Traffic Safety in the METIS-II 5G Connected Cars Use Case: Technology Enablers and Baseline Evaluation

David Martín-Sacristán, Carlos Herranz, Jose F. Monserrat
Universitat Politècnica de València – iTEAM research institute
Camino de Vera S/N, 46022, Valencia, Spain
{damargan, carhercl, jomondel}@iteam.upv.es

***Abstract*—Ultra-reliable V2V communications with extreme transmission rate probably constitute the most ambitious use case of the fifth generation mobile. At present, both the scientific community and the standardization bodies are addressing the design of the technologies that will make it possible, although there is no unanimity in which technologies to incorporate. This paper approaches this topic from the work developed in the METIS-II project, describing the use case, the technology enablers and some details of the evaluation of these techniques in realistic scenarios. Results show that, for a baseline system, carrier bandwidths needed to fulfil the requirements are between 30 and 100 MHz, depending on the scenario. Nevertheless, results show potential to reduce the needed bandwidth to a range between 20 and 50 MHz by incorporating additional technology enablers to the studied baseline system.**

Keywords—5G; V2V; traffic safety; connected cars; METIS-II; 5GPPP

I. Introduction

There is a global consensus in the fact that the fifth generation mobile, the 5G, will be based on three main characteristics of service provisioning: the extreme data rate transmission, the ultra-reliability of communications and the connectivity of a massive number of machines [1]. Based on these three pillars, and depending on the forum, different use cases have been defined to validate the technologies proposed as candidates for the 5G. Because of its relevance, it can be highlighted the definition of use cases made in METIS-II project [2]-[3], which includes the specification of the use case requirements, configuration and main characteristics. Among all the proposed use cases, the most demanding is undoubtedly the use case of communication between vehicles, better known as Vehicular-to-Vehicular (V2V) communications. In this case, the three main characteristics of the 5G are necessary, since the ultra-reliability is needed to guarantee the safety of the passengers of the vehicle, an extreme mobile broadband access is required to allow, among other things, the autonomous driving, and there is also a massive number of vehicles to be connected.

Concerning the precise requirements that V2V-based services will need in the 2020s, the METIS-II project has specified a set of stringent requirements that will not be achievable by the technological solutions available today, including LTE-V [3].

This is the starting point of this article, and is presented in Section II together with the necessary condition to justify the need for the technological solutions discussed in the literature and that are compiled in Section III. Indeed, in this Section III, and starting from the current status of the specification of V2V communications within the 3GPP, the characteristics of the main enabling technological solutions of the future of V2V communications in the 5G are reviewed.

This paper then focuses on a feasible subset of these technology enablers, forming the system described in Section IV, to see how close these solutions are to the requirements. Simulation results based on the models and configuration presented in Section V are provided and discussed in Section VI, which motivates the main conclusions of the paper with respect to the most convenient way forward in specifications in Section VII.

II. METIS-II Connected Cars Use Case

The European project METIS-II identified five 5G use cases [3] that cover the three main 5G services (extreme mobile broadband, ultra-reliable communications and machine type communications), have stringent requirements, and whose technical solutions are expected to serve also for other similar use cases. The “connected cars” use case addresses information exchange among vehicles and with the infrastructure to enable: (i) a safer and more efficient transportation and (ii) real-time remote computing for mobile terminals.

Concerning traffic efficiency and safety, the main challenges of this use case lie in the required reliability, availability, and latency of automotive safety services. A maximum wireless network end-to-end delay (including wireless device detection, connection setup and radio transmission but excluding the time needed from the vehicle to process and generate the information message) of 5 ms, with transmission reliability of 99.999% should be guaranteed to deliver the driving safety service. Additional requirements with regard to relative positioning accuracy (below 0.5 m), availability (~100%), and ability to support the use case across multiple operators are provided.

Data traffic specified for communication between vehicles in this use case consists of periodic broadcast of at least 1600 payload byte packets with repetition rate of at least 5-10 Hz.

Three different mobility environments are distinguished: urban (with maximum speed of 60 km/h and required communication range of 50 m), rural (with maximum speed of 120 km/h and required range of 500 m), and highway (with maximum speed of 250 km/h and required range of 1 km). The density of users and devices depends on the environment (up to 1000 users per km^2 in urban environment and up to 100 users per km^2 in the other environments).

Compared to other connected vehicles use cases within the framework of the 5G Public Private Partnership (5G-PPP), the METIS-II use case is more demanding in terms of latency sensitivity and user throughput [4]. Two scenarios are also defined by the 3GPP for connected cars [5]: one in a highway and another in an urban grid. In both cases, the maximum number of messages per second is 50, but neither the packet payload nor the required reliability level and range are specified at the time of writing this paper.

III. TECHNOLOGY ENABLERS

A. Status of Release 14 3GPP specifications

Enabling direct communication between vehicles within the cellular system is key to deal with the necessary safety requirements for the autonomous cars deployment. The standardization of V2V communications began in Release 13 with a study item on the requirements of Intelligent Transportation System (ITS) services. There are several specific aspects of this type of communication that make it particularly complex, including the relative lack of synchronism between the terminals and the high speed of transmitter and receiver, which requires a higher density of pilots to enable a proper coherent detection. In Release 14 these issues are being addressed within the study item "Support for V2V services based on LTE sidelink". Although the study item has not yet been closed, the radio aspects are considered completed, being included in 3GPP technical report TR 36.785 [6], while operational procedures were completed by March 2017.

The system is supposed to operate with different bandwidths, including 10 MHz, using a dedicated carrier for V2V communications and the use of Global Navigation Satellite System (GNSS) for time synchronization. Two configurations have been defined. In configuration 1, the system is fully distributed, both for interference management and for scheduling, and it was defined a new way of scheduling, mode 4, which allows sensing and semi-persistent scheduling. Resource allocation also depends on the geographic information. In configuration 2, mode 3 scheduling is used, which allows eNodeBs to assist in decision-making regarding interference management and scheduling, by using specific signaling over the radio interface. In short, the eNodeB determines the set of resources that vehicles distribute dynamically.

B. Technology enablers proposed in the literature

In addition to the coexistence aspects with regard to legacy technologies, scheduling, and band occupancy, there are many more technological solutions that are currently being investigated and could be useful in the METIS-II connected cars use case. This section describes some of them starting from the physical layer aspects up to networking issues.

<u>Above 6 GHz transmission</u>

Regarding the high data rate needs, the provision of extended spectrum bands according to the demand of ITS is a necessary step that should be accompanied by an increasingly efficient use of the radio bands. In this context, the transmission through frequency bands different to currently used dmW (decimeter waves) band, such as cmW (centimeter waves) or mmW (millimeter waves) may be an alternative [7].

Although mmW is considered by some authors as the only feasible line of attack to provide high data rate to connected vehicles (see [8]), we promote that the technology shall go beyond radiofrequency-only approaches and use also the visible spectrum as a viable alternative. Light emitting diodes (LEDs) are transforming the lighting industry. Since costs have drop rapidly and efficiencies have improved, LED popularity has skyrocketed as a long life-expectancy and low-power consumption substitute for the typical widespread (and energy-wasting) halogen lamps of the automotive industry. The fast switching speeds of LEDs make them appropriate as an alternate path for data communication between vehicles, known as Visible Light Communications (VLC), while keeping their original illumination purpose as headlights or rear lamps.

<u>Use of new waveforms</u>

OFDM implementations in 4G technologies are sensible to the lack of synchronization between V2V emitters [9]. However, there exist mechanisms that improve OFDM robustness (e.g. increasing the length of the cyclic prefix or filtering). On the other hand, offset QAM (OQAM) Filter-Bank Multi-Carrier (FBMC) is more robust against the lack of synchronization, but not as easily applicable to MIMO as OFDM due to its implementation complexity. In summary, a proper fitting of waveforms would permit increasing the range of V2V communication without peer-to-peer synchronization.

<u>Multi-antenna transmission</u>

Vehicles have large dimensions as compared with conventional mobile devices, making them suitable for the deployment of multiple antennas. The availability of several antennas provides diversity that can be used to alleviate the effect of shadowing produced by other vehicles in the V2V transmission [10]. However, multiple antennas could be also exploited for the transmission of parallel flows since the large size of vehicles, and the subsequent large separation of the antenna elements, may lead to richer channels. What seems mandatory for the car industry is to have at least 4 antenna elements per vehicle in the 2020 horizon.

<u>Frame structure design</u>

One of the main requirements to ensure ultra-reliability is to reduce the end-to-end delay in the communication. A very simple way to achieve this is to reduce the frame duration at the same time as the packet size. Currently, extensive research is dedicated to the design of new, more flexible organizational solutions for transmission in the time domain, alternating synchronized frames and periods of contention. It is also expected that the frame duration in 5G could be reduced by a factor of 8 with respect to the current millisecond of LTE.

Channel coding for small packets

Channel coding schemes in 4G technologies are based on turbo coding. Turbo codes are effective fault-correcting schemes for large block sizes, but are far from simple and consume large computing capacity. Low Density Parity Check (LDPC) codes allow achieving similar or even superior performance to turbo codes, with very low complexity at the cost of needing more memory storage, and do not have patents linked to their use. On the other hand, polar codes are characterized by moderate complexity, and distribute the computational effort between transmitter and receiver. For large packets its efficiency is somewhat lower than that of LDPC codes or turbo codes, but with small sizes its correction capacity is much better. That is why polar codes are studied for transmission of small packets in V2V communications.

Multi-hop communications

Experimental results performed in METIS-II realistic Madrid Grid scenario [4] have proven that current V2V technologies have serious limitations due to the problems of lack of coverage and hidden nodes in motorway and urban environments. In this direction, there is a clear need to extend current communications paradigms to multi-hop procedures, thus guaranteeing the extension of coverage thanks to the cooperation of intermediate nodes, those being other cars or infrastructure elements.

Cellular broadcast/multicast

Broadcasting technologies in cellular networks, like E-MBMS in LTE, are significantly more efficient in terms of resource consumption than the unicast mode, whenever emergency messages are to be delivered to a set of vehicles in close vicinity [11]. Recent standardization of LTE, including the possibility of multicasting and single-cell point to multipoint communication, should be further extended to embrace also the possibility of V2V multi-casting.

IV. DETAILS OF THE EVALUATED V2V SYSTEM

The technical solution assessed in this paper is in fact a simple 4G solution that from the above mentioned technical enablers considers just the availability of large bandwidths for V2V communications. We use this simple solution to obtain a baseline evaluation of the connected cars use case of METIS-II.

Specifically, the evaluated system is based on the use of direct communication between the vehicles, i.e. only sidelink is used for V2V communication, while neither road side units nor cellular infrastructure are used to transmit user data. It is assumed that a dedicated pool of resources of certain bandwidth is available for V2V and managed by a central controller. Frame structure is assumed to be equal to the LTE structure, i.e. with 1 ms subframes. Packet transmissions are supposed to be fully contained in each subframe, with transmissions from multiple users being multiplexed in frequency during each subframe thanks to the division of the system bandwidth into multiple subbands. Given the low latency requirement, retransmissions are not allowed neither at physical nor at link layers. Concerning the transmission power, no power control is used. Instead, all users use a fixed transmission power.

The resources of the pool are allocated in a semi-persistent way to the vehicles, i.e. a specific frequency subband is allocated to each vehicle during one subframe with certain periodicity. The controller knows the periodicity of the traffic generated by the vehicles to allocate the resources with the same periodicity. In addition, the controller knows the precise time instance when each vehicle generates the periodical packets and uses this knowledge to ensure the fulfilment of the maximum end-to-end latency requirements by allocating to the vehicle a subframe close to that time instance.

The controller aims at minimizing the interference among users by maximizing the distance among the vehicles using the same physical resources (the same subframe and subband). With this target, the controller modifies the resource allocation to a user whenever this user significantly changes its position (50 m in urban scenarios and 200 m in highway scenarios).

The communication between the controller and the vehicles requires the presence of a network infrastructure: either a cellular network or another dedicated network. In this work, a cellular network exists, and a portion of the V2V dedicated spectrum is devoted to the communication between vehicles and the cellular infrastructure.

V. SIMULATION SETUP

The basis for the performance evaluation presented in this paper is described in [13]. Three relevant scenarios are used in this assessment: an urban realistic scenario created in METIS, known as Madrid Grid scenario, an urban synthetic scenario, which will be referred to as 3GPP Grid in this evaluation, and a Highway scenario, being the latter two replicas of the scenarios in [5], basically.

For the sake of completeness, Table I presents the main parameters of the simulations conducted. Concerning the density of vehicles, the 3GPP Grid and Highway scenarios present a fixed value, due to the specific UE dropping model in [13]. In the Madrid Grid, we have considered a set of densities from 100 to 1000 vehicles/km^2, 1000 being the maximum vehicle density envisioned for urban environments in [13]. The definition of the traffic model is another element of paramount importance. We have used exactly the traffic model defined in [13], which considers the requirements indicated for traffic safety in Section II: packets of 1600 bytes and 10 Hz frequency. Note that carrier frequency and bandwidth values are provided for the sidelink, i.e. the direct D2D link between vehicles. Different carrier bandwidths have been considered. For each one, a set of subband sizes has been used, ranging from a size equal to the system bandwidth to 1/50 the system bandwidth. With regard to mobility, in the 3GPP Grid scenario, vehicles move along the streets at 60 km/h. At the intersections, vehicles have 50% probability to go straight and 25% probability of turning left or right. In the urban realistic scenario, cars, buses, and pedestrians are dropped and move within the Madrid Grid according to the car mobility models and traces described in [13]. In the Highway scenario, vehicles move along the lanes of the highway at 140 km/h.

The channel modelling is detailed in [13]. In the Madrid Grid, the V2V channel model follows the ITU-R UMi model in Manhattan scenarios, with lower transmitter height plus 10 additional dB of attenuation in case of having other cars in the middle of the communication channel. In the other two scenarios, the modelling considers also geometry-stochastic channel models based on those used by 3GPP.

The simulator used in this assessment is a C++ proprietary simulator based on the LTE-Advanced simulator in [14], extended with V2V capabilities in METIS-II. Note that in this assessment synchronization errors have not been considered.

TABLE I. MAIN SIMULATION PARAMETERS

Parameter	**Value**		
	Madrid Grid	***3GPP Grid***	***Highway***
Carrier frequency	6 GHz (sidelink)		
Carrier bandwidth	10, 20, 30, 40, 50 and 100 MHz (sidelink)		
UE tx power	23 dBm		
UE antenna gain	3 dBi		
UE noise figure	9 dB		
UE number of tx antennas	1		
UE number of rx antennas	2		
Density of vehicles	100, 250, 500, 750 and 1000 vehicles/km^2	595 vehicles/km^2	10.25 vehicles per lane and km
Speed	60 km/h	60 km/h	140 km/h
Traffic model	Constant bit rate: packets of 1600 bytes, 100 ms periodicity		

VI. RESULTS

The main Key Performance Indicator (KPI) in this study is the Packet Reception Ratio (PRR). PRR measures the reliability in the reception of transmitted packets for different ranges of distance with respect to the transmitter of the packet. As presented in Section II, the requirement set in [3] for traffic safety packets is a maximum latency of 5 ms with reliability of 99.999%. This reliability should be valid within the specified communication range that is 50 m in urban scenarios, and 1 km in highway scenarios. No KPI related to the latency will be shown in this section since the resource allocation algorithm ensures the fulfilment of the maximum latency requirement, as explained in Section IV.

PRR curves for Madrid Grid with different vehicle densities are shown in Fig. 1 for a system bandwidth of 10 MHz. The PRR curves have been obtained with a granularity of 5 m, i.e., each point represents the PRR for a range of distances [x-5, x] being x the value of the abscissa. It is worth noting the high variation of some curves, that show local increases of PRR with the distance, which is due to the specific geometry of the scenario and the distribution of users that may improve/worsen the reception of packets for specific distances.

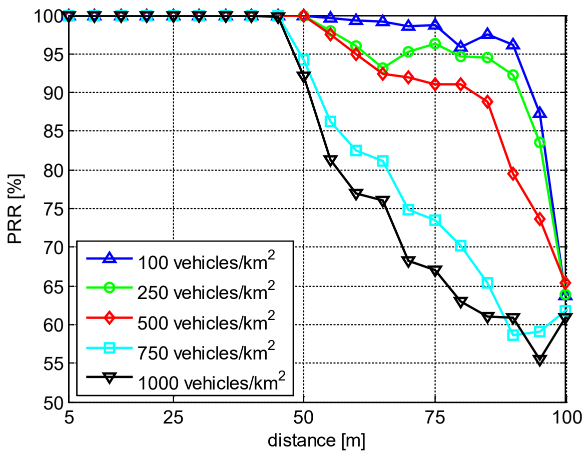

Fig. 1. PRR in Madrid Grid with 10 MHz bandwidth for different vehicle densities.

In Fig.1, it can be seen how the performance degrades as the density increases, due to the higher level of interference. A PRR higher than 99.999% has been achieved with 10 MHz for a range of 50 m and the lowest user density (100 vehicles/km^2). For higher densities, the 99.999% reliability has been achieved for shorter ranges: 45 m for 250 and 500 vehicles/km^2, 40 m for 750 and 1000 vehicles/km^2. Therefore, the 10 MHz bandwidth commonly used for V2V communications is not enough to support the higher densities in the studied system.

Fig. 2 shows the PRR curves for the highest density considered in the Madrid Grid, 1000 vehicles/km^2, and different system bandwidths. Note that for each system bandwidth the best tested subband size configuration is shown. The coverage range supported with 99.999% reliability is 40 m for 10 MHz, 45 m for 20 and 30 MHz, 50 m for 40 MHz, and more than 100 m for 50 MHz. The main conclusion of this assessment is that the 5G requirements can be fulfilled with the considered system and a bandwidth greater than or equal to 40 MHz. Besides, the system performance is very close to the requirements with shorter bandwidths such as 20 MHz. Therefore, it seems feasible that a small improvement provided by any of the above-mentioned technology enablers, that could increase signal power or reduce interference, may reduce the bandwidth needed to meet requirements down to 20 MHz.

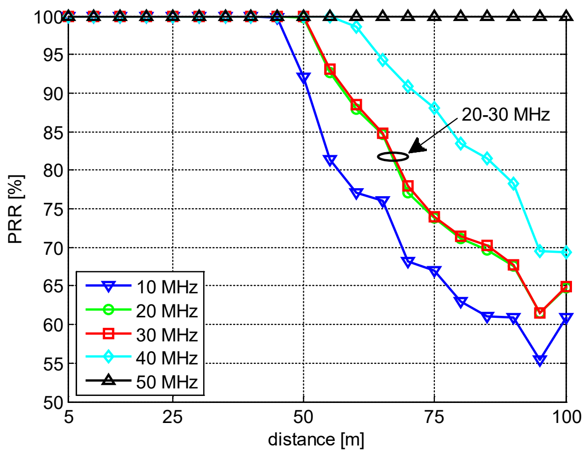

Fig. 2. PRR in Madrid Grid with 1000 vehicles/km^2.

The PRR curves for 3GPP Grid are shown in Fig. 3. The 99.999% PRR requirement has been achieved for 50 m and a bandwidth of 40 MHz. Specifically, the 99.999% PRR is achieved for a range of 35 m with 10 MHz, 45 m with 20 and 30 MHz, 55 m with 40 MHz, and 75 m with 50 MHz. Again, it seems feasible a reduction of the required bandwidth down to 20 MHz with minor changes. For the sake of comparison with the Madrid Grid, consider that in the 3GPP Grid the length of roads per unit of area is higher than in the Madrid Grid. In fact, in vehicles per km, the density of 595 vehicles/km^2 in the 3GPP Grid is almost equal to the 1000 vehicles/km^2 in the Madrid Grid (24 and 25 vehicles/km respectively).

The PRR curves for the Highway scenario are shown in Fig. 4. The results indicate that the evaluated system is able to fulfil the reliability requirements for a range of 1000 m with 100 MHz, which is the highest required bandwidth compared to the other studied scenarios. Note that the density in vehicles per km is lower in this scenario but the coverage range is much higher than in the urban scenarios. The 99.999% PRR is achieved for a range of 100 m with 10 MHz, 150 m with 20 MHz, 400 m with 30 and 40 MHz, and 600 m with 50 MHz. In case of relaxing the coverage range down to 500 m, which is a reasonable value, a bandwidth of 50 MHz would be enough to fulfil the requirements.

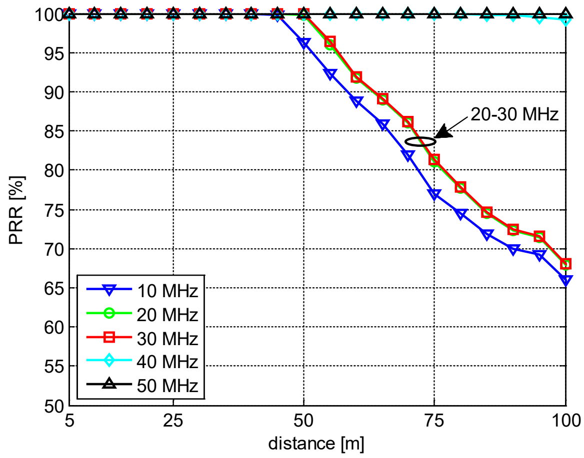

Fig. 3. PRR in 3GPP Grid.

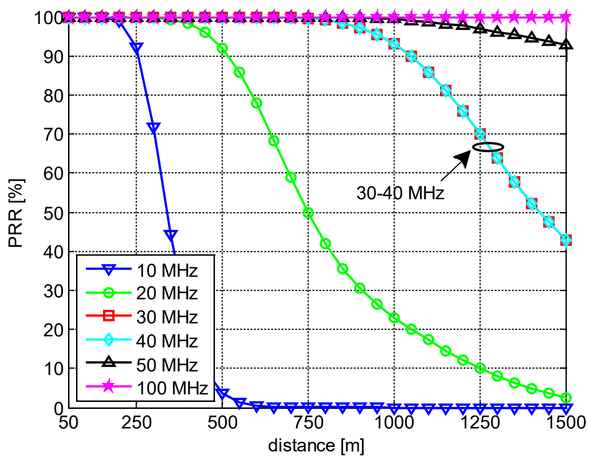

Fig. 4. PRR in Highway.

VII. Conclusion

This article has presented the requirements set by the METIS-II project for vehicular communication. After describing the technological solutions contemplated in the literature, it has been evaluated to what extent current systems are prepared to support the new requirements of the 5G. The results have shown that both latency and reliability requirements can be fulfilled with system bandwidths between 30 and 100 MHz, depending on the scenario. According to the results, it seems feasible to reduce the needed bandwidth down to 20 MHz or less in the urban scenarios and 50 MHz or less in the highway scenario adding some technology enablers to the studied system. Due to its potential to extend coverage and reduce interference, the first set of candidate technology enablers to be considered in our future work will be the multi-antenna transmission, the use of spectrum above 6 GHz and new frame structures. In addition, multi-hop transmission will be studied in the highway scenario for coverage extension.

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