KNN-BASED MIXED NUMEROLOGY RESOURCE ALLOCATION FOR 5G-V2X COMMUNICATIONS

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Abstract: 5G-V2X is an emerging technology for vehicular networks where radio resource allocation plays a crucial role in the overall network performance. In this paper, we highlight the resource scheduling problem for two V2X applications, the safety applications and the non-safety applications, in a mixed numerology scenario in which different 5G numerologies are multiplexed in the time domain. Machine learning is leveraged to select the best numerology. The K-Nearest Neighbor (KNN) algorithm learns the channel characteristics to obtain the optimal numerology selection. A priority policy is applied in favor of the safety traffic since this is the most time-constrained V2X traffic type. Then, the remaining resources are optimally scheduled for the non-safety traffic. The simulation results show that the proposed Priority and Satisfaction-based Resource Allocation algorithm with KNN mixed numerology for 5G-V2X communications (PSRA-KNN) algorithm achieves better performance in terms of end-to-end delay for safety traffic.

Keywords: 5G-V2X, resource allocation, 5G numerology, machine learning, KNN.

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, known as Dedicated Short Range Communication (DSRC) or ITS G5 based on the 802.11p standard, followed by the cellular technology Cellular-V2X (C-V2X).

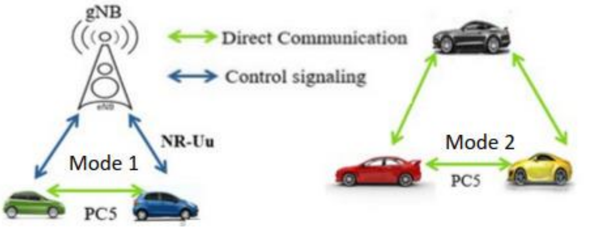

Figure 1. Resource Allocation Modes in 5G-V2X

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 Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, based on the sidelink PC5 interface, and the Vehicle-to-Network (V2N) communications based on the Uu interface. The direct V2V communication via the sidelink PC5 interface is the basic mode of V2X communications. The International Telecommunication Union (ITU) has dedicated the 5.9 GHz band for V2X sidelink communications. Since 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. The European

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Cooperation Centre (ECC) 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. However, it is not prohibited for safety applications to use the non-safety bands. In addition, other countries have not decided 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 [1]. 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. For example, regarding the Max-C/I algorithm, 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.

The 5G numerologies are considered as one of the most important 5G key features. A numerology refers to the spacing between Orthogonal Frequency Division Multiplexing (OFDM) subcarriers. In the LTE system, a fixed subcarrier spacing of 15 kHz is used. However, in 5G, multiple 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 [2], 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. Therefore, our algorithm benefits from the flexibility of the 5G NR frame structure to achieve the requirements of different V2X applications, by applying an adaptive numerology approach. In our algorithm, we propose to use k-nearest neighbors (KNN) for mixed numerology selection to find the optimal numerology which can achieve the minimum Block Error Rate (BLER).

After the KNN-based numerology selection, we apply our previously proposed PSRA-MN scheduling scheme for mode 1 of 5G-V2X. We allocate radio ressources for 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. Then, we give an overview of the side-link resource allocation in 5G-V2X in Section III. Section IV presents the related works. The proposed PSRA-KNN algorithm are presented in details 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

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.

Figure 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. Traffic safety applications require low latency and high reliability and can be considered as part of Ultra Reliable Low Latency Communication (URLLC), while entertainment applications require high data rates and belong to enhanced Mobile Broadband (eMBB). 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 [3].

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. Overview of 5G NR Numerologies

The concept of numerologies, standardized in Release 15 by 3GPP, refers to the spacing between OFDM subcarriers. 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.

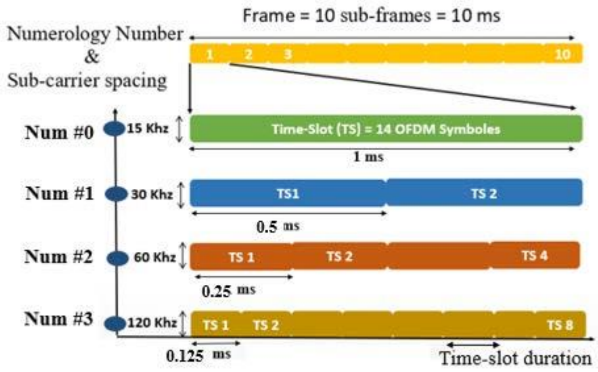

Figure 3. NR-V2X Frame Structure

In Table 1, we present the parameters for each numerology such as the Cyclic Prefix (CP) which is used to avoid the Inter-Symbol Interference (ISI) problem in the multipath propagation environment.

Table 1. Main parameters of NR-V2X numerologies

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	16	8.92	0.125	Normal
4	240	32	4.46	0.0625	Normal

In 5G NR, a frame lasts 10 milliseconds. Similar to LTE, a frame has 10 subframes each of them has a duration of 1 ms. A subframe has 2^{μ} time-slots. A time-slot duration reduces by factor of 2 when the numerology increases by 1. 14 (standard CP) or 12 (extended CP) OFDM symbols can be used in each time-slot. All the subcarrier spacing have exactly 14 OFDM symbols. However, extended CP type can be supported only with 60 KHz spacing.

To decide which numerology to use, we should think for the following physical layer parameters: cell size, carrier frequency, latency, cyclic prefix length, frequency error and phase noise. 5G NR has three frequency ranges: low frequency (< 1 GHz), high frequency (between 1 and 6 GHz) and frequency greater than 6 GHz which correspond to the millimeter wave.

For higher carrier frequencies, approaching the mmWave range, implementation limitations such as phase noise becomes more critical. Thus, as frequency carrier increases, the phase noise also increases, which introduces frequency errors. In fact, OFDM systems are very sensitive to frequency errors due to the existence of multiple sub-carriers. Hence, whenever there is a frequency error, the corresponding sub-carrier will shift either to the right or to the left. Shifting from the original position introduces then an Inter-Carrier Interference (ICI). Frequency error is visible on smaller sub-carrier spacing. That’s why, higher carrier frequency demands higher subcarrier spacing.

The cell size is a key parameter to decide on the right numerology. Expected cell sizes are smaller at high frequencies due to challenging propagation conditions. In fact, path loss increases with cell size and carrier frequency. It is proportional with $\frac{d^2f^2}{k}$ where d is the distance between the transmitter and the receiver, f is the frequency used and k is a constant. Thus, to minimize the path loss, higher frequencies should expect smaller cell sizes. From another point of view, a smaller cell size will demand a smaller cyclic prefix, since the delay spread will be narrower.

Wider subcarrier spacing (Δf) implies small sample duration (T_s) which implies shorter cyclic prefix (L_{cp}) because $\Delta f = \frac{1}{T_s}$ and $L_{cp} = n\frac{1}{T_s}$ where n is the number of samples. Hence, a smaller cell size expects a larger subcarrier spacing. In this case, we reach another logic to decide the right numerology.

At this stage, we can conclude that:

- For mmWave, cell size will be smaller and hence wider subcarrier spacing would be more beneficial.

- For lower carrier frequency, larger cell size will be preferred.

- For sub 1GHz, cell size will be relatively larger, smaller sub-carrier spacing (SCS) would be more desirable.

Low latency services can be supported with wider sub-carrier spacing. Indeed, the latency is determinated by the minimum scheduling duration which is fixed to one slot. The slot duration is inversely proportional to sub-carrier spacing. So basically, low latency can be also achieved in larger cells using wider subcarrier spacing. However, this may incur a performance penalty in terms of reliability or throughput.

Table 2 summarizes the different cases to choose the suitable numerology depending on physical parameters and application types.

Table 2. Deciding the best numerology

Parameters	Requirement
High carrier frequency	Wider SCS
High carrier frequency	Smaller cell size
Smaller cell size	Wider SCS
Lower carrier frequency	Smaller SCS
Lower carrier frequency	Larger cell size
Larger cell size	Smaller SCS
Low latency service	Wider SCS

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 done either by the Frequency Division Multiplexing (FDM) technique, the Time Division Multiplexing (TDM) technique (Fig. 4) or by mixing both FDM and TDM techniques [4].

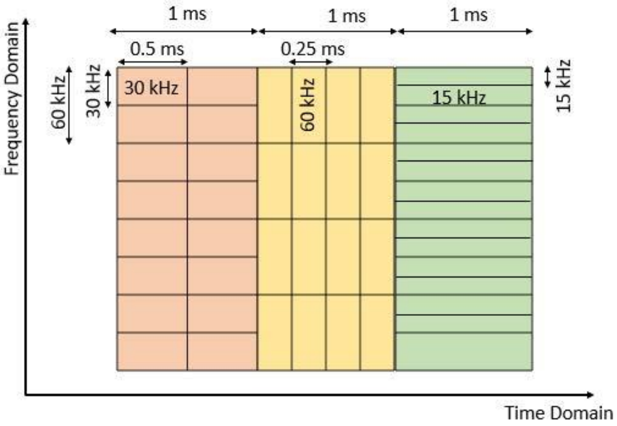

Figure 4. TDM Numerology Multiplexing

C. Sidelink Resource Allocation 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 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 $\frac{1}{2^{\mu}}$ where μ 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.

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 [5].

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.

III. RELATED WORK

As the NR-V2X is recently standardized by the 3GPP, there exist few research works that deal with resource allocation algorithms in mode 1 of 5G-V2X. In [6], 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 [7], 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. [8]. The main goal of this algorithm is to maximize the system throughput by assigning to vehicles the optimal transmit power. At this point, it is interesting to point out that there are already hundreds of scheduling schemes in 5G that consider QoS. 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 as they aim to reduce the number of road accidents. 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.

With respect to the 5G numerology concept, we note that there are few research works that address resource allocation with mixed numerology in 5G. However, the cited research works are not interested in the vehicular scenario, which is very different from traditional networks, due to dynamicity, the high mobility of vehicles and the influence of Doppler effect as a consequence.

In our paper [9], an efficient resource allocation scheme was presented taking into account the requirements of vehicular applications. The appropriate numerology was selected considering the characteristics of the vehicular scenario as discussed in our previous work [2]. However, the selection numerology phase is static, non-learning and depends only on the delay spread.

Following this line, we propose in this paper our PSRA-KNN algorithm an extension of the PSRA-MN presented in [9]. It takes into account the different V2X applications and optimization for resource allocations and a KNN learning model for numerology selection at each time slot.

IV. PSRA-KNN ALGORITHM

The PSRA-KNN algorithm includes three main phases. The first phase consists of selecting the appropriate numerology according to the channel conditions and vehicle speed. The second one 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 during the third phase. The diagram of the PSRA-KNN algorithm is presented in Fig. 5.

A. Numerology Selection Phase

Before starting the radio resource scheduling process, the PSRA-KNN algorithm selects the appropriate numerology index as a first step according to the TDM multiplexing technique. The flexibility of the NR frame structure allows us to process a scheduling scheme with mixed numerology. In PSRA-KNN, the selection of the appropriate numerology is done according to the recommendations for numerology selection presented in the paper [2], 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.

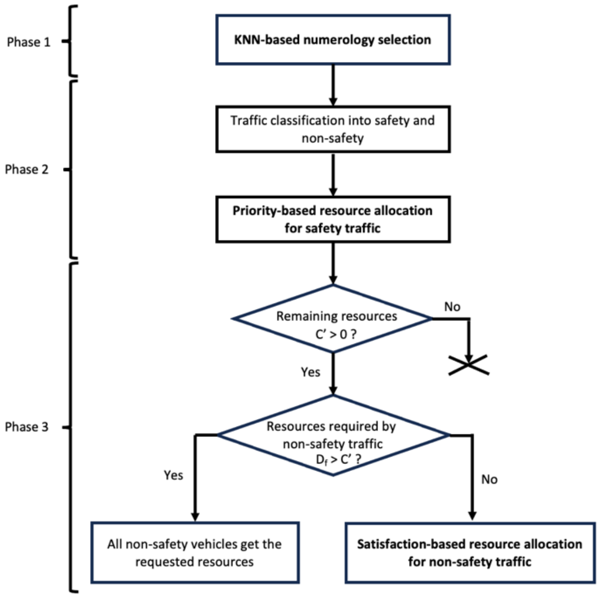

Figure 5. Diagram of the PSRA-KNN algorithm

For this reason, we propose to use the KNN machine learning algorithm to hide the complexity and stochastic of the environment and helps the gNB to make efficient and quick decisions that adapt according to the channel information. Moreover, the proposed algorithm gains the ability to learn with time and adapts to different and unseen situations. The choice of the KNN was based on its simplicity, ease of understanding, implementation and highly accurate predictions.

The training samples can be generated by simulation or measurement. The supervised learning is applied to train the KNN model by using the numerology with minimal BLER. When the training is completed and achieves a good accuracy, we can deploy the proposed KNN for selecting the numerology.

The BLER is defined as the ratio of the number of transport blocks received in error to the total number of blocks transmitted over a certain number of radio frames.

$$BLER = \frac{Number\ of\ erroneous\ blocks}{Total\ number\ of\ transmitted\ blocks} \qquad (1)$$

The BLER closely reflects on the RF channel conditions and the level of interference. For a given modulation depth, the cleaner the radio channel or higher the SNR, the less likely the transport block being received in error. That indicates a lower BLER.

B. Safety Traffic Resource Allocation Phase

After the numerology selection step, we carry out the first phase of the resource scheduling in the PSRA-KNN algorithm. We classify the traffic into safety and non-safety. We apply then a priority-based resource allocation strategy, where we prioritize the safety traffic by assigning the necessary amount of RBs to the requesting vehicles.

Let $\mathbb{V} = \{v_1, v_2, \dots, v_M\}$ denotes the set of Mvehicles present in the cell at a given time and sending requests to the gNB for resource allocation. We denote by $C = \{RB_j\}, |C| = N$, the total system capacity. N is the number of available Resource Blocks (RBs) in the cell, depending on the channel bandwidth.

We classify the vehicles into 2 classes according to their traffic type:

- Safety vehicles: denoted by $\mathbb{V}_{\mathbb{S}} = \{v_1^S, v_2^S, \dots, v_K^S\}$ where K is the total number of vehicles running safety applications.

- Non-safety vehicles: denoted by $\mathbb{V}_{\mathbb{F}} = \{v_1^F, v_2^F, \dots, v_L^F\}$ where L represents the total number of non-safety vehicles.

This means that $\mathbb{V}_{\mathbb{S}} \cup \mathbb{V}_{\mathbb{F}} = \mathbb{V}$. The priority discipline is assumed to have priority classes, with the safety class having the higher priority than the non-safety class. A vehicle $v \in \mathbb{V}$ has the higher priority if $v \in \mathbb{V}_{\mathbb{S}}$.

Since RB is the smallest resource unit that can be allocated to a vehicle, we define x_p^s and x_q^fas the numbers of RBs allocated by the gNB to safety vehicle $v_p^s \in \mathbb{V}_{\mathbb{S}}$ and non-safety vehicle $v_q^f \in \mathbb{V}_{\mathbb{F}}$ 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.

We denote by $D_S = (d_1^s, d_2^s, \dots, d_K^s)$ and $D_F = (d_1^f, d_2^f, \dots, d_L^f)$ the resource demand vectors conainting the numbers of resources requested by safety and non-safety vehicles respectively. In this phase, the gNB should allocate the required resources to all safety vehicles so that the total number of RBs allocated to safety traffic is $\sum_{p=1}^{K} x_p^s = \sum_{p=1}^{K} d_p^s$. The pseudo code of the resource allocation in the second phase for safety traffic is presented in Algorithm 1.

Algorithm 1 Priority-based Safety Traffic Resource Allocation

```
Input: $C = \{RB_j\}$
for $p = 1$ to $K$ do
    $x_p^s \leftarrow d_p^s$
    $C = C \setminus \{RB_{|C|-x_p^s}, \dots, RB_{|C|}\}$
end for
Output: $C' = C$
```

C. Non-Safety Traffic Resource Allocation Phase

After the safety traffic resource allocation phase, we allocate the remaining resources to the non-safety vehicles. In this phase, we aim to maximise an average satisfaction factor. The average satisfaction rate is a fairness indicator as proposed earlier by Jain in [10]. It indicates the average satisfaction rating of all non-safety vehicles. In fact, the satisfaction rate is calculated as a function of whether a vehicle is allocated a number of resource blocks less than or equal to its demand. Indeed, a vehicle is 100 % satisfied if the gNB allocates to that vehicle the requested number of RBs specified in its demand. The average satisfaction factor Γ is calculated as follows:

$$\Gamma = \frac{1}{L} \sum_{q=1}^{L} \gamma_q^f \tag{2}$$

where $\gamma_q^f = \frac{x_q^f}{d_q^f}$ 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 demand d_q^f.

The resource allocation for non-safety vehicles can be mathematically modelled by the following linear optimization problem:

$$\max \ \Gamma = \frac{1}{L} \sum_{q=1}^{L} \gamma_q^f \tag{3}$$

s.t.

$$\sum_{q=1}^{L} x_q^f \leq \mathrm{N} - \sum_{p=1}^{K} x_p^s \tag{4}$$

$$0 \leq x_q^f \leq d_q^f, q \in \{1..L\} \tag{5}$$

where, Eq. 3 models our goal for maximizing the average satisfaction factor Γ and Eq. 4 models the fact that resource blocks are allocated to non-safety vehicles after ensuring the requirements of all safety vehicles.

VI. PERFORMANCE EVALUATION

The simulation is conducted through the Simu5G simulator [11]. Simu5G is an OMNeT++-based open-source simulator [12] cooperating with a road network simulator SUMO [13] and Veins simulator [14] for Inter-Vehicular Communication (IVC) via Traffic Control Interface (TraCI).

A. Simulation Scenario

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 vehicles periodically send a CAM message to their neighbors as illustrated in Fig. 6.

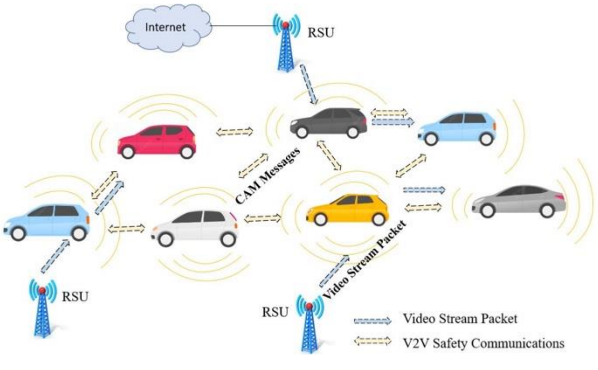

Figure 6. Simulation Scenario

The V2V non-safety application is considered as a video streaming application for infotainment. The relevant parameters of our simulations can be found in Table 3.

Table 3. 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
Video size	100 MB
Video packet length	3000 bytes
Transmission time interval	1 ms
Average speed	40 km/h
Length lane	300 m
CAM message length	190 bytes
CAM transmission time interval	10 ms

B. *Dataset Generation*

To make training samples, we generate a synthetic dataset using MATLAB. We use 600 random channel conditions in which the delay spread and distance are uniformly distributed over [32 ns, 850 ns] [9] and [500 m, 900 m] respectively. Then, we simulate the transmission of OFDM waveform using all possible numerologies for different channel realizations. In this way, the training samples are classified to the different labels of numerology and the class label is the index of the optimal numerology that can achieve the minimum BLER.

A. *Evaluated Metrics and Result Analysis*

In our simulations, we evaluate the performance of the proposed algorithm in terms of average end-to-end (E2E) delay because the main impact of numerology selection in 5G is delay reduction. The average E2E delay is defined as the average time that takes a packet to be transmitted from the source to the destination.

The average E2E delay is considered as one of the most important requirements of V2X applications to provide the basic safety services. For this reason, we present in our simulations the results of E2E delay for the safety traffic. The performance of the proposed PSRA-KNN algorithm is compared with the PSRA-MN algorithm, the PSRA algorithm [9] with numerology 3 and the standard Max-C/I scheduling mechanism [15].

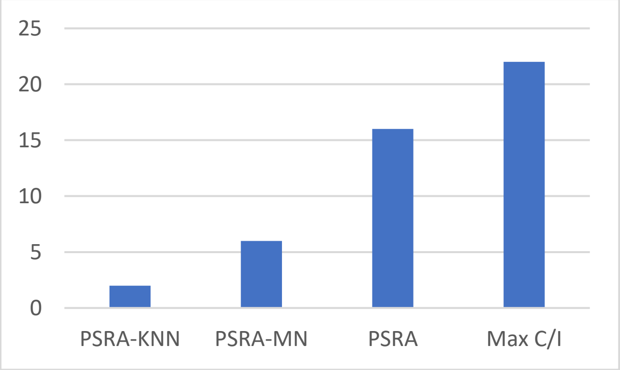

Figure 7. Average end-to-end delay (ms) for safety traffic

Figure 7 shows the average end-to-end delay for safety traffic for each scheduling algorithm. Our proposed PSRA-KNN algorithm managed to reduce the latency by two third, i.e from 6 ms to 2 ms. As can be seen, the average delay of both PSRA and PSRA-MN is lower than that of the Max-C/I algorithm. For the PSRA algorithm, the E2E delay is about 16 ms and for PSRA-MN is about 6 ms while the average delay of Max-C/I exceeds 20 ms. Unlike the PSRA algorithm, in the Max-C/I, a safety vehicle must sometimes wait until another non-safety vehicle is scheduled, which increases the overall safety message delay for Max-C/I. The use of the TDM multiplexing approach allows the use of different numerologies. In fact, when a high numerology index is used, the average delay decreases, as explained earlier in [2]. 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. The E2E delay of PSRA-KNN is very small compared to PSRA-MN and PSRA in micro urban scenario. This is because numerologies selected by the KNN method and non-learning approach are not the same and lead to different E2E delay. The KNN tries to select the optimal numerologies regarding the channel characteristics, distance and velocity so that the latency is minimized.

IV. CONCLUSION

In this paper, we propose a machine learning-based numerology selection for the priority and satisfactory-based resource allocation algorithm with mixed numerology for 5G-V2X mode 1. In the proposed PSRA-KNN algorithm, we select the appropriate numerology corresponding to the channel conditions and vehicle speed using the KNN supervised learning algorithm. After that, 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-KNN algorithm is validated by simulations using the Simu5G simulator compared with the PSRA-MN, PSRA and Max-C/I algorithms. The obtained results show that the use of KNN have significantly improved the average delay of safety traffic. The mixed numerology considered in PSRA-KNN is based on the time division multiplexing technique. In our future work, we will apply

PSRA-KNN in the 5G-V2X context with a mixed-numerology considering the frequency division multiplexing approach enabled by the bandwidth part technique.

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