8	4	5	1	7 - 15	(bits)

Figure 10. SCI format 1 fields

In our proposed solution, we assume that the UEs transmit their current counter value in each transmission and that the maximum counter value is 63 that can really be represented in 6 bits. Therefore, we propose for the counter to be transmitted in each SCI format 1 transmission in conjunction with some of the reserved information bits. In this way, the UEs are able to know the counter value of their surrounding UEs by just decoding the SCI. This could be really useful deployment to enhance the reliability in future 5G eV2X services.

IV. CONCLUSION

In this work, we provide an overview of the SL D2D modes 3 and 4 for vehicular communications. We provide details about the resource allocation and scheduling mechanisms with focus on a comparison between modes 3 and 4. We highlight the main differences from the modes 1 and 2 in order to address the latency and reliability requirements using enhanced resource allocation and scheduling respectively. Simulation is also carried out in order to evaluate the performance of SL D2D modes 3 and 4 in terms of BLER and collision probability. In the sequel, we consider the 5G enhanced V2X (eV2X) service requirements such as message payload size, reliability and latency as they are specified by 3GPP Rel.1. We propose a cooperative resource allocation and scheduling approach, which is able to address the challenge of both ultra-reliable and low latency communications (URLLC). The proposed solution is also able to address the challenge of in and out of coverage application scenarios in a cooperative fashion. Implementation details within the 3GPP system are also given for possible deployment scenario towards robust 5G eV2X communication services.

REFERENCES

[1] 3GPP TR 22.886, ”Study on enhancement of 3GPP Support for 5G V2X Services”, v16.1.1, Sep. 2018.
[2] 3GPP TS 22.186, ”Enhancement of 3GPP support for V2X scenarios”, v16.0.0, Sep. 2018.
[3] H. Seo, K-D. Lee, S. Yasukawa, Y. Peng and P. Sartori, ”LTE Evolution for Vehicle-to-Everything Services”, IEEE Communi. Magazine, vol. 54, no.6, pp. 22-28, Jun. 2016.
[4] E. Uhlemann, ”Initial Steps Toward a Cellular Vehicle-to-Everything Standard”, IEEE Veh. Technol. Magazine, vol. 12, no.1, pp. 14-19, Mar. 2017.
[5] Y.Lan Tseng, ”LTE-Advanced Enhancement for Vehicular Communication”, IEEE Wirel. Communications, vol. 22, no. 6, pp. 4-7, Dec. 2015.
[6] S-Yu Lien, C-C. Chien, G Shu-Tsz Liu, H-L. Tsai, R. Li and Y. J. Wang, ”Enhanced LTE Device-to-Device Proximity Services”, IEEE Communi. Magazine, vol. 54, no. 12, pp. 174-182, Dec. 2016.
[7] 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. Tech. Magazine, vol. 12, no. 1, pp. 30-38, Mar. 2017.
[8] M. Höyhtyä, O. Apilo and M. Lasanen, Review of Latest Advances in 3GPP Standardization: D2D Communication in 5G Systems and Its Energy Consumption Models, Future Internet, vol. 10, no.1, MDPI, https://doi.org/10.3390/fi10010003, MDPI, Jan. 2018.
[9] S. Chen, J. Hu, Y. Shi, Y. Peng, J. Fang, R. Zhao and L. Zhao, Vehicle-to-Everything (v2x) Services Supported by LTE-Based Systems and 5G, IEEE Comm. Stand. Magaz., vol.1, no. 2, pp. 70-76, Jul. 2017.
[10] X. Ge, H. Cheng, G. Mao, Y. Yang and S. Tu, Vehicular Communications for 5G Cooperative Small-Cell Networks, IEEE Trans. Veh. Techn., vol. 65, no. 10, pp. 7882-7894, Oct. 2016.
[11] M-J. Shih, H-H. Liu, W-D. Shen and H-Y. Wei, UE Autonomous Resource Selection for D2D Communications: Explicit vs. Implicit Approaches, 2016 IEEE Conference on Standards for Communications and Networking (CSCN), Oct.-Nov.2016.
[12] K. Lee, J. Kim, Y. Park, H. Wang and D. Hong, Latency of Cellular-Based V2X: Perspectives on TTI-Proportional Latency and TTI-Independent Latency, IEEE Access, vol. 5, pp. 15800-15809, Jul. 2017.

[13] N. Bonjorn, F. Foukalas and P. Pop, 'Enhanced 5G V2X services using sidelink device-to-device communications", Med-Hoc-Net 2018, Jun. 2018.
[14] 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 Veh. Tech. Magaz., vol.12, no.4, Dec. 2017.
[15] 3GPP, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification (Release 14)", TS 36.331 V14.4.0, Sept. 2017.
[16] 3GPP, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 14)", TS 36.213 V14.4.0, Sept. 2017.
[17] 3GPP, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (Release 14)", TS 36.321 V14.4.0, Sept. 2017.

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