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A New Priority and Satisfaction-based Resource Allocation Algorithm with Mixed Numerology for 5G-V2X communications

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***Abstract*—5G-V2X is today a new emerging technology for vehicular networks, where resource allocation mechanisms play a crucial role in its overall performance. For this reason, scarce and precious resources must be efficiently managed to meet the various QoS requirements of a wide range of V2X use cases. In this paper, we highlight the resource scheduling problem for two different V2X applications, namely the safety applications and the non safety applications. Therefore, we propose a new Priority and Satisfaction-based Resource Allocation algorithm with Mixed Numerology for 5G V2X communications (PSRA-MN). In PSRA-MN, we apply a priority policy in favour of the safety traffic, since the latter is the most time-constrained V2X traffic type. Then, the remaining resources after ensuring the demands of safety traffic are optimally scheduled for the non-safety traffic. The PSRA-MN algorithm is executed in a mixed numerology scenario, in which different 5G numerologies are multiplexed in the time domain. The PSRA- MN scheduling scheme is validated through simulations conducted using the Simu5G simulator. The simulation results show that the PSRA-MN algorithm achieves better performance in terms of average allocation rate, average satisfaction rate and average delay compared to the Max C/I algorithm.**

***Index Terms*—5G-V2X, Resource Allocation, V2X applications, Numerology.**

I. Introduction

Vehicle-to-Everything V2X communications have attracted a lot of attention in recent years. Indeed, connected vehicles will revolutionize the transport sector and the automotive industry. Road safety remains the main objective of the automotive industry. For this reason, the integration of wireless communication technologies in this sector has led to a new paradigm known as V2X communication. V2X communications aim to provide road safety and traffic management services. They are also capable of providing other types of service, such as entertainment applications.

In vehicular networks, the first standardized technology for V2X communications is the Wi-Fi technology [1], known as DSRC (Dedicated Short Range Communication) or ITS G5 based on the 802.11p standard, followed by the cellular technology C-V2X (Cellular-V2X) [2].

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Fig. 1: Resource Allocation Modes in 5G-V2X

The resource allocation in C-V2X has drawn the attention of the research community in the last few years. As there always exist areas that cannot be served by a base station, C-V2X presents two modes of resource allocation: a centralized under-coverage mode and a distributed out-of-coverage mode. In 5G-V2X, they are respectively known as modes 1 and 2 as illustrated in Figure 1. In the under-coverage mode, the resources are scheduled and allocated by Next Generation Node B (gNB) to vehicles. However, in the out-of- coverage mode, the vehicles autonomously select their radio resources using the sensing-based Semi-Persistent Scheduling (SPS) algorithm. In this paper, we are interested in the under-coverage mode, where the resources are scheduled and allocated by the gNB to vehicles.

C-V2X provides integration of both V2V (Vehicle-to- Vehicle) and V2I (Vehicle-to- Infrastructure) communications, based on the sidelink PC5 interface, and the V2N (Vehicle-to- Network) communications based on the Uu interface. The direct V2V communication via the sidelink PC5 interface is the basic mode of V2X communications. The ITU (International Telecommunication Union) has dedicated the 5.9 GHz band for V2X sidelink communications [2]. since the sidelink communications can support both the safety traffic and the

non-safety traffic, efficient resource allocation mechanisms are imperative to guarantee the QoS requirements of the different traffic types. Regarding the regulation of the 5.9 GHz band, it should be noted that the use of this frequency band varies from one area to another. On the one hand, the ECC (European Cooperation Centre) has divided the allocated spectrum between safety applications and non-safety applications by allocating part of the spectrum to safety traffic and another part to non-safety traffic [3]. However, it is not prohibited for safety applications to use the non-safety bands. In addition, other countries, do not decide on the possibility of sharing frequencies for these applications. The contribution of this work addresses the case where the safety and non-safety traffic share the same spectrum bands.

Indeed, vehicular applications include not only safety applications, but also other types of services such as traffic management applications and entertainment applications [4]. However, since the main goal of ITS is to ensure the road safety service, the safety-related traffic is considered as critical traffic in vehicular networks. Consequently, the application of a priority policy in the resource scheduling scheme to distinguish between safety-related and non-safety-related traffic is a necessary step. As for traditional resource allocation algorithms, we note that they are not always suitable for V2X applications [5]. For example, regarding the Max-C/I algorithm [5], which aims to maximize the system throughput by scheduling the vehicle with the best radio-link conditions first, we find that this algorithm can schedule a non-safety vehicle before another safety vehicle if that non-safety vehicle has good radio-link conditions, which is very dangerous for the safety service. To this end, the main objective of this paper is to propose a new resource allocation algorithm that aims to ensure the necessary resources for safety vehicles by applying a priority mechanism in favour of safety traffic. The remaining resources after safety allocation are then allocated to the non-safety vehicles by solving an integer linear optimization problem that aims to maximize the average satisfaction rate of non-safety traffic.

To benefit from the flexibility of the 5G NR frame structure to achieve the requirements of different V2X applications, the proposed resource allocation algorithm is executed in a mixed numerology scenario. The 5G numerologies are considered as one of the most important 5G key features. A numerology refers to the spacing between OFDM (Orthogonal Frequency Division Multiplexing) subcarriers. In the LTE system, a fixed subcarrier spacing of 15 kHz is used. However, in 5G, other subcarrier spacing values such as 15 kHz, 30 kHz, 60 kHz, or 120 kHz can be used. The choice of the appropriate numerology for a particular V2X application is of particular importance. This topic has already been studied in the paper presented in [6], where we conclude that the choice of the appropriate numerology depends not only on the application requirements, but also on the channel conditions and the vehicle speed. To get closer to reality, we considered different channel conditions and vehicle speeds in our scenario and then selected the appropriate numerology before allocating radio resources. In summary, the main contributions of this work are as follows:

- we propose a TDM (Time Division Multiplexing) approach for multiplexing different 5G numerologies, where the choice of the numerology at each time-slot is based on the channel conditions and vehicle speed as presented in [6].
- We propose a new scheduling scheme for mode 1 of 5G-V2X for the allocation of safety traffic in an initial phase. Then, the non-safety traffic is optimally allocated by solving an integer linear optimization problem.

The rest of this paper is structured as follows. We start with an introduction to the V2X communication in Section II-A. Then, we give an overview of the side-link resource allocation in 5G-V2X in Section II-B. Section III presents the related works. The motivation and contribution is presented in Section IV. Then, we detail the proposed algorithm in Section V. Section VI presents the simulation scenarios and the analysis of the results. Finally, we conclude our paper in section VII.

II. Technical Background

In this section, we present a general overview of V2X communications in Section II-A. Then, a technical background on the sidelink resource allocation in 5G-V2X is presented in Section II-B.

A. Overview of V2X communications

V2X communications can be divided into four main types: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Network (V2N), as shown in Figure 2. The main objective of V2X communications is to ensure road safety and traffic management services in order to reduce the number of accidents. In addition, they can also provide other types of services, such as entertainment applications.

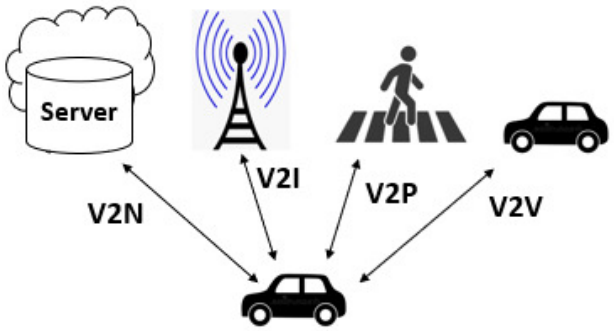

Fig. 2: V2X Communication types

In fact, applications in vehicular networks can be divided into three main categories: traffic safety applications, traffic management applications, and entertainment applications [4]. Traffic safety applications require low latency and high reliability and can be considered as part of URLLC (Ultra Reliable Low Latency Communication), while entertainment applications require high data rates and belong to eMBB (enhanced

Mobile Broadband). Traffic safety applications are based on the broadcasting of periodic messages known as Cooperative Awareness Messages (CAM) indicating the position, speed and direction of the vehicle. Another type of message, which is aperiodic in nature, is exchanged between vehicles to prevent a particular event. These aperiodic messages are known as Decentralized Environmental Notification Message (DENM), as described in [7]. Collision warnings and emergency vehicle warning are examples of such safety applications.

The second category of applications, which is traffic management, aims at managing road traffic by exchanging informations between Road Side Units (RSU) and vehicles, e.g., information about the regulatory speed limits or the status of traffic lights. The third category of V2X applications is the infotainment applications, which is related to the comfort of drivers and travelers. As examples of such applications, we mention finding a parking place, downloading media, or downloading maps.

B. Side-link Resource Allocation in 5G-V2X

In this section, we start with a technical background on resources in 5G-V2X in Section II-B1. Then, we provide an overview of 5G NR numerologies in Section II-B2. Finally, in Section II-B3, the resource allocation mode 1 of 5G-V2X is explained.

1) Resources in 5G-V2X: In NR-V2X, we still find the same radio frame of 10 ms and the sub-frame of 1 ms as in LTE-V2X [8] whatever the used numerology, as shown in Figure 3. A Physical Resource Block (PRB) is defined by 12 consecutive sub-carriers in frequency domain and a time-slot is defined by 14 OFDM symbols. The Resource Element (RE) is the smallest resource unit. It is defined in the frequency domain as well as in the time domain. A Resource Element is defined by 1 sub-carrier in frequency domain for 1 OFDM symbol duration in time domain. The duration of a time-slot depends on the used numerology. The time-slot T_{slot} is computed as:

$$T_{slot} = 1/2^n \tag{1}$$

where n indicates the order of the numerology. For example, in case of numerology 0, the time-slot value is 1 ms and it is of 0.5 ms for numerology 1.

2) Overview of 5G NR Numerologies: The concept of numerologies, standardized in Release 15 by 3GPP, refers to the spacing between OFDM subcarriers [8]. Unlike LTE-V2X, where the subcarrier spacing is fixed at 15 kHz, in NR-V2X it can take other values that are multiples of 15 kHz, i.e. 30, 60 and 120 kHz, as shown in Figure 3. Since the subcarrier spacing is variable, the time slot, i.e., the time to transmit 14 OFDM symbols, is also variable and decreases as the subcarrier spacing increases, which reduces the latency and therefore favors time-critical applications. In Table I, we present the parameters for each numerology.

The multiplexing of different numerologies is another level of flexibility of the NR frame structure. The multiplexing of numerologies can meet the requirements of different applications. The NR-V2X numerology multiplexing can be

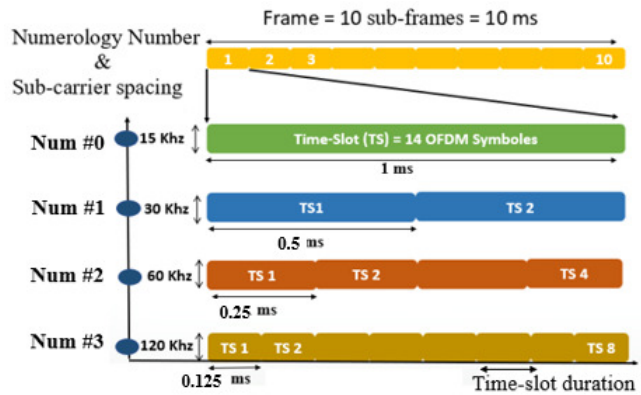

Fig. 3: NR-V2X Frame Structure

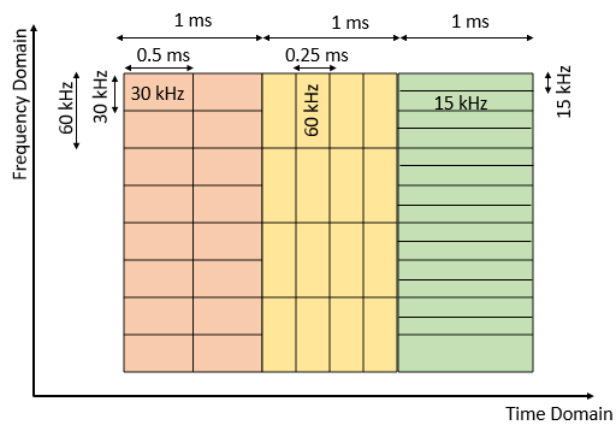

Fig. 4: TDM Numerology Multiplexing

done either by the Frequency Division Multiplexing (FDM) technique , the Time Division Multiplexing (TDM) technique or by mixing both FDM and TDM techniques [9]

In the PSRA-MN, we adopt the TDM numerology multiplexing technique as illustrated in Figure 4.

3) Mode 1 in 5G-V2X: In mode 1, the gNB schedules and allocates resources to vehicles. Like the LTE-V2X mode 3, the NR-V2X mode 1 uses the Dynamic Grant (DG) scheduling, but it uses the Configured Grant (CG) Scheduling instead of the Semi-Persistent Scheduling (SPS) used in LTE-V2X mode 3 [10]. In the DG, the vehicle requests resources to the gNB for each transmission using the Physical Uplink Control CHannel (PUCCH). Then, the gNB responds with the Downlink Control Information (DCI) over the Physical Downlink Control CHannel (PDCCH). The DCI indicates the sub-channels and slot allocated to the vehicle for the transmission of its message. Then, the vehicle informs other vehicles about the scheduled resources using the Sidelink Control Information (SCI). As a result, the nearby vehicles operating in mode 2 are informed about the resources that will be used by vehicles in mode 1.

Numerology	Sub-carrier spacing (kHz)	Slots per sub-frame	Symbol length (μs)	Slot length (ms)	CP
0	15	1	71.42	1	Normal
1	30	2	35.71	0.5	Normal
2	60	4	17.85	0.25	Normal/Extended
3	120	8	8.92	0.125	Normal
4	240	16	4.46	0.0625	Normal

TABLE I: Main parameters of NR-V2X numerologies

III. Related work

As the 5G-V2X is recently standardized by the 3GPP, there exist few research works that deal with resource allocation algorithms in mode 1 of 5G-V2X [11–13]. In [11], Song *et al.* propose a new resource allocation algorithm for mode 1, in which the authors suppose that the gNB allocates resources to vehicles based on the reported Channel State Information (CSI). However, the reporting of the channel state information can lead to the overhead problem. Thus, in order to cope with this problem, the authors propose in a first stage a new power allocation scheme of CSI transmission, that aims to reduce the energy consumption in transmitting the CSI from the vehicles to the gNB. Then, in the second stage, authors try to maximize the system throughput by modeling the sidelink radio resource allocation problem as a Mixed Binary Integer Non-linear Programming (MBINP). In [12], Abbas *et al.* propose a two-level resource allocation scheme that aims to reduce the latency, increase the throughput and guarantee the reliability for V2V and V2N communications. In this work, the authors consider the scenario where the direct link between the gNB and a transmitting vehicle is blocked by a bypassing trailer. So, in this case, another vehicle can act as a relay between the gNB and the transmitting vehicle. In this scenario, the vehicle considered as a relay should obviously have a good connection with both the transmitting vehicle and the gNB. This vehicle can forward an uplink signal with the V2N link or a downlink one with the V2V link. Hence, the authors consider two types of traffic, which are the V2V and the V2N communications, sharing the same radio resources. In this context, authors propose an efficient resource allocation algorithm that aims to avoid the interferences between the V2V and V2N vehicles and guarantee the different QoS requirements of both V2N and V2V communications. The simulation results show that this proposal enables to increase the throughput and decrease the latency. Another Deep Neural Network (DNN)-based resource allocation algorithm for mode 1 is proposed by Gao *et al.*. The main goal of this algorithm is to maximize the system throughput by assigning to vehicles the optimal transmit power [13]. At this point, it is interesting to point out that there are already hundreds of scheduling schemes in 5G that consider QoS [14–18]. However, the vast majority of these proposed resource allocation solutions are related to classical downlink and uplink transmissions in cellular networks, which is not the case in our work since we are interested in vehicular side-link communications. Moreover, applications in vehicular networks are somewhat different from those in traditional cellular networks. Since the main goal of intelligent transportation systems is to ensure road safety, vehicular applications are more critical than other mobile applications in terms of reliability and latency, since they aim to reduce the number of road accidents. For this reason, an efficient resource allocation scheme should take into account the requirements of vehicular applications. With respect to the 5G numerology concept, we note that there are few research works that address resource allocation with mixed numerology in 5G [19–24]. However, the cited research works are not interested in the vehicular scenario, which is very different from traditional networks. Indeed, unlike other Mobile Adhoc NEtworks (MANETs), the vehicular network is an extremely dynamic network, which is naturally due to the high mobility of vehicles. Consequently, the vehicular environment is strongly influenced by the Doppler effect [25]. Since this later has a great impact on the choice of the numerology, it is interesting to consider realistic vehicular environments and select the appropriate numerology considering the characteristics of the vehicular scenario, which has already been considered in our previous work [6].

IV. Motivation and Contribution

The above resource allocation algorithms presented in the Related Work section do not take into account the different V2X applications. In this context, we note that there is a lack of research works that address the resource allocation considering the different requirements and categorization of different V2X applications. Since the resource allocation strategies have a great impact on the overall performance of V2X communications, we emphasize here that efficient radio resource allocation is required for safety and non-safety V2X applications, which is the goal of the PSRA-MN algorithm.

A. Numerology Selection Phase

Before starting the radio resource scheduling process, the PSRA-MN algorithm selects the appropriate numerology index as a first step. The flexibility of the NR frame structure allows us to process a scheduling scheme with mixed numerology. In PSRA-MN, the selection of the appropriate numerology is done according to the recommendations for numerology selection presented in the paper [6], where we demonstrate that the choice of the appropriate numerology depends not only on the application requirements, but also on the channel conditions and the vehicle speed. For this purpose, the delay spread in our scenario is varied in a wide range from 32 ns to 850 ns, and then the appropriate numerology is selected based on the delay spread value and the vehicle speed.

B. Radio Resource Allocation Phase

After the numerology selection step, we perform the resource scheduling in the PSRA-MN algorithm. First, we apply a priority-based resource allocation strategy, where we prioritize the safety traffic by allocating the required number of RBs to the safety vehicles. Then, we optimally allocate the remaining resources after the safety allocation to the non-safety vehicles so that the average satisfaction factor Γ is maximized. The average satisfaction rate is a fairness indicator as proposed earlier by Jain in [26]. The average satisfaction factor indicates the average percentage of satisfaction of all non-safety vehicles present in the scenario. Here, the satisfaction is calculated as a function of whether a vehicle is allocated a number of resource blocks less than or equal to its demand. That is, a vehicle is satisfied at 100% if the gNB allocates to that vehicle the requested number of RBs specified in its demand.

V. System Model and Problem Formulation

Let $\mathbb{V} = \{v_1, v_2, .., v_M\}$ denote the set of M vehicles present in the cell at a given time and sending requests to the gNB in order to be allocated. We denote by C, the total system capacity, defined as the set of available Resource Blocks (RBs). The system capacity C, which depends on the used channel bandwidth, can be formulated as follows:

$$C = \{RB_j\}_{j \in \{1..N\}} \tag{2}$$

where N designates the total number of RBs.

We classify the vehicles into 2 groups according to their traffic type. The first group represents the safety vehicles, which we denote by $\mathbb{V}_{\mathbb{S}} = \{v_1^s, v_2^s, .., v_K^s\}$, where K is the total number of safety vehicles in the scenario. By safety vehicles we mean here the vehicles that run safety applications. The second group represents the non-safety vehicles, which we denote by $\mathbb{V}_{\mathbb{F}} = \{v_1^f, v_2^f, .., v_L^f\}$, where L represents the total number of non-safety vehicles in the scenario. This means that:

$$\mathbb{V}_{\mathbb{S}} \cup \mathbb{V}_{\mathbb{F}} = \mathbb{V} \tag{3}$$

We denote by D_S and D_F the vector of the resource demands of safety vehicles and non-safety vehicles, respectively. These requirements are represented as the number of resource blocks requested by the vehicles. We denote by $d_p^s \in \mathrm{D}_S$ and $d_q^f \in \mathrm{D}_F$ the resource demands of the safety vehicle $v_p^s \in \mathrm{V}_S$ and the non-safety vehicle $v_q^f \in \mathrm{V}_F$, respectively:

$$D_S = (d_1^s, d_2^s, ..., d_K^s) \tag{4}$$

and

$$D_F = (d_1^f, d_2^f, ..., d_L^f) \tag{5}$$

Since the Resource Block (RB) is the smallest unit of resource that can be allocated to a vehicle, we define x as the number of RB allocated by the gNB to a vehicle. We use x_p^s and x_q^f to denote the number of resource blocks that the gNB assigns to the safety vehicle v_p^s and the non-safety vehicle v_q^i, respectively.

For example, x_2^s = 4 and x_5^f = 7 mean that the gNB allocates 4 RBs to the safety vehicle v_2^s and 7 RBs to the non-safety vehicle v_5^f.

For the optimization problem, the average satisfaction factor Γ is calculated as follows:

$$\Gamma = \frac{1}{L} \sum_{q=1}^{L} \gamma_q^f \tag{6}$$

Here γ_q^f is the satisfaction factor of the non-safety vehicle v_q^f, which is the ratio between the number of resource blocks x_q^f allocated by the gNB to the vehicle v_q^f and its actual demand d_q^f. This means that:

$$\gamma_q^f = \frac{x_q^f}{d_q^f} \tag{7}$$

In this proposal, the resource allocation for non-safety vehicles can be modeled mathematically by the following optimization problem:

$$\max \frac{1}{L} \sum_{q=1}^{L} \frac{x_q^f}{d_q^f} \tag{8}$$

s. t.

$$\sum_{q=1}^{L} x_q^f \leq N - (\sum_{p=1}^{K} x_p^s) \tag{9}$$

$$0 \leq x_q^f \leq d_q^f, q \in \{1..L\} \tag{10}$$

where, equation (8) models our goal for maximizing the average satisfaction factor Γ and equation (9) models the fact that resource blocks are allocated to non-safety vehicles after ensuring the requirements of all safety vehicles. Algorithms 1 and 2 represent the first and second phases of resource allocation for safety and non-safety traffic, respectively.

VI. Simulation Scenario and Result Analysis

In this section we present the scenario of our simulation. We also present the reference algorithm, Max-C/I, which is used to compare the performance with our algorithm. Finally, we analyze the simulation results and present the performance of the PSRA-MN algorithm.

A. Simulation Scenario

The simulation is conducted through the Simu5G simulator. Simu5G is an OMNeT++-based open-source simulator. In our scenario, we have 50 vehicles running a V2V safety application. Among them, a subset of 20 vehicles runs a non-safety application in parallel. In the safety V2V application, the transmitting vehicles periodically send a CAM message of 190 bytes to their neighbors every 10 ms. The second application, an infotainment application, is a video streaming

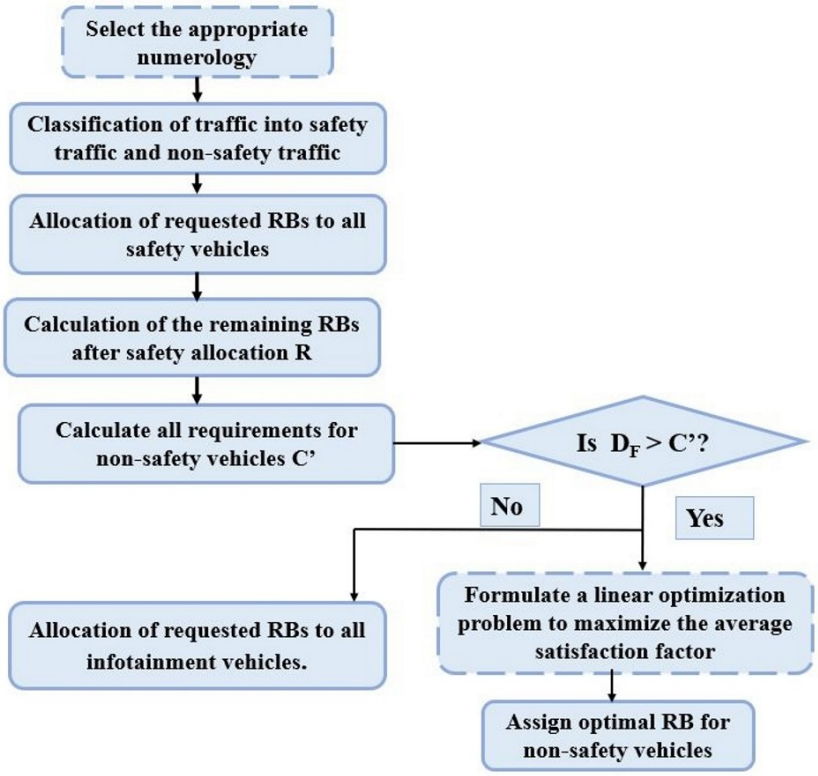

Fig. 5: Diagramm of the PSRA-MN algorithm

Algorithm 1: Resource allocation in phase 1 for safety vehicles

Result: $\mathbb{C}'$

Select the appropriate numerology index μ corresponding to channel conditions and vehicle speed [6] ;

$\mathbb{C}$ = {RB};

/* $\mathbb{C}$ is the available capacity in terms of the set of RB */

for $p = 1$ **to** K **do**

  /* K is the total number of safety vehicles requesting resources */

  $v_p^s \longleftarrow \mathrm{d}_p^s$;

  /* Assign to vehicle v_p^s the resource blocks requested in its demand d_p^s, where d_p^s is the number of RB requested by safety vehicle v_p^s; */

  $\mathbb{C}'$ = $\mathbb{C}$ \d_p^s ;

end

/* $\mathbb{C}'$ is the rest of the capacity in terms of number of RB after the allocation of all safety vehicles. */

Algorithm 2: Resource allocation in phase 2 for non-safety vehicles

Result: $\mathbb{X}$

if $|\mathbb{C}'| <= D_F$ **then**

  X = optimize (equations 8 under the constraints of 9, and 10) ;

  /* call the optimization function which returns the matrix X containing exactly the resources that should be allocated to each non-safety vehicle ; */

end

for $q = 1$ **to** L **do**

  $v_q^f \longleftarrow x_q^f$;

  /* Assign to vehicle v_q^f the optimal number of resource block x_q^f with respect to the optimization problem. */

end

application, in which the non-safety vehicles receive video stream packets from other transmitting vehicles.

For vehicle mobility, we used the traffic simulator SUMO (Simulation of Urban MObility) [27]. The vehicles move at an average speed of 40 km/h on a lane of 300 m length. The relevant parameters of our simulations can be found in Table II.

B. Evaluated Metrics and Result Analysis

In our simulations, we evaluate the performance of the proposed algorithm with the following Key Performance Indicators (KPI):

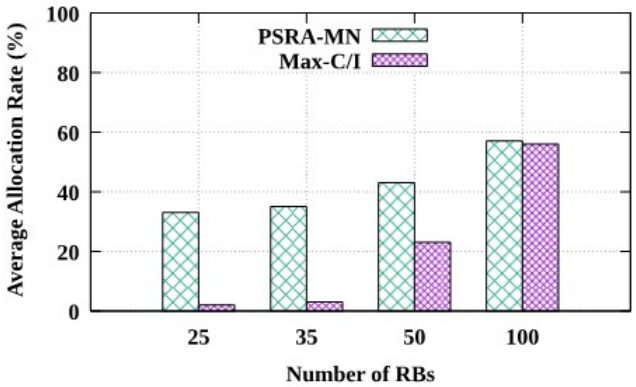

Fig. 6: The Average Allocation Rate (AAR) for safety traffic

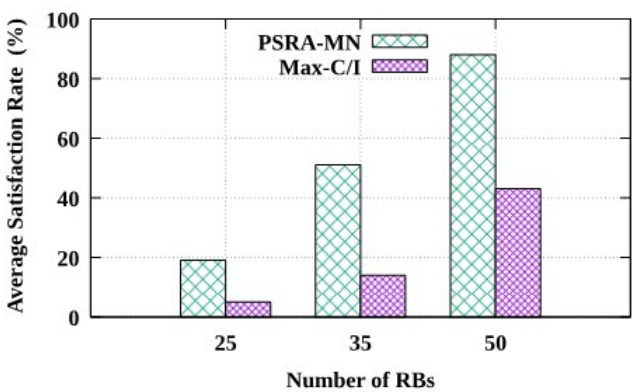

Fig. 7: The Average Satisfaction Rate (ASR) for non-safety traffic

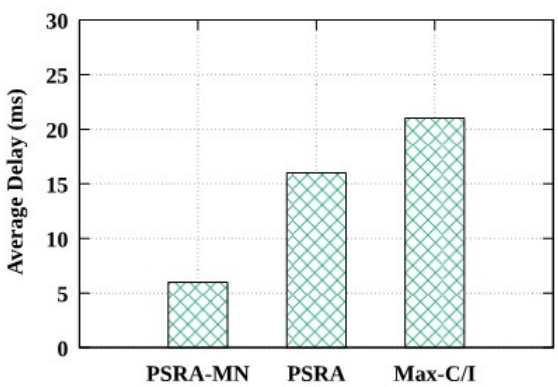

Fig. 8: The Average end-to-end delay for safety traffic

- The Average Allocation Rate (AAR): is defined as the ratio between the number of allocated vehicles N_{alloc} and the total number of vehicles requesting RBs N_{req}.

$$AAR = \frac{N_{alloc}}{N_{req}} \tag{11}$$

- The Average Satisfaction Rate (ASR): is already defined in the Section V by the Equation 8.

TABLE II: Simulation Parameters using Simu5G

Parameter	Value
Frequency	5.9 GHz
Scenario	Urban Macro (UMa)
UeTxPower (dBm)	23 dBm
gNBTxPower (dBm)	46 dBm
Fading channel model	Rayleigh
Number of vehicles	50 vehicles
Simulation time	20 s

- The average delay: is defined as the average time it takes a packet to travel from source to destination.

The AAR parameter indicates the priority level, while the ASR parameter indicates the fairness level. Moreover, the average delay is analyzed here as one of the most important requirements of V2X applications to provide the basic safety service. For this purpose, in our simulations, we analyze the Average Allocation Rate (AAR) and the average delay for the safety traffic, while the Average Satisfaction Rate (λ) is analyzed for the non-safety traffic.

The comparison between the performance of the PSRA algorithm and the Max-C/I algorithm is made by analyzing the AAR, the ASR, and the average delay, as shown in Figures 6, 7, and 8, respectively.

1) Average Allocation Rate (AAR) : Figure 6 shows the average allocation rate for safety traffic in function of the number of RBs, for the PSRA-MN algorithm compared to the Max-C/I algorithm. The AAR increases when the number of RBs increases for both algorithms. The difference between PSRA-MN and Max-C/I is very clear in the figure for the lower number of RBs. As can be seen from Figure 6, for a fixed number of RBs, the AAR for safety traffic is higher for the PSRA-MN than for the Max-C/I algorithm. For example, with 50 RBs, the AAR for PSRA-MN exceeds 40%, whereas the AAR for Max-C/I in this case does not reach 30%. This is due to the fact that the PSRA-MN algorithm allocates more safety vehicles than the Max-C/I algorithm due to the priority policy applied by PSRA-MN in favour of the safety traffic. Unlike PSRA-MN, Max-C/I allows a non-safety vehicle to be scheduled before another safety vehicle if the non-safety vehicle has good channel conditions. For this reason, the Max-C/I presents a lower performance with respect to the AAR for safety traffic. We conclude that PSRA-MN performs better than the Max-C/I algorithm in terms of the AAR for safety traffic, especially when the number of RBs is smaller.

2) Average Satisfaction Rate (ASR) : Figure 7 shows the average satisfaction rate for non-safety traffic as a function of the number of RBs for the PSRA-MN algorithm compared to the Max-C/I algorithm. The ASR increases as the number of RBs increases. As can be seen in this figure, for a fixed number of RBs, the ASR is higher for PSRA-MN than for Max-C/I. For example, with 100 RBs, the ASR of PSRA-MN exceeds 90%, while that of Max-C/I does not reach 30%. The Max-C/I algorithm does not consider a fairness strategy in its allocation process. Therefore, when Max-C/I is applied, there are some vehicles that are satisfied at 100%, while others are

not scheduled, which means that the average satisfaction rate is not very high. In contrast, PSRA-MN tries to satisfy the large number of vehicles in the scenario by maximizing the average satisfaction rate. As a conclusion, we can state that PSRA-MN achieves better performance than Max-C/I in terms of ASR for non-safety related traffic, thus providing a high degree of fairness compared to the Max-C/I algorithm.

3) Average end-to-end delay : Figure 8 shows the average delay for safety traffic for our algorithm with fixed and flexible numerology, which corresponds in the figure to PSRA and PSRA-MN, respectively, compared to Max-C/I. As can be seen in this figure, the average delay of both PSRA and PSRA-MN is lower than that of the Max-C/I algorithm. The average delay of the PSRA algorithm is about 16 ms and that of PSRA-MN is about 6 ms, while the average delay of Max-C/I algorithm exceeds 20 ms. In fact, there are two reasons for this result. First, unlike the PSRA algorithm, in the Max- C/I algorithm a safety vehicle must sometimes wait until another non-safety vehicle is scheduled, which increases the overall safety message delay for Max C/I. Second, the use of the TDM multiplexing approach allows the use of different numerologies. However, when a high numerology index is used, the average delay decreases, as explained earlier in [6]. For this reason, when mixed numerology is used in our scheduling scheme, PSRA-MN has the lower average delay value compared to PSRA and Max-C/I.

In this context, we emphasize that PSRA-MN outperforms Max-C/I in terms of latency, which is a very important KPI since the safety-related applications are time-sensitive.

VII. Conclusion and perspectives

In this paper, we propose a new priority-based resource allocation algorithm for mode 1 of 5G-V2X, named PSRA-MN. First, in the PSRA-MN algorithm, we select the appropriate numerology corresponding to the channel conditions and vehicle speed. Second, we apply a prioritization policy in favor of the safety traffic in order to ensure the required resources for the safety-related service. Finally, the remaining resources after safety allocation are optimally allocated to non-safety vehicles so that the average satisfaction rate is maximized. The PSRA-MN algorithm is validated by simulations using the Simu5G simulator compared with the Max-C/I algorithm. The obtained results show that PSRA-MN outperforms Max-C/I in terms of the AAR, the ASR, and the average delay. In our future work, we will apply PSRA-MN in the 5G-V2X context with a mixed-numerology scenario considering the Frequency Division Multiplexing (FDM) approach enabled by the Bandwidth Part technique (BWP).

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