# Implementation and Assessment of IEEE 802.11bd for Improved Road Safety

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*Abstract*— **Cooperative Intelligent Transport Systems (C-ITS) are built based on vehicular communication technologies with real-time information exchange to improve overall traffic management such as road safety, efficiency, and comfort. Road safety depends on several factors that should be considered, among which the reliability of the used in-vehicle awareness systems. Therefore, communication technologies are rapidly evolving, and New Radio Access Technologies (RATs) are emerging to provide enhanced performances in terms of reliability, coverage, and throughput. C-ITS can benefit from these new RATs enhancements to allow new use cases and applications and then prevent additional road accidents. In this context, the IEEE 802.11bd and cellular vehicle-to-everything (C-V2X) technologies such as LTE-V2X and NR V2X are being developed. This advance is fundamentally reshaping the C-ITS landscape as both technologies (IEEE 802.11bd and LTE-V2X) are competing. In this paper, we analyze how these technologies help increase road safety by making communication more reliable. Furthermore, we will compare their performance using our IEEE 802.11bd implementation in OMNeT++ in terms of packet reception ratio. Finally, we will forecast the number of avoided serious injuries on the European roads.**

**Keywords— IEEE802.11p, IEEE802.11bd, LTE-V2X, C-ITS, V2X, Road Safety.**

## I. INTRODUCTION

Recent European (EU) statistics showed that road fatalities and serious injuries have been mitigated by 19% over the last six years after reaching 25500 deaths in 2016 [2]. This number is decreasing over the last three years; however, it is still high compared to the EU safety target. Using information and communication technologies in the vehicular environment is one of the EU comity's seven strategic objectives for road safety that would help to reach this target.

Road safety depends on several factors, some are manageable and measurable, others are related to different road effects and driver's behavior (human factor). Thus, analyzing some of these factors can help us have a deeper understanding of the causes of road fatalities and then try reducing or preventing some of them. Cooperative Intelligent Transport Systems (C-ITS) are identified by many stakeholders as a promising instrument to help to achieve the societal goal of improving road safety. This is achieved by boosting the vehicular and road infrastructure to enable exchanging safety and awareness messages to provide services such as hazardous location warnings, in-vehicle speed limit displays, and alerts to improve intersection safety. Alert delivery reliability in C-ITS communication is one of the previously mentioned factors. So, improving the delivery ratio of alert/warning messages would help reducing more road accidents and thus improving road safety. Nowadays, wireless access in vehicular environments (WAVE) such as Dedicated Short-Range Communication (DSRC) and ITS-G5 technologies for V2X communications are based globally on the IEEE 802.11p™-2010 standard. However, a new standard is emerging as an amendment of this latter, namely the IEEE 802.11bd technology which is a result of the IEEE Task Group 802.11bd (TGbd) project, created in Jan 2019 [3]. It is worth noting that vehicular communications are highly impacted by mobility [4] which requires careful adaptation of the existing standards to reach the expectations of new prevention systems. This Next Generation V2X (Vehicle-to-everything) standard is proposed to support new V2X services such as support of self-driving vehicles, vehicular vision with see-through, and platooning. These services require stringent end-to-end latency, high reliability, and high data rate. These requirements cannot be fully supported by the actual technologies that are based on IEEE 802.11p. Therefore, the IEEE 802.11bd standard is designed to replace the IEEE 802.11p standard to enable vehicular ad-hoc environment with enhanced performance in terms of throughput, latency, reliability, and communication range. However, the IEEE 802.11bd standard must maintain backward compatibility with 802.11p as long as they coexist and operate on the same frequency band (5.9 GHz). On the other hand, a focus has been given to developing suitable cellular technologies for C-ITS (C-V2X) to fulfill the requirements of the new generation V2X applications that could not be satisfied by the Wi-Fi-related technologies mainly IEEE 802.11p [5]. This is achieved using the LTE Sidelink (i.e. LTE-V2X PC5) introduced in the release 14 of the 3GPP standardization process. The Sidelink direct communications are based on the LTE device to device (D2D) direct communication [6]. This technology can enhance the reliability of V2X messages delivery and retransmission using enhanced mechanisms and strategies.

The finding in [5] presents an evaluation of the performance of V2X technologies by modeling their complete PHY features in MATLAB. Adding to that most studies that dealt with C-ITS technologies performance derive their results from analytical modeling [7]. In our study, we propose an evaluation of the IEEE 802.11p, IEEE 802.11bd, and LTE-V2X using the OMNeT++ simulator within the Artery framework [8] and SimuLTE framework [9]. Furthermore, we will forecast the number of serious injuries that can be avoided for each of these technologies based on different parameters. This metric will help us find how road safety is depending on both the used technology and its penetration rate in ITS stations. The rest of this paper is organized as follows. In section II, we give a brief overview of the IEEE 802.11p, IEEE 802.11bd, and LTE-V2X standards. Section III provides important outlines concerns our implementation of the IEEE 802.11bd standard and a comparison between each of IEEE 802.11p, IEEE 802.11bd, and LTE-V2X focusing mainly on packet reception ratio (PRR). Section IV presents the road safety performance study in terms of the number of avoided serious injuries. Finally, section V concludes the paper and proposes some directions for future work.

## II. Overview of IEEE 802.11p, IEEE 802.11bd, and LTE-V2X

### A. IEEE 802.11p overview

IEEE 802.11p standard is based on the IEEE 802.11a standard, this latter was modified to support VANET communication with high-mobility challenges. The declared objectives of the 802.11p RAT can be summarized as follows:

- Relative velocities up to 200 km/hr.
- Response times of around 100 milliseconds.
- Communication ranges up to 1000 meters.

However, due to the vehicular environment specifications, this standard does not assure good reliability of message delivery. Referring to [10], we can say that the average delivery reliability of IEEE 802.11p is around 78%. This can be explained by the following Physical and MAC layers specifications.

The physical layer of IEEE 802.11p is based on Orthogonal Frequency Division Multiplexing (OFDM) as most of the IEEE 802.11 standards. The main difference compared to IEEE 802.11a is that carrier spacing and bandwidth are reduced by a factor of two (10MHz of bandwidth and 156.25 kHz sub-carrier spacing) which result in two times longer symbol duration. The cyclic prefix (CP) duration is also doubled, which offers a way to compensate for larger delay spreads. The MAC layer protocol uses the Enhanced Distributed Channel Access (EDCA) method with carrier sense multiple access and collision avoidance (CSMA/CA) mechanism. Furthermore, there is no exponential back off and no message acknowledgment [11] since transmissions in V2X communications are broadcast messages. To provide low latency the IEEE 802.11p standard is operating in the out-of-context of a basic service set (OCB) which means that there is no association nor authentication before sensing the channel, which imposes that no message retransmission is allowed, consequently, a loss in the message delivery reliability. To recover lost packets the IEEE 802.11p uses binary convolutional coding (BCC) which is a weak coding mechanism compared to the low-density parity-check coding (LDPC). In high modulation scenarios and high range communication (i.e. >50 meters) BCC loses its capability to recover erroneous messages. The maximum MCS that the IEEE 802.11p can handle is a 64-QAM offering with that a theoretical 24 Mbps throughput which is too low for new V2X applications like platooning and streaming applications.

### B. IEEE 802.11bd overview

Nowadays, a new set of V2X applications is being discussed and developed. So, to fulfill these applications' requirements, an amendment to the IEEE 802.11p was defined as the IEEE 802.11bd standard. According to the project authorization report (PAR) [12] the IEEE 802.11bd expected objectives are:

- At least one mode that achieves twice the MAC throughput of 802.11p with relative velocities up to 500 km/hr.
- At least one mode that achieves twice the communication range of 802.11p.
- At least one form of vehicle positioning in affiliation with V2X communications.

IEEE 802.11bd standard is based on the IEEE 802.11ac (i.e. Wi-Fi 5) which makes it more powerful than its predecessor IEEE 802.11p. These previously mentioned objectives could not be satisfied without the existing performant mechanisms that were introduced in the IEEE 802.11n/ac standards, in both, the PHY and MAC layers.

According to the IEEE 802.11bd task group authorization report [12], the IEEE 802.11bd PHY layer offers a 20 MHz bandwidth channel for communication instead of 10 MHz, an MCS profile that can reach 256-QAM, a multiple-input multiple-output antenna, and probable use of the millimetric waves (> 60 GHz), which will help in providing very high throughput. To maintain reliability in an environment of 500 km/hr. velocity and using 256-QAM MCS, IEEE 802.11bd uses the LDPC coding mechanism and midambles. The midambles are similar in form to a preamble [13] and are used in-between the OFDM data symbols to estimate the channel variation, thus reduce the interference effects on the message integrity. Another version of the 802.11bd standard is currently under discussion, namely the IEEE 802.11$bd^{DC}$ is a variant of the IEEE 802.11bd that is based on the IEEE 802.1ax standard, the IEEE 802.11$bd^{DC}$ implements the dual-carrier modulation (DCM) to have an extended communication range. IEEE 802.11bd MAC layer is also based on the EDCA method to access the channel, however, with a 20 MHz bandwidth and a 256-QAM MCS, we can allow the message retransmissions by sending each OFDM symbol over two different sub-carriers, which with the help of LDPC and midambles will promise good reliability of message delivery compared to the IEEE 802.11p standard.

### C. LTE-V2X overview

LTE-V2X Sidelink (a.k.a. PC5 interface) was standardized under the umbrella of 3GPP's release 14 [14] to include support for direct V2X communications. It can offer a much higher communication range and increase reliability by adding a redundant transmission per packet. LTE-V2X over the PC5 interface should offer support for 350km/hr velocity, a higher throughput compared to IEEE 802.11 technologies, and a very low latency suitable for V2X communication [7]. This is made possible with the following PHY and MAC layers proprieties.

The cellular V2X (C-V2X) physical layer is based on Single Carrier Frequency Division Multiplexing Access (SC-FDMA) and supports 10 or 20 MHz channels. Each channel is divided into sub-frames, each sub-frame into sub-channels, and each sub-channel to resource Blocks (RBs). One RB is a group of 12 sub-carriers of 15 kHz (i.e. 180 kHz). Thus, when transmitting a message, the LTE-V2X is more flexible than IEEE 802.11p in terms of used bandwidth. LTE-V2X uses turbo coding to send its data in high modulation profiles, which is much more reliable than BCC that is used in IEEE 802.11p. On the other hand, modulation and coding schemes are selected according to the channel state (i.e. the channel quality indicator (CQI)) which offers a good reliability and performance ratio. LTE-V2X uses the demodulation reference signal (DMRS) symbols to estimate the channel state. In the MAC layer, the reliability of the message delivery can also be improved using a hybrid automatic repeat request (HARQ) retransmission.

LTE-V2X Sidelink offers 2 modes of communications the $\mathrm{LTE-V2X}_{Mode\ 3}$ and the $\mathrm{LTE-V2X}_{Mode\ 4}$, both modes use the LTE-V2X PC5 interface. $\mathrm{LTE-V2X}_{Mode\ 3}$ is the on-coverage mode, where resources are managed and allocated by the base station (i.e. eNodeB). The $\mathrm{LTE-V2X}_{Mode\ 4}$ is the out-of-coverage mode, where resource allocation and management are performed by vehicles in a distributed manner. In our experiments, we use the $\mathrm{LTE-V2X}_{Mode\ 3}$ mode as it is implemented in the SimuLTE framework [9].

## III. IEEE 802.11BD IMPLEMENTATION OUTLINES AND PERFORMANCE EVALUATION

### A. Implementation outlines

To measure the performance of IEEE 802.11bd and to judge on his capacity to reach the expected performance, we implemented its important building blocks over the INET framework, then we used this implementation in the Artery framework to benefit from its enhanced features in our VANET simulation scenarios. The details about this implementation are available in our work [1]. Here are the most important modifications on the INET and Artery frameworks that we did in our implementation:

- Adding a new IEEE 802.11 mode-set representing the IEEE 802.11bd standard
- Adding a new 5.9 GHz band namely the "5.9GHz&20MHz"
- Changing the default behavior of the Artery to support the IEEE 802.11bd mode
- Adding the "5.9GHz&20MHz" band to Artery
- Adding parameters to the services.xml file to support services that transmit on a band with 20 MHz bandwidth
- The implementation does not contain the LDPC coding

Our implementation was validated by a comparison between the theoretical specifications and the obtained simulation outputs. We also measured the performance of our implementation in terms of throughput, latency and PRR compared to the IEEE 802.11p.

### B. Packet error ratio performance evaluation

The Packet Reception Ratio (PRR) is commonly used by the vehicular community to evaluate the maximum range of technology over the distance and to find out how reliable is a technology in terms of packet delivery. Thus, to assess road safety performance, PRR performance evaluation is needed. To get this PRR data, we defined a simple evaluation scenario that is based on the Manhattan urban grid road type, where V2V communication is considered between vehicles with the following characteristics:

- Max vehicle speed: 40 km/h
- Between vehicles Gap: 0.5 m (meter)
- Vehicle acceleration: 0.8 m/s²
- 10 messages per second for CAM message (Cooperative Awareness Message) and alert/warning messages

To have accurate and free interoperability results while evaluating the PRR performance, we launched separated and isolated simulation runs for each technology. We run three separate simulation instances, one with the IEEE 802.11bd 8th MCS profile (256-QAM), one with the 64-QAM IEEE 802.11p MCS (bitrate of 24 Mbps), and the last one with 64-QAM MCS LTE-V2X profile.

We used OMNeT++ as a discrete event simulation environment. To simulate the IEEE 802.11p and IEEE 802.11bd standards, we use the Artery framework, while the LTE-V2X technology is simulated using the SimuLTE framework. The following table summarizes the parameters of our simulation runs:

TABLE I. Main simulation parameter set

| | IEEE 802.11p | IEEE 802.11bd | LTE-V2X |
|---|---|---|---|
| Simulation time | 120s | | |
| Message length | From 200 Bytes to 1400 Bytes. | | |
| Channel bandwidth | 10 MHz | 20 MHz | 20 MHz |
| MCS | Up to 64-QAM with ¾ coding | Up to 256-QAM with ¾ coding | Up to 64-QAM |
| Num. NSS | | 1 | |
| Receiver sensitivity | -85 dBm | -85 dBm | -85 dBm |
| Noise | -110 dBm | -110 dBm | -110 dBm |
| Receiver energy detection | -85 dBm | -85 dBm | -85 dBm |
| Transmit power | 23 dBm | 23 dBm | 15 dBm |

In LTE, the MCS profile is determined according to the channel state which is reported and estimated using the Channel Quality Indicator (CQI). The better is the CQI (between 1 and 15) the higher is the MCS profile. To study the impact of CQI reports on the reliability of message delivery, we run our simulation scenario using $LTE-V2X_{mode\ 3}$ as C-ITS communication technology while varying the distance between vehicles. In Fig. 1, we compare results obtained from different CQI values simulation runs, to show how it impacts the PRR while augmenting the distance between vehicles. We can notice that if the CQI is low (i.e. equal to 1 or 2) we obtain a very weak PRR that will not exceed 20% in all scenarios. In low distances, we can notice that PRR is tightly related to the CQI (i.e. the higher is the CQI, the higher is the PRR). However, if we augment the distance, we see that the CQI became inversely related to the PRR because of the used MCS. Because augmenting the MCS means encoding more bits in one OFDM symbol, thus, the signal becomes more fragile and more sensitive to interferences.

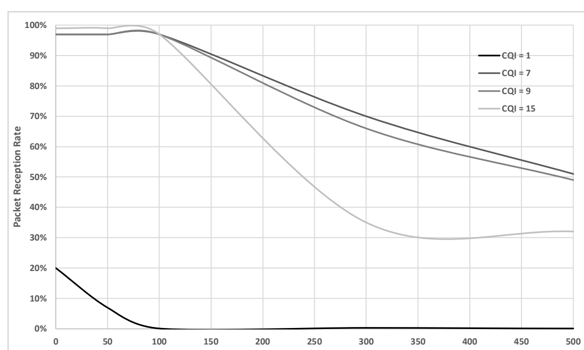


Fig. 1. PRR variations according to the CQI and the distance

In Fig. 2, we compare the PRR between IEEE 802.11p, IEEE 802.11bd, and $LTE-V2X_{mode\ 3}$. At this stage, it is worth noting that our implementation of the 802.11bd standard in OMNeT++ does not include LDPC coding. So, to make a fair comparative study of PRR between IEEE 802.11-related technologies and LTE-V2X, we have integrated with our simulation results from the finding in [15] that affirms that LDPC offers a gain of 1~4 dB gain over the Binary Convolutional Codes (BCC), which is translated into a 20% PRR gain over BCC.

From the plotted results in Fig. 2, we see that $LTE - V2X_{mode\ 3}$ outperforms the Wi-Fi related technologies at higher distances. However, we notice that IEEE 802.11bd is giving better PRR than $LTE - V2X_{mode\ 3}$ in distances between 50 and 100 meters. This is due to the use of LDPC and midambles that help to reduce the impact of interferences on the signal integrity, and because of the CQI estimation that affects the PRR as shown previously. In between the IEEE 802.11-related technologies, we see that the "bd" is outperforming the "p".

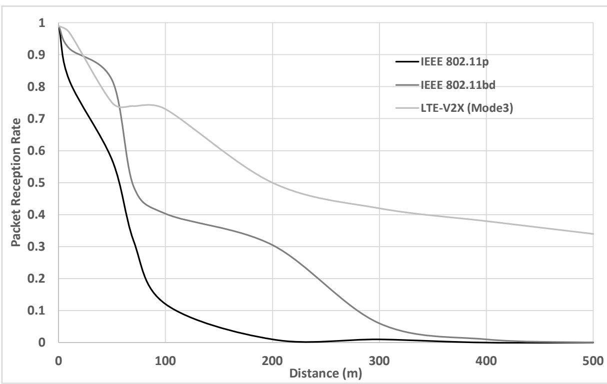


Fig. 2. PRR variations according to the distance (packet of 300 bytes)

Now that we analyzed these technologies in terms of PRR we are going to use these simulation outputs to assess the road safety performances in terms of the number of avoided serious injuries using each of the studied technologies.

## IV. Road Safety Assessment

In this section, we present the methodology used for comparing the relative performance of the three previously presented technologies (i.e. IEEE 802.11p, IEEE 802.11bd, $\mathrm{LTE - V2X}_{Mode\ 3}$) in regard to improving road safety in the EU roads. Towards this end, we will present and adapt an assessment model developed by the 5G Automotive Alliance (5GAA) [10]. We will in this model use the PRR results obtained from the previous section, to evaluate the relative performance of the IEEE 802.11p, IEEE 802.11bd, and $\mathrm{LTE - V2X}_{Mode\ 3}$ technologies with regards to improving road safety in the EU roads.

### A. Model specifications

To focus our study on the improvement of road safety, we will assess the number of avoided serious injuries using the three presented C-ITS technologies. To do so, we will consider the three technologies in isolation, to avoid any interoperability and fairness issues in all methodology parameters and inputs. For the simulation environment, we will consider the same urban road scenario of "Section III, B". And to have a realistic penetration rate of the IEEE 802.11bd technology in vehicles, we will assume that the IEEE 802.11bd standard will be published by the end of 2021 [16]. With that fixed, the number of fatalities and serious injuries that can be avoided can be modeled as followed:

$$N_{Avoid}(t) = N_{Base}(t)\, P_{C-ITS}(t)\, F_{avoided}\, D_{C-ITS}\, E \quad \text{(Eq. 1)}$$

With:

$N_{Avoid}(t)$ as the number of avoided serious injuries in year t.

$N_{Base}(t)$ as the number of serious injuries in year t.

$P_{C-ITS}(t)$ as the High and low penetration rate of the two RATs among vehicles in the EU roads over time.

$D_{C-ITS}$ as the likelihood performance in successfully delivering actionable warning messages between vehicles.

$F_{avoided}$ as the likelihood of fatalities and serious injuries that can be avoided using C-ITS technologies.

E as the effectiveness of a received warning message on a vehicle's driver.

As presented in the 5GAA Study [10], we used a baseline number of serious injuries extrapolated from the Community Road Accident Database (CARE data) released by the European Commission as an input that represents the number of fatalities and serious injuries in the absence of C-ITS technologies. As another input to our model, we will consider the penetration rates of these technologies in vehicles. High and low penetration rates as used in the 5GAA model and a neutral penetration rate scenario where the penetration rates for each technology are equal. High penetration is the representation of an optimal penetration of these technologies in vehicles, and low penetration is simply based on the deployment density of these technologies in new cars as expected by car vendors [17]. To get penetration rates over time for the 802.11bd, we will simply shift up the penetration rate of the IEEE 802.11p [10] by one year because the IEEE 802.11bd RAT is a short-range technology (same type as 802.11p) that will be available in 2021. The probability that an accident can be avoided with C-ITS technology was fixed to 0.82 by excluding accidents caused by drivers that are under the influence of drugs or alcohol [10], The effectiveness of a warning message was fixed to 67% based on the DRIVE C2X Study [18].

All these parameters are extracted from the EU statistical [2] study and assumptions, except the alert delivery reliability i.e., Packet Reception Ratio (PRR) that was extracted from the obtained simulation outputs in the Packet error ratio performance evaluation sub-section. Each run was defined by a specific bitrate (i.e. specific MCS) and a fixed distance that does not go beyond the limits of the urban grid simulation scenario.

### B. Improving Road Safety

Now that our model is defined and that the PRR of the different technologies is obtained from our simulation study, we have deduced an average alert delivery reliability of 75% for the IEEE 802.11p, 88% for the IEEE 802.11bd, and 90% for $\mathrm{LTE - V2X}_{Mode\ 3}$. In this sub-section, we analyze the ability of C-ITS to reduce the number of fatalities and serious injuries caused by road accidents in the EU. Towards this end, we calculate the number of avoided serious injuries caused by road accidents according to the previously presented mathematical modeling above.

We considered two experiments to study road safety. Like the 5GAA study, we considered high and low penetration rates to see how these latter are impacting the number of avoided serious injuries by each technology. These penetration rates are the result of a squared probability, i.e., the product of the likelihood penetration of the relevant technology in both vehicles involved in the accident. On the other hand, we aim to show how each technology behaves regarding road safety with neutral and similar penetration rates.

We notice in Fig. 3 and Fig. 4, that in both 5GAA scenarios (i.e. low and high penetration rates), LTE-V2X is performing better than the IEEE 802.11-related technologies. This is due to its superior radio link level for ad hoc/direct communications, its ability to better cope in dense urban settings with many competing vehicles, and its higher projected penetration in vehicles as it is based on an already deployed cellular network. We can see that the "bd" will allow us to avoid 17,533 more serious injuries by 2040 in high penetration rates which is too close to the number of avoided serious injuries by LTE-V2X. Nevertheless, according to the way each plot is growing over time, we can deduce that the IEEE 802.11bd will catch up with LTE-V2X's performances, thus outperforming the "p" by far. We also notice that the effectiveness of the three technologies remains low in the first years of deployment due to a small penetration rate in vehicles.

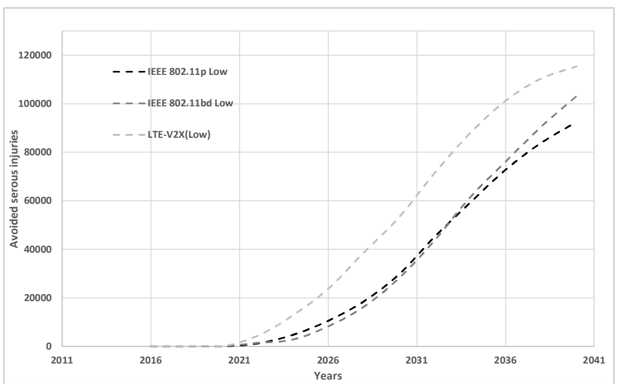


Fig. 3. Number of Avoided serious injuries in low penetration rates

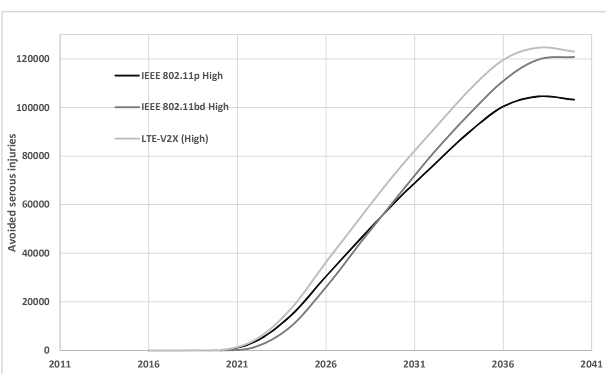


Fig. 4. Number of Avoided serious injuries in high penetration rates

By analyzing the neutral experiment results plotted in Fig. 5, we can see that, if all technologies were deployed concurrently by car vendors, we will expect that IEEE 802.11bd and LTE-V2X will help to avoid approximately the same number of road accidents. For example, in 2030, IEEE 802.11bd will allow avoiding 10496 extra serious injuries compared to 802.11p, and the $\mathrm{LTE}-\mathrm{V2X}_{Mode\ 3}$ will help avoiding 11867 extra serious injuries compared to 802.11p. This is because both technologies offer very high throughput and powerful coding mechanisms, thus comparable reliability. However, we notice that even in this optimistic case the IEEE 802.11p performance remains low.

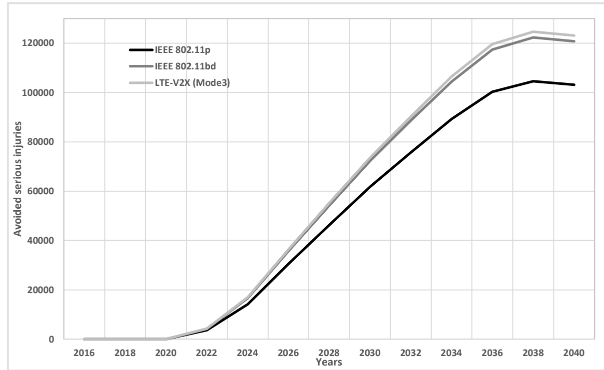


Fig. 5. Number of Avoided serious injuries in neutral penetration rates

## V. CONCLUSIONS

In this paper, we investigated the assessment of the IEEE 802.11p, IEEE 802.11bd, and LTE-V2X in the context of road safety. We first analyzed the performances of the IEEE 802.11 technologies and the LTE-V2X. Then, we used our basic IEEE 802.11bd implementation in OMNeT++/Artery to compare its performance with the 802.11p and $\mathrm{LTE}-\mathrm{V2X}_{Mode\ 3}$ in terms of PRR. We found that $\mathrm{LTE}-\mathrm{V2X}_{Mode\ 3}$ offers better alert delivery reliability than IEEE 802.11-related technologies in most cases. These results help us to evaluate the improvement of the IEEE 802.11bd over the IEEE 802.11p in the context of reliable delivery of alert/warning messages to avoid accidents on an urban road. In this assessment, estimated and neutral penetration rates were considered to show the effect of deployment constraints in preventing accidents. In a high aggressive deployment scenario, we could have a 16,98% (resp. 19.20%) road safety improvement with IEEE 802.11bd (resp. $\mathrm{LTE}-\mathrm{V2X}_{Mode\ 3}$) over IEEE 802.11p. On the other hand, in similar penetration rates, we observed that LTE-V2X and IEEE 802.11bd are both, concurrently, avoiding more serious injuries than IEEE 802.11p. For future work, we envision to continue this work to compare our results with other C-ITS technologies such as 5G NR-V2X to complete the overall picture. We are aiming to compare these technologies in a real-world scenario too, with deployed OBUs and RSUs equipment.

## VI. REFERENCES

[1]. Badreddine Yacine Yacheur et al. "Analysis and Comparison of IEEE 802.11p and IEEE 802.11bd". Nets4Worshop: 15th International Workshop on Communication Technologies for Vehicles. Bordeaux, France. 2020.

[2]. European Commission, "Road Safety: Encouraging results in 2016 call for continued efforts to save lives on EU roads," *Press release,* 2017.

[3]. IEEE P802.11-TASK GROUP BD (NGV) Group. http://www.ieee802.org/11/Reports/tgbd_update.htm. Accessed 30 May 2019

[4]. Inzillo V., De Rango F., Ariza Quintana A.: "Supporting 5GWireless Networks Through IEEE802.11ac StandardWith New Massive MIMO Antenna System Module Design in Omnet++," in *Proceedings of 8th International Conference on Simulation and Modeling Methodologies, Technologies, and Applications - Volume 1: SIMULTECH*, Porto, Portugal, 2018.

[5]. Anwar, W., Franchi N., Fettweis G: "Physical Layer Evaluation of V2X Communications Technologies: " *Vodafone Chair Mobile Communications Systems,* 2019.

[6]. D. Flore: Initial Cellular V2X standard completed. September, 3GPP RAN Chairman, 2016 Available online: http://www.3gpp.org/news-events/3gppnews/1798-v2x_r14.

[7]. Naik G, Choudhury B., Park J.-M: "IEEE 802.11bd & 5G NR V2X: Evolution of Radio Access Technologies for V2X Communications," *The Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, VA 24060, USA,* vol. vol 7, pp. 70169-70184, June 10, 2019.

[8]. Riebl, R., Günther, H.J., Facchi, C., Wolf, L.: "Artery Extending Veins for VANET applications," in *2015 Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, Budapest, Hungary, June 2015.

[9]. Antonio Virdis, Giovanni Stea, and Giovanni Nardini. "SimuLTE-A modular system-level simulator for LTE/LTE-Anet works based on OMNeT++". In: 2014 4th International Conference on Simulation and Modeling Methodologies, Technologies, and Applications (SIMULTECH). IEEE. 2014, pp. 59–70.

[10]. 5GAA, "An assessment of LTE-V2X (PC5) and 802.11p direct communications technologies for improved road safety in the EU," 5GAA Automotive Association, 5 December 2017.

[11]. Hassan M.I., Vu H.L., Sakurai T: "Performance analysis of the IEEE 802.11 MAC protocol for DSRC safety applications," *IEEE Trans. Veh. Technol,* vol. vol 60, pp. 3882-3896, OCT 2011.

[12]. Sun, H.B., Zhang, H.: "802.11 NGV proposed PAR," IEEE 802.11-18/086lr8, 09/2018.

[13]. R. Cao: "Potential PHY Designs for NGV," IEEE 802.11-19/0016r0, 01 2019.

[14]. 3GPP, "TS 36.300 Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (v14.3.0, Release 14)," Tech. Rep, Jun 2017.

[15]. Sharama P., Cao R., Zhang H: "LDPC Investigation for 11bd," Marvell, 2019-03-14.

[16]. Moerman, K.:Next generation vehicular networks IEEE 80211bd. NXP, 6 March 2019 (2019).

[17]. Visiongain, "Automotive Vehicle to Everything (V2X) Communications Market 2016-2026," 2016.

[18]. TNO, "Drive C2X - Impact Assessment and User Perception of Cooperative Systems.," 2014.