



HAL
open science

A Comprehensive Study of the Impact of 5G Numerologies on V2X Communications

Sehla Khabaz, Kaouthar Ouali Boulila, Thi Mai Trang Nguyen, Guy Pujolle, Moustapha El Aoun, Pedro Velloso

► **To cite this version:**

Sehla Khabaz, Kaouthar Ouali Boulila, Thi Mai Trang Nguyen, Guy Pujolle, Moustapha El Aoun, et al.. A Comprehensive Study of the Impact of 5G Numerologies on V2X Communications. 2022 13th International Conference on Network of the Future (NoF), Oct 2022, Gand, Belgium. pp.1-9, 10.1109/NoF55974.2022.9942567 . hal-03885678

HAL Id: hal-03885678

<https://hal.science/hal-03885678>

Submitted on 5 Dec 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

A Comprehensive Study of the Impact of 5G Numerologies on V2X Communications

Sehla Khabaz ^{*†}, Kaouthar Ouali Boulila ^{*‡}, Thi Mai Trang Nguyen ^{*},
Guy Pujolle ^{*}, Moustapha El Aoun [†], and Pedro B.Velloso ^{*}

^{*}*Sorbonne Université, CNRS, LIP6*

4 Place Jussieu, 75005 Paris, France

[†]*Polytechnic school of Mauritania*

BP 4303 Cité Cadres - Sebkha - Nouakchott - Mauritania

[‡]*University of Carthage, Supcom, innov'com lab, Tunisia.*

Emails: {Sehla-Nana.Khabaz, Thi-Mai-Trang.Nguyen, Guy.Pujolle, Pedro.Velloso}@lip6.fr,

Oualikaouthar@gmail.com, mo.elaoun@esp.mr

Abstract—5G Vehicle-to-Everything (5G-V2X) is a new emerging technology for vehicular networks standardized by 3GPP to contribute to road safety services. The flexibility of the New Radio (NR) frame structure is one of the most interesting 5G key features enabled by the use of the new 5G numerologies. The 5G numerologies are an enabler to meet the requirements of a wide range of 5G services. Indeed, V2X communication encompasses a variety of applications with different requirements. Therefore, the choice of the appropriate numerology for each V2X scenario is of particular importance. To this end, in this paper we present a comprehensive study of the impact of 5G numerologies on the performance of V2X applications. Using the Simu5G and 5GVLL simulators, we demonstrate that the choice of the appropriate numerology is a trade-off between the targeted requirements of V2X applications, the Inter-Carrier Interference (ICI) and the Inter-Symbol Interference (ISI) issues.

Index Terms—5G-V2X, 5G Numerologies, V2X applications

I. INTRODUCTION

5G, the fifth generation of mobile networks, is considered as a real technological breakthrough in telecommunications networks. In fact, communication networks are experiencing a real revolution nowadays due to the different requirements for different services. The growing number of mobile subscribers, the very high demand for bandwidth and data transmission rates, the emergence of Intelligent Transport Systems (ITS), the Internet of Things (IoT) and, above all, the forecasts for smart cities are the main drivers of this revolution. However, the fourth generation of mobile networks (4G) is not able to meet all these different requirements of the different sectors. Therefore, the standardisation of a new generation of mobile networks is a necessary step to meet all these requirements. To this end, the 3GPP (Third Generation Partnership Project) standardisation body has completed the standardisation of 5G technology to meet the requirements set by the International Union of Telecommunication (IUT-R) for IMT 2020, including a peak data rate of about 20 Gbit/s, a low latency of 1 ms, and a high mobility of 500 km/h [1].

Indeed, 5G has the potential to meet all these requirements of different services, thanks to the emergence of new key features and technologies such as small cell with dual connectivity, massive Multiple Input Multiple Output (MIMO), beamforming, new 5G numerologies, Network Function Virtualization (NFV), Network Slicing (NS) and Mobile Edge Computing (MEC). Therefore, the 5G network will have a great impact on various sectors, not only on the telecommunication one, but also on other sectors such as the medical sector and the automotive industry.

In the automotive industry, the first standardized technology for V2X (Vehicle-to-Everything) communications is Wi-Fi technology, known as DSRC (Dedicated Short Range Communication) or ITS G5 based on the 802.11p standard [2], followed by the cellular technology LTE-V2X (Long Term Evolution-V2X). Today, applications in vehicular networks are evolving with high reliability and low latency requirements. The IEEE 802.11p and the LTE-V2X cannot really meet the requirements of future applications. To do so, standardization bodies have recognized the need to develop new technologies. 3GPP has standardized NR-V2X (New Radio-V2X) in its Release 16 to support advanced V2X applications [3], such as vehicle platooning, extended sensors, advanced and remote driving applications.

In this context, the 5G numerologies are considered as one of the 5G key features. A numerology refers to the spacing between OFDM (Orthogonal Frequency Division Multiplexing) subcarriers. While a fixed subcarrier spacing of 15 kHz is applied in the LTE system, different subcarrier spacing values can be used in 5G, e.g., 15 kHz, 30 kHz, 60 kHz, or 120 kHz. For URLLC (Ultra Reliable Low Latency Communication) services, higher subcarrier spacing can be used to meet ultra-low latency requirements. In the vehicular context, as mentioned above, there are several use cases. However, choosing the appropriate numerology for a particular V2X application is an open question that needs to be addressed. Regarding the literature review, there are few research works that address the choice of the numerology for vehicular

communication. However, the vehicular environment, which is a dynamic network due to the high mobility of vehicles, is strongly influenced by the Doppler effect [4]. Since this later has a great impact on the choice of the numerology, it is interesting to consider realistic vehicle environments and study the impact of numerologies on the communication performance. This study can then be used to decide on the choice of the appropriate numerology. Although theoretically it is known that the use of higher numerologies can increase throughput, reduce latency, and overcome the ICI problem, but they are more susceptible to the ISI problem, it is necessary to simulate a wide range of realistic scenarios considering different channel conditions in order to demonstrate the choice of the appropriate numerology depending on the scenario. For this reason, the main contributions of this paper can be summarized as follows:

- In a first part, we present a comprehensive study on the impact of 5G numerologies on V2X application performance considering both physical and application layers.
- Based on the conducted simulations and the analyzed results, we present our recommendations for the selection of the appropriate numerology considering the scenario.

In this work, we have considered two different V2X applications, namely the safety V2V application and the infotainment application. System performances are calculated at both application and physical layers.

The rest of this paper is structured as follows: the motivation of our work and the related work are presented in Section II. Then we present the technical background in Section III. The simulation scenarios and the analysis of the results are presented in Section IV. Finally, we conclude our paper in section V.

II. MOTIVATION AND RELATED WORK

As mentioned earlier, the new 5G numerologies are one of the most important features of 5G, but choosing the appropriate numerology for a particular V2X scenario is still an open issue. As far as the literature is concerned, there are only a few research works dealing with the concept of numerology. In [5–8], the authors investigate the impact of numerologies on 5G system performance. However, they do not investigate their impact on V2X use cases. Among the few research works that address their impact on V2X communications are those presented in [9, 10], where authors are interested in the impact of numerologies on the sidelink autonomous mode 2 of NR-V2X, in which the resources are autonomously selected by vehicles using the Sensing-based Semi Persistent Scheduling (SPS) algorithm. Indeed, the authors show that the used numerology affects the size of the sensing and resource selection windows used in the SPS algorithm for mode 2. In this context, the authors show that increasing the numerology improves the overall performance of the system. Moreover, the authors of [11] propose an adaptive numerology selection algorithm that aims to choose the appropriate numerology to satisfy the QoS (Quality of Service) of V2X applications such as reliability

and throughput. However, the authors do not clearly present the direct impact of these numerologies on the requirements of V2X applications. To the best of our knowledge, the only research work that makes an attempt in this direction is the one presented in [12], where the authors study the impact of 5G numerologies on V2X communication performance considering the BLock Error Rate (BLER) parameter. The authors conclude that the choice of the appropriate numerology depends on the Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI) problems. However, the limitation of this work is that the authors have only focused on the physical level performance evaluation and neglected the impact of these numerologies on the application level system performance. In addition, the authors do not consider a wide range of use cases for the channel conditions, which makes this study is not very exhaustive. Therefore, the main objective of this work is to present a more comprehensive study on the impact of 5G numerologies on V2X communications, considering both application-level and physical-level parameters. We have selected two different V2X applications. The first application is a safety V2V application and the second one is an infotainment application. In order to analyse the impact of 5G numerologies on the performance of V2X applications, we chose a rigorous Key Performance Indicator (KPI) for each application. Since the safety V2V application is a time-critical application, we evaluated the impact of the numerologies on the latency for this application, while we are interested in the average throughput of the infotainment application. Our study includes two complementary parts. In the first part, we are interested in studying the impact of numerologies on application layer performance, while in the second part we focus on physical layer performance. Our study can be considered as a reference study for researchers interested in resource allocation in 5G V2X communications.

III. TECHNICAL BACKGROUND

A. Overview of V2X communications

Nowadays, vehicular networks form a large and important research area that attracts the automotive and telecommunication industries. Road safety remains the most important goal of the automotive industry. In this context, the integration of wireless communication technologies in this sector has led to the emergence of a new concept known as V2X communication.

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 1. 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.

In fact, applications in vehicular networks can be divided into three main categories: traffic safety applications, traffic management applications, and entertainment applications [13]. Traffic safety applications require low latency and high

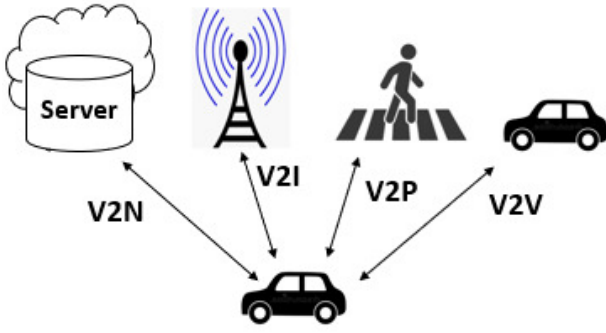


Fig. 1: V2X Communication types

reliability and can be considered as part of URLLC, 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 [14].

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 space, 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 [15]. 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 2. 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. The duration of a time slot depends on the used numerology. The time slot follows the rule: time slot = $1/2^n$, where n indicates the numerology order. For example, in the case of numerology 0, the time slot value is 1 ms and for numerology 1 it is 0.5 ms. In the Table I, we present the parameters for the individual numerologies. As can be seen from the table, each numerology has its own symbol length, slot length and Cyclic Prefix (CP). The CP parameter is used to avoid the ISI problem in the multipath propagation environment.

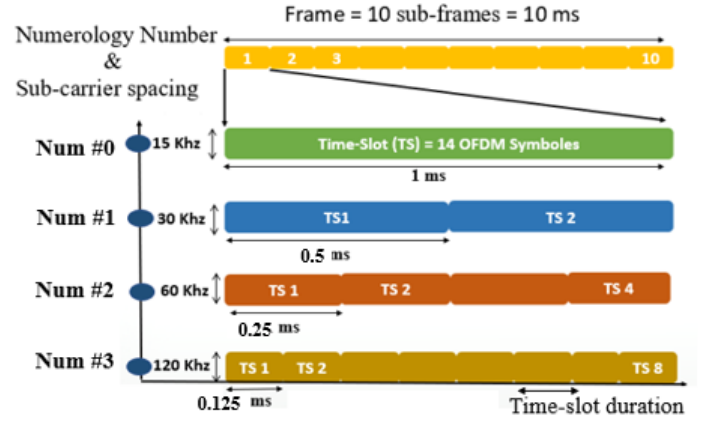


Fig. 2: NR-V2X Frame Structure

IV. SIMULATION SCENARIO AND RESULT ANALYSIS

Our study can be divided into two parts. In the first part, we have studied the impact of the 5G numerologies on the performance of V2X applications by considering the throughput and latency parameters, while in the second part we are interested in the impact at the physical layer by considering the BER (Bit Error Rate) parameter. In the following subsections, we present the simulated scenarios and the analysis of the results obtained for the first and second parts of the study, respectively.

A. Application layer performance evaluation

1) *Simulation Scenario*: in the first part of our study, we simulated two different V2X applications using the network simulator Simu5G [16], an OMNeT++ based simulator. In our scenario, we have 20 vehicles. Among these vehicles, 12 vehicles are running safety applications and 8 vehicles are running infotainment applications. The first simulated application is the safety V2V application, where the transmitting vehicles periodically send a CAM message of 190 bytes to their neighbors every 10 ms. The second application, an infotainment application, is the video streaming application where infotainment vehicles receive video stream packets from other transmitting vehicles. The chosen parameters for the video streaming application are as follows:

- Video size: 100 MB.
- Video packets length: 3000 bytes.
- Transmission time interval: 1 ms.

For vehicle mobility, we used the traffic simulator SUMO (Simulation of Urban MObility) [17]. 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 the Table II.

2) *Result Analysis*: the main objective of the first part of our study is to evaluate the impact of 5G numerologies on V2X application performance, considering the more interesting KPIs required for each application type. Since the safety V2V application is a time-critical application, the main KPI parameter we evaluate for this application is the latency.

| Numerology | Sub-carrier spacing (kHz) | Slots per sub-frame | Symbol length (μ s) | 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

TABLE II: Simulation Parameters using Simu5G

| Parameter | Value |
|----------------------|-------------------|
| Frequency | 5.9 GHz |
| Scenario | Urban Macro (UMa) |
| Number of RBs | 50 RB |
| UeTxPower (dBm) | 23 dBm |
| gNBTxPower (dBm) | 46 dBm |
| Fading channel model | Rayleigh |
| Number of vehicles | 20 vehicles |
| Simulation time | 60 s |

However, we are interested in the average throughput of the video stream application. The latency is defined as the average time of sending packets from source to destination. The throughput is defined as the average number of received packets per second.

Figures 3(a) and 3(b) show the average latency and average throughput for safety and video streaming applications, respectively. When we vary the numerology index from 0 to 3, we find that the average throughput increases with the increase of the numerology index, unlike the latency, which decreases as the numerology index increases.

In fact, when we increase the numerology index, the number of transmitted symbols per 1 ms time slot increases. As a result, the number of packets transmitted during a given time period also increases, increasing the average throughput. In other words, as we increase the numerology index, the transmission rate increases and the transmission delay decreases, reducing the overall latency.

Based on the above results, we can conclude that increasing the numerology index increases throughput and decreases latency, which is beneficial for both infotainment and safety applications. At this level of our study, we can quickly confirm that the higher numerologies are always the best choice for all V2X scenarios. However, in this context, we mean by the throughput the average number of packets received per second, which may or may not be received correctly. Thus, the results obtained at the application layer do not provide any information about the reliability of the transmissions. For this purpose, a comprehensive study is performed at the physical layer regarding the reliability, which is very interesting in V2X communications and especially in the case of the safety V2V communications.

B. Physical layer Performance Evaluation

1) *Simulation Scenario*: in this part of our study, we present an in-depth analysis of the impact of 5G numerologies on physical-level performance. For this purpose, we used a

Matlab-based link-level simulator, namely the 5G Vienna Link Level (5GVLL) simulator [18].

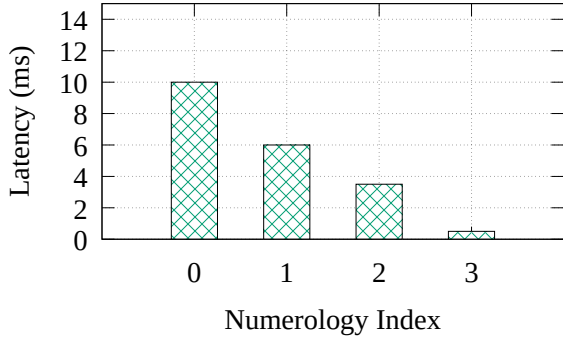
TABLE III: Simulation Parameters using 5GVLL

| Parameter | Value |
|--------------------------|------------------|
| Channel Bandwidth | 5 MHz |
| Frequency | 5.9 GHz |
| Subcarrier Spacing (Khz) | 15, 30, 60, 120 |
| Number of Subcarriers | 384, 192, 96, 48 |
| UeTxPower (dBm) | 23 |
| gNBTxPower (dBm) | 46 |
| Doppler channel model | Jakes |
| Number of Simulations | 50 |

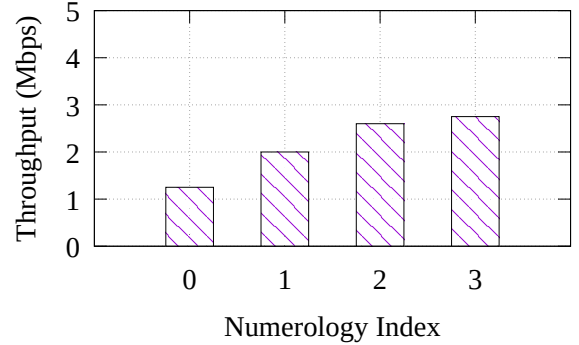
For the physical layer performance evaluation, we have chosen the Bit Error Rate indicator.

The vehicle speed is varied from 0 to 250 km/h. This wide range of vehicle speeds allows us to study a large number of use cases. For each vehicle speed value, we calculated the average BER after 50 simulations with 95% confidence interval. The simulation parameters using the 5GVLL simulator are presented in Table III. In order to vary the simulation scenarios, we have also considered both urban and rural scenarios with different delay spread values. The delay spread of the channel is defined as the difference between the arrival time of the last multipath component and the arrival time of the first multipath component in a multipath propagation environment. The delay spread values chosen for our simulations can be found in the table IV. These values are chosen based on the standardized values considering different scenarios for urban and rural areas. The characterization of urban or rural scenarios is related to the values for the delay spread parameter, as described in [19]. For the rural scenario, low delay spread values are considered, with the longest value being 153 ns, while for the urban scenario, higher delay spread values of over 800 ns are considered, as shown in Table IV.

In order to obtain accurate results depicting the impact of 5G numerologies on physical layer performance, we simulate only one vehicle moving at speeds ranging from 20 km/h to 250 km/h. The choice of a single vehicle is intended to avoid inaccuracy in the results. In fact, many factors, such as the problem of interference between vehicles [20] can have an impact on the BER. However, the choice of the appropriate numerology is directly influenced by only two types of interference, namely the Inter-Carrier Interference (ICI) and the Inter-Symbol Interference (ISI), as already shown in the work presented in [12]. For this reason, we have avoided the presence of other types of interference in order to obtain only the errors due to the choice of the numerology and not the errors due to other factors. In contrast, if there are many



(a) Average Latency as a function of numerology for Safety V2V application



(b) Average Throughput as a function of numerology for UD-PVideoStream application

Fig. 3: Average Latency and Throughput varying numerologies for Rural Macro (RMa) scenario

vehicles in the scenario, we cannot accurately show the impact of the choice of numerology, since the BER will be higher, as it includes all errors, including errors due to inter-vehicle interference. Therefore, to avoid inter-vehicle interference and hence the inaccuracy of the results, we simulated only one vehicle in the scenario using the 5GVLL simulator.

2) *Result Analysis*: in the following paragraphs, we present the result analysis of the rural and urban scenarios:

TABLE IV: Delay Spread Values

| Scenario | Delay spread value | | |
|-------------------|--------------------|--------|--------|
| | Short | Normal | Long |
| Urban Macro (UMa) | 93 ns | 363 ns | 850 ns |
| Rural Macro (RMa) | 32 ns | 37 ns | 153 ns |

a) *Rural scenario*: for the rural scenario, Figures 4(a), 4(b) and 4(c) show the BER as a function of vehicle speed, considering delay spread values of 32 ns, 37 ns and 153 ns, respectively.

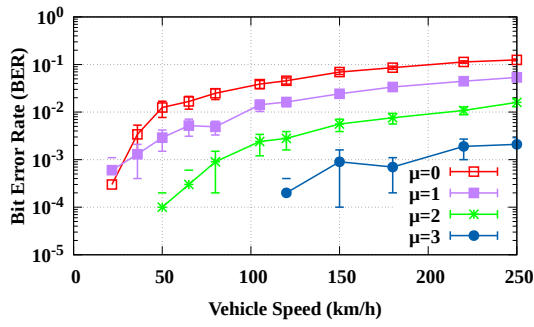
As can be seen in Figures 4(a) and 4(b), the BER increases with the increase in vehicle speed. This can be explained by the ICI caused by the Doppler effect due to vehicle mobility. However, we note that for the same vehicle speed, the BER decreases as the numerology increases. This behavior can be explained by the fact that as the numerology increases, the sub-carrier spacing is increased and the system is then less affected by the ICI phenomenon. For that, the lower numerologies are more affected by the ICI than the higher numerologies due to their lower sub-carrier spacing values as shown in [12]. In this context, we also notice that the BER has a particular behavior for numerology 3. Regarding the curves of numerology 3 in Figures 4(a), 4(b) and 4(c), we note that BER is almost independent of the velocity values of the vehicles. This behavior, which can be seen more clearly in Figure 4(c), can be explained by the fact that the system performance is not affected by the ICI when numerology 3 is used, since the subcarrier spacing is larger, which can overcome the ICI problem.

Looking at figures 4(a), 4(b) and 4(c), we notice that the curves of the same numerologies show the same behavior for numerology index 0, 1, and 2. However, for the curves of numerology 3, we notice that BER increases when the delay spread is increased from 32 ns to 153 ns. As a result, the system exhibits a performance degradation when numerology 3 is used in this case.

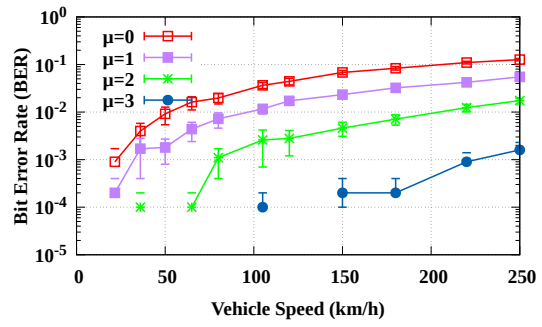
In this context, it is interesting to explain a second problem at physical layer, namely the problem of ISI. In fact, ISI is one of the most well-known forms of signal distortion that occurs in a multipath propagation environment. To avoid the occurrence of the ISI problem, the used cyclic prefix must be longer than the delay spread of the channel. As explained in section III-B, each numerology has its own cyclic prefix. However, depending on the delay spread of the channel, the cyclic prefix of the numerology may or may not overcome the ISI problem. In this context, we have considered different delay spread values in our simulations corresponding to both Urban Macro environment (UMa) and Rural Macro environment (RMa).

b) *Urban scenario*: for the urban scenario, Figures 5(a), 5(b) and 5(c) show the variation of the BER as a function of vehicle speed considering three delay spread values of 93 ns, 363 ns and 850 ns, respectively.

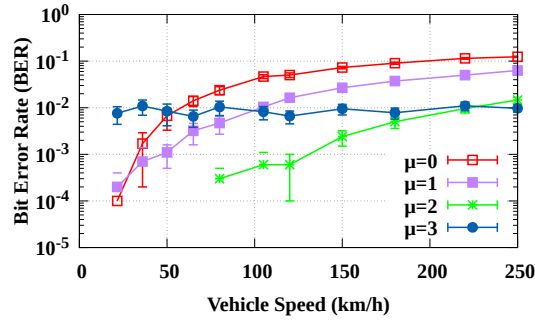
If we compare the curves of the same numerologies in Figures 5(a) and 5(b) with delay spread values of 93 ns and 363 ns, respectively, we find that the curves of numerologies 0 and 1 show the same behavior, while the curves of numerologies 2 and 3 show a remarkable difference. Looking at the curves of numerologies 2 and 3, we notice that the BER values are higher for a delay spread of 363 ns than for a delay spread of 93 ns. Moreover, we find that the BER is higher with numerology 3 when compared to numerology 2. Furthermore, if we increase the delay spread value to 850 ns, we find that the BER also increases for numerology 3, 2, and even more for numerology 1, as shown in Figure 5(c). Thus, we conclude that the system performance decreases significantly when using higher numerologies as the delay spread of the channel



(a) BER with delay spread = 32 ns

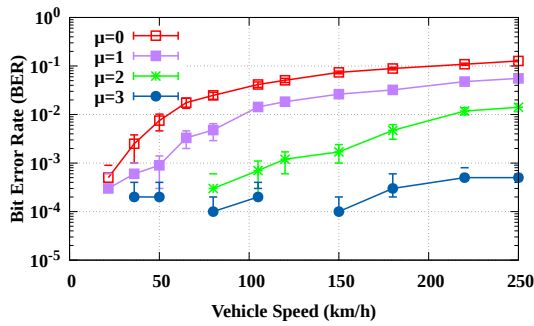


(b) BER with delay spread = 37 ns

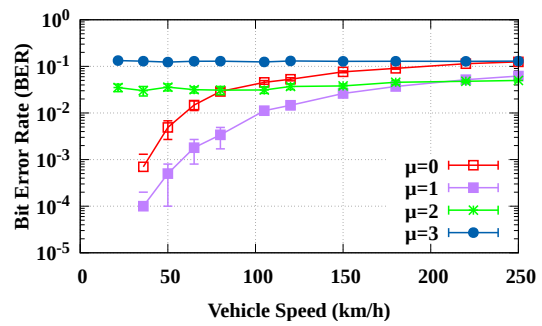


(c) BER with delay spread = 153 ns

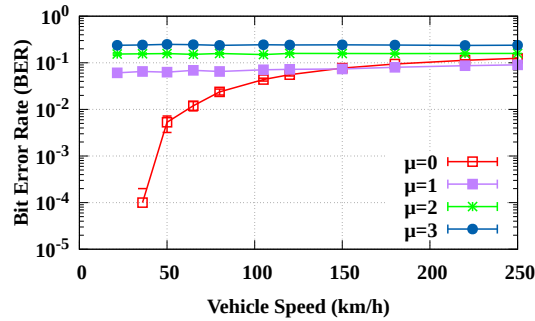
Fig. 4: BER as a function of vehicle speed varying numerology index (μ) for Rural Macro (RMA) scenario



(a) BER with delay spread = 93 ns



(b) BER with delay spread = 363 ns



(c) BER with delay spread = 850 ns

Fig. 5: BER as a function of vehicle speed varying numerology index (μ) for Urban Macro (UMA) scenario

TABLE V: Our Recommendations for the Selection of the appropriate Numerology based on the delay spread of the channel and vehicle speed

| Delay Spread | Appropriate Numerology Index |
|--------------|--|
| 32 ns | 3 |
| 37 ns | 3 |
| 93 ns | 3 |
| 153 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 2 for speed \leq 240 km/h • 3 for speed \geq 240 km/h |
| 250 ns | 2 |
| 300 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 1 for speed \leq 100 km/h • 2 for speed \geq 100 km/h |
| 363 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 1 for speed \leq 225 km/h • 2 for speed \geq 225 km/h |
| 450 ns | 1 |
| 520 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 0 for speed \leq 40 km/h • 1 for speed \geq 40 km/h |
| 650 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 0 for speed \leq 90 km/h • 1 for speed \geq 90 km/h |
| 750 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 0 for speed \leq 125 km/h • 1 for speed \geq 125 km/h |
| 850 ns | depends on vehicle speed: <ul style="list-style-type: none"> • 0 for speed \leq 150 km/h • 1 for speed \geq 150 km/h |

increases. Indeed, the system performance is more susceptible to the ISI problem when using the higher numerologies due to their shorter cyclic prefix. For this reason, we note that in urban scenarios and with higher delay spread values, it is not recommended to use the higher numerologies.

Since the numerology 3 exhibits a special behavior, we show in Figure 6 the BER as a function of vehicle speed for the numerology 3 only, considering four delay spread values: 32 ns, 153 ns, 363 ns, and 850 ns. The figure demonstrates the hypothesis already explained above.

Another observation is that for lower values of the delay spread, i.e. 32 ns, and for lower vehicle speeds, i.e. speed \leq 120 km/h, the BER of numerology 3 is practically zero for most values of the vehicle speed, as can be clearly seen in Figure 6 (if there is no BER value for a given vehicle speed in the curve, it means that the BER is close to zero). This behavior can be explained by the fact that using numerology 3 with low delay spread value can overcome the ICI and ISI problems.

C. Our recommendations for the selection of the appropriate numerology

After analyzing the results obtained from the two parts of this study, we demonstrate a theoretical hypothesis, which is that increasing numerology leads to an increase in throughput

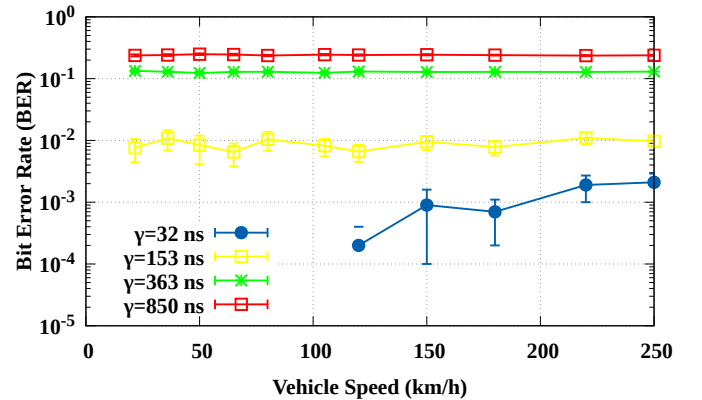
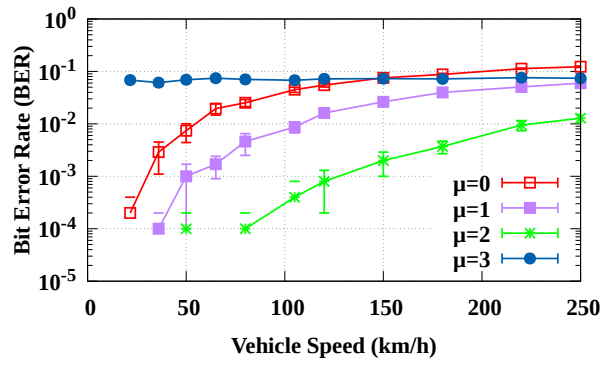
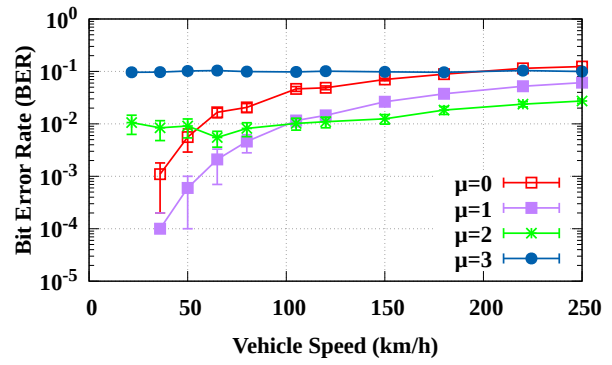


Fig. 6: BER as a function of vehicle speed varying delay spread (γ) for numerology index 3

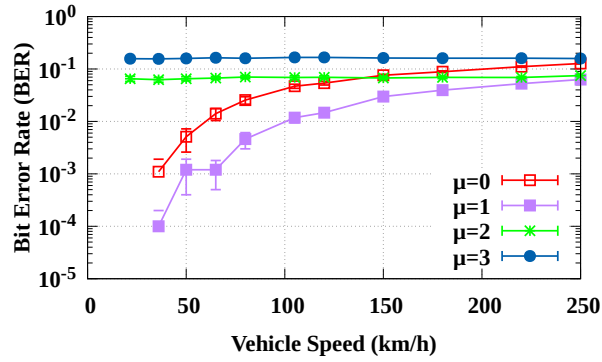
and a decrease in latency. These results seem to lead to the conclusion that higher numerologies are almost the best choice for all V2X scenarios. However, this is not always the case, since problems at physical layer such as Doppler shift and multipath variation have to be taken into account, which causes the ICI and ISI problem, respectively. The obtained results show that higher numerologies can mitigate the ICI



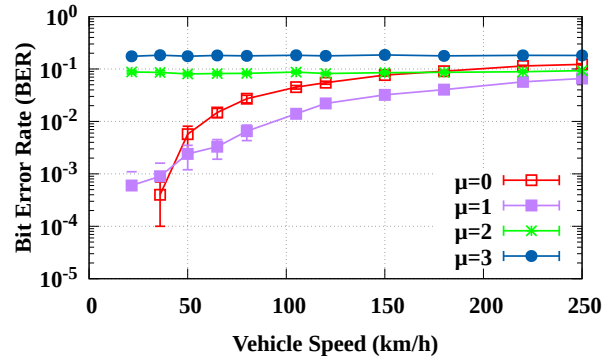
(a) BER with delay spread = 250 ns



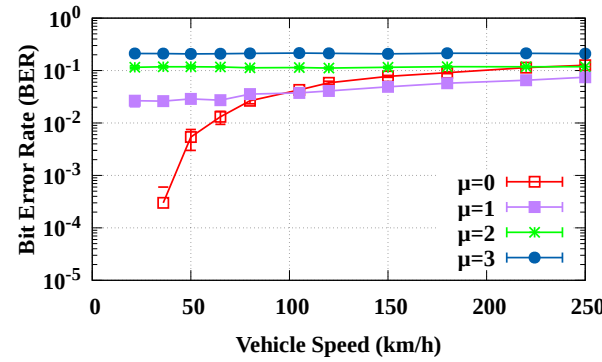
(b) BER with delay spread = 300 ns



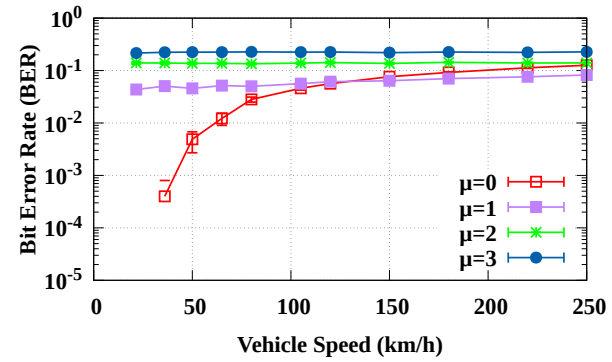
(c) BER with delay spread = 450 ns



(d) BER with delay spread = 520 ns



(e) BER with delay spread = 650 ns



(f) BER with delay spread = 750 ns

Fig. 7: BER as a function of vehicle speed varying numerology index (μ) for different delay spread values

problem due to their larger subcarrier spacing, but they are more susceptible to the ISI problem. In contrast, the lower numerologies can mitigate the ISI problem in a multipath propagation environment with their higher cyclic prefix, but they are more prone to the ICI problem. In conclusion, our study allows us to prove the following hypothesis:

- Throughput increases as the numerology index increases, as opposed to latency, which decreases as the numerology index increases.
- The BER increases with vehicle speed for numerologies

0, 1, and 2 due to the Doppler effect leading to the ICI problem, while it is fixed for numerology 3 thanks to their higher subcarrier spacing that overcomes the ICI problem.

- When using the higher numerologies, the BER increases when the delay spread is increased due to the ISI problem.
- Unlike the higher numerologies, the lower numerologies can overcome the ISI problem, but they are more susceptible to the ICI problem.

Here it is interesting to highlight that the before-

demonstrated hypothesis do not bring an exact choice for the appropriate numerology for a given V2X scenario. For this reason we have extended our study by performing a series of simulations, in which we consider randomly a wide range of delay spread values and vehicle speeds, as shown in the Figure 7. The analysis of these figures follows the same strategy as that of the previously analyzed figures. After analyzing all those figure, we present our recommendations for choosing the appropriate numerology as a function of channel conditions and vehicle speeds in the table V. In fact, in a real scenario, it is possible to determine the delay spread of the channel and the vehicle speed accurately enough to choose the appropriate numerology. Based on these parameters, this table can be used as a reference for choosing the appropriate numerology. As can be seen from the table, we can propose to use numerology 3 for the urban scenario with a delay spread of 93 ns and also for the rural scenario with a delay spread of 32 ns and 37 ns. However, numerology 2 seems to be the best choice for the rural scenario with a delay spread of 153 ns when the vehicle speed is less than 240 km/h, while numerology 3 can be selected for this delay spread when the vehicle speed is more than 240 km/h.

Thus, we conclude that the choice of the appropriate numerology depends not only on the V2X requirements such as latency or throughput but also on the vehicle speed and propagation channel conditions as more detailed in Table V.

V. CONCLUSION AND PERSPECTIVES

The 5G numerologies are considered as one of the most important 5G key features to meet the requirements of various 5G services. However, in V2X communication, choosing the appropriate numerology for a particular V2X scenario is still a challenging task. In this paper, we have studied the impact of 5G numerologies on V2X communication performance, considering both safety and infotainment applications. Our study shows that higher numerologies are the best choice to achieve higher throughput and low latency, which is beneficial for both infotainment and safety applications, respectively. However, considering the problems at physical layer such as ICI and ISI, we find that the choice of the appropriate numerology depends on the propagation channel conditions and the vehicle speed, which affects the reliability of the V2X communications. Finally, we conclude that the choice of the appropriate numerology is a trade-off between the stringent requirements of V2X applications, the ICI problem, and the ISI problem. As future work, we will propose a new dynamic numerology selection algorithm that aims to select the appropriate numerology for each vehicle separately, taking into account the vehicle speed and channel conditions.

ACKNOWLEDGMENT

This work was partially supported by the ENE5AI project funded by BPI France.

REFERENCES

[1] 3GPP. Study on Scenarios and Requirements for Next Generation Access Technologies, 3GPP TR 38.913 version 14.2.0 Release 14. Technical report, May, 2017.

[2] IEEE Standard for Information Technology Telecommunications and information exchange between systems Local and metropolitan area networks Specific requirements part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications amendment 6: Wireless Access in Vehicular Environments. Technical report, 2020.

[3] 3GPP. Technical Specification Group Services and System Aspects; Summary of Rel-16 Work Items. Technical Report TR 21.916 V1.0.0, December, 2020.

[4] Qian Zhao, Xintan Ma, and Xiang Liu. Analysis of doppler effect of vehicle noise on environmental noise. In *2020 5th International Conference on Information Science, Computer Technology and Transportation (ISCTT)*, pages 589–592. IEEE, 2020.

[5] Natale Patriciello, Sandra Lagen, Lorenza Giupponi, and Biljana Bojovic. 5G New Radio numerologies and their impact on the end-to-end latency. In *2018 IEEE 23rd international workshop on computer aided modeling and design of communication links and networks (CAMAD)*, pages 1–6. IEEE, 2018.

[6] David Segura, Emil J Khatib, Jorge Munilla, and Raquel Barco. 5G Numerologies Assessment for URLLC in Industrial Communications. *Sensors*, 21(7):2489, 2021.

[7] Noélia Correia, Feroz Al-Tam, and Jonathan Rodriguez. Optimization of Mixed Numerology Profiles for 5G Wireless Communication Scenarios. *Sensors*, 21(4):1494, 2021.

[8] Abdullah Hossain and Nirwan Ansari. 5G Multi-Band Numerology-Based TDD RAN Slicing for Throughput and Latency Sensitive Services. *IEEE Transactions on Mobile Computing*, 2021.

[9] Claudia Campolo, Antonella Molinaro, Francesco Romeo, Alessandro Bazzi, and Antoine O Berthet. 5G NR V2X: On the impact of a flexible numerology on the autonomous sidelink mode. In *2019 IEEE 2nd 5G World Forum (5GWF)*, pages 102–107. IEEE, 2019.

[10] Zoraze Ali, Sandra Lagén, and Lorenza Giupponi. On the impact of numerology in NR V2X Mode 2 with sensing and no-sensing resource selection. *arXiv preprint arXiv:2106.15303*, 2021.

[11] Tapisha Soni, Ali Ramadan Ali, Karthikeyan Ganesan, and Malte Schellmann. Adaptive numerology A solution to address the demanding qos in 5G-V2X. In *2018 IEEE Wireless Communications and Networking Conference (WCNC)*, pages 1–6. IEEE, 2018.

[12] J Flores de Valgas, David Martín-Sacristán, and J Monserrat. 5G New Radio Numerologies and their Impact on V2X Communications. *Waves, Universitat Politècnica de Valencia*, pages 15–22, 2018.

[13] ETSI. Intelligent Transport Systems (ITS), Vehicular Communications, Basic Set of Applications. Technical Report TR 102 638, 2009.

[14] ETSI. Intelligent Transport Systems (ITS) Vehicular Communications Basic Set of Applications, Part 2: Specification of Cooperative Awareness Basic Service. Technical Report EN 302 637-2 V1.3.1, 2014.

[15] 3GPP. 5G NR Physical channels and modulation. Technical Report TS 38.211 version 16.2.0 Release 16, July 2020.

[16] Giovanni Nardini, Dario Sabella, Giovanni Stea, Purvi Thakkar, and Antonio Virdis. Simu5G—An OMNeT++ Library for End-to-End Performance Evaluation of 5G Networks. *IEEE Access*, 8:181176–181191, 2020.

[17] Pablo Alvarez Lopez, Michael Behrisch, Laura Bieker-Walz, Jakob Erdmann, Yun-Pang Flötteröd, Robert Hilbrich, Leonhard Lücken, Johannes Rummel, Peter Wagner, and Evamarie Wießner. Microscopic Traffic Simulation using SUMO. In *The 21st IEEE International Conference on Intelligent Transportation Systems*. IEEE, 2018.

[18] Stefan Pratschner, Bashar Tahir, Ljiljana Marjanovic, Mariam Mussbah, Kiril Kirev, Ronald Nissel, Stefan Schwarz, and Markus Rupp. Versatile mobile communications simulation: the Vienna 5G Link Level Simulator. *EURASIP Journal on Wireless Communications and Networking*, 2018(1):226, September 2018.

[19] ETSI. 5G; Study on channel model for frequencies from 0.5 to 100 ghz (3GPP TR 38.901 version 14.0.0 release 14). Technical Report TR 138 901, May, 2017.

[20] Xiaoran Liu, Jiao Zhang, and Jibo Wei. Numerology selection for ofdm systems based on deep neural networks. *arXiv preprint arXiv:2011.04247*, 2020.