IEEE 802.11p Performance Evaluation: Simulations vs. Real Experiments

Thales T. Almeida[1,2], Lucas de C. Gomes[2], Fernando M. Ortiz[2], José G. R. Júnior[1] and Luís H. M. K. Costa[2]

Abstract— **The employment of IEEE 802.11p-compliant devices in the automotive environment is crucial to traffic safety and control applications. Thus, performance evaluation of the standard before its widespread adoption in real systems is of paramount importance. Nonetheless, due to the high cost and reasonably low availability of off-the-shelf devices, most of the work involving IEEE 802.11p vehicular networks is still based on simulations. In order to investigate the distance to real-world equipment, this work investigates the results of experimentation with commercial devices, in V2I (Vehicle-to-Infrastructure) and V2V (Vehicle-to-Vehicle) scenarios. The performance obtained by real on-board and road-side units is then compared to those presented by widely used NS-3 simulator. Three key metrics are evaluated: the maximum range, packet delivery rate (PDR), and packet inter-reception time (PIR). The influence of different modulations defined in IEEE 802.11p and of different mobility levels are analyzed. For both simulation and experimentation, the results agree on the PDR degradation at intense vehicle speeds and higher PHY data rates. Nevertheless, the results in terms of maximum range, moderate speed impact, and the weak correlation between the PIR and PDR show that NS-3 simulation models still need to evolve.**

I. INTRODUCTION

Research on vehicular networks and Intelligent Transportation Systems (ITS) is motivated by the problems related to the unbridled growth of the number of vehicles. In the United States, a 2015 report already indicated that congestion was the main cause of an annual loss of US$160 billion, including in 3.1 billion gallons of fuel wasted and 6.9 billion hours of lost productivity [1]. The information exchanged by OBUs (on-board units) carried by vehicles and fixed-infrastructure RSUs (road-side units) allows the execution of preventive actions, such as identifying jammed areas and broadcasting safety alerts. IEEE 802.11p is the main candidate standard for this communication. Even if cellular networks fit some vehicular applications, they can hardly meet the requirements of delay-constrained ones such as emergency-brake alerts.

Practical solutions have been proposed with the aim of increasing traffic safety and mitigating traffic jams [2], [3]. Nevertheless, before employing these technologies, it is necessary to assess their capability of data transmission in the established architecture. Although there is continuing development of implemented solutions in real devices, issues such as the cost and the limited variety of commercial devices contribute to the fact that most studies only consider simulations. A small number of works evaluate the performance of the IEEE 802.11p standard in real scenarios. Furthermore, there is the issue of how simulators perform in mimetizing the real world.

To verify the equivalence real experiments and simulation, this paper evaluates the performance of a safety application on the IEEE 802.11p standard in both environments. Based on the exchange of Basic Safety Messages (BSMs), defined in the SAE J2735 standard, the network measurements in V2I and V2V scenarios are investigated using commercial OBUs and RSUs. The results are compared with the same scenario in the NS-3 network simulator. We evaluate the maximum communication range obtained, the amount of packet losses by measuring the packet delivery rate (PDR), and we estimate the delay by measuring the packet inter-reception time (PIR). Moreover, the modulations defined in the standard and the mobility pattern are varied to assess their impact on the performance.

The obtained results show that the maximum theoretical range of IEEE 802.11p is not supported for any of the chosen modulations. With the modulation associated with the 6 Mbps PHY rate the range is 700 meters, in both environments. For the other PHY rates, the PDR indicates that the real experiments range is greater than the one indicated by the simulations. According to the different modulations, the results indicate that the higher the PHY data rate, worse the PDR. More intense in the simulations, this PDR degradation is also strongly impacted by the increase in vehicle speed. Nevertheless, this does not occur in real experiments, whose PDR was only impacted in the scenario that considers high relative speeds (up to 160 km/h). These and other divergences, like the weak correlation between the PIR and the PDR, indicate the need to revisit the VANET simulation models for in NS-3. To the best of our knowledge, there are no studies in the literature that compare the results of NS-3 simulations with practical experiments with commercial off-the-shelf IEEE 802.11p devices.

The rest of the paper is organized as follows. Section II reviews related work. Section III presents the experimental scenario, configuration of the experiments and relevant details of the NS-3 implementation. Section IV analyses both experimental and simulation results. Section V concludes the paper and presents future work.

II. RELATED WORK

Some previous works characterize the performance of ITS and IEEE 802.11p. ElBatt *et al.* [4] analyze the performance

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[1] Federal Centre of Technological Education of Minas Gerais – CEFET-MG. Leopoldina, Minas Gerais, Brazil `thales,jgrjunior@cefetmg.br`

[2] Federal University of Rio de Janeiro – UFRJ. PEE/COPPE/GTA, Rio de Janeiro, Rio de Janeiro, Brazil `thales,gomes,fmolano,luish@gta.ufrj.br`

of a frontal collision prevention system. They develop a simulation scenario using a realistic mobility model. Every vehicle has a high precision GPS and a DSRC (Dedicated Short Range Communications) radio. Packets transmitted have a fixed size of 100 B. Two scenarios are evaluated: (1) high vehicle density and low speed; (2) low vehicle density and high speed. The packet inter-reception time (PIR) and the packet delivery rate (PDR) are evaluated. The results show that, in the high density scenario, the PIR is higher due to the higher occurrence of losses, suggesting a tradeoff between PDR and PIR. In the low-density high-speed scenario, the number of packets delivered is higher, with a lower PIR. Those results demonstrate that in the simulated scenarios the network load is more important than the speed of vehicles, which may not always be the case.

Jaffari *et al.* [5] investigate the impact of the speed (from 80 km/h to 130 km/h) and of the packet size (from 250 B to 1.000 B) on the network performance, also using a realistic mobility model and the NS-2 simulator. The packet transfer rate, end-to-end delay and packet loss rate (PLR) are measured. The results show that any vehicle receives data when they are within 138 m from the source. Furthermore, in this range, the different speeds did not affect the results. A relation between the packet size, end-to-end delay and throughput was identified. Other studies investigate the performance of IEEE 802.11p through simulations [6], [7], [8]. As mentioned in Section I, the cost, the limited variety of devices and the complexity of real measurements are an obstacle to evaluating the performance of IEEE 802.11p standard in field experiments. Nonetheless, synthetic simulation results may not reflect all real-world situations.

Teixeira *et al.* [9] describe an experimental analysis of IEEE 802.11p. They employ speeds between 20 km/h and 60 km/h and vary the packet size from 15 to 1,460 B. The maximum communication range, data transfer rate, latency, jitter, PLR, and association time are measured. Two scenarios are used: (1) inside the lab, two IEEE 802.11p-compliant laptops communicate with each other and measure the association time; (2) in the open field, two laptops in different vehicles are used to evaluate the other metrics. The best results in terms of average bitrate are obtained with 500 B packets, while the largest variation occurred for 1,460 B packets. Although the instability increases for moving nodes, the devices were able to transfer data over distances greater than 300 m, with rates over 8 Mbps.

Renda *et al.* [10] empirically evaluate the PIR with vehicles exchanging situational information messages (beacons). The aim is to assess the probability of situational awareness "blackouts" in the vehicular network. In the experiments, the authors have used devices compatible with IEEE 802.11p. Data from two and three vehicles was collected, in different trajectories and heights. In addition to PDR and PIR, the number of blackouts and frequency at which they occur were also measured. The authors concluded that the PIR can be directly affected by situational awareness blackouts and that those are relatively frequent. In addition, they conclude that the PIR can not be reliably estimated from the PDR, since no strong correlation was found between the two metrics.

Other real measurements have also been performed with the goal of evaluating the performance of the IEEE 802.11p standard. In a V2V scenario, [11] define a sorting method of LoS (Line-of-Sight) conditions. Two vehicles equipped with IEEE 802.11p devices exchange data using the 6 Mbps PHY rate. RSSI (Received Signal Strength Indicator), PDR, and latency are evaluated. Barcelos *et al.* [12] propose a low cost device based on IEEE 802.11p for traffic monitoring. In order to demonstrate their efficiency based on the results of PLR, latency and packet transfer rate, vehicles containing the devices performed transmissions at 6 Mbps rate and traveled between 20 km/h and 60 km/h. Lastly, [13] conducted experiments with V2I and V2V scenarios. Using commercial OBUs and RSUs that communicated at 6 Mbps rate, the authors evaluated latency, jitter, and PLR. It should be noted that due to the inherent complexity of the execution of experiments involving vehicular networks in a real environment, the majority of the works in the literature are limited in terms of the variation of parameters of the IEEE 802.11p standard and scenarios, e.g. the used modulation and vehicle speed.

Although all above related work evaluate the performance of the IEEE 802.11p through simulation or real experiments, none has tried to match the results of simulation and experimentation. Differently from those, Sassi *et al.* [14] simulate the IEEE 802.11p PHY layer using Matlab, and perform real measurements using communication devices from Arada Systems. They analyze V2I and V2V communications. In the V2I scenario, one of the vehicles acted as an RSU, while the other moves towards the first at different speeds. In the V2V scenario, both vehicles move and cross each other. The impact of vehicle speed and different IEEE 802.11p modulations was evaluated in terms of maximum range and PLR. The results show that, in both environments, modulations associated with lower data rates perform better on long range communications. They also show the impact of the vehicle speed in the quality of communication.

Similar to [14], we compare simulation and real experimentation of IEEE 802.11p. Differently from most of the experimental evaluations, high mobility scenarios are configured, with relative speeds of up to 160 km/h, and the influence of different modulations is investigated. Moreover, our simulation results consider NS-3, one of the most popular simulators in the networking community. To the best of our knowledge, it is the first work of the type to target this simulator. Finally, besides the communication range and PDR, the metrics evaluated in [14]), the packet inter-reception time (PIR) is also measured with the same goal as in [10], i.e. to tell if the metric correlates with the PDR.

III. IEEE 802.11P EXPERIMENTATION SETUP

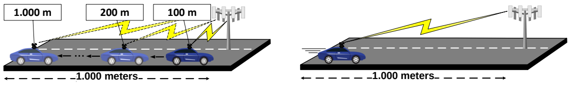
The experiments consist of simulations executed on the NS-3 network simulator and real measurements using *Cohda Wireless* OBUs and RSUs. We define three scenarios for both simulation and practical experiments.

Scenario 1: Maximum range – this scenario is intended to verify the maximum communication range of

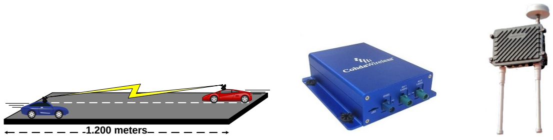
IEEE 802.11p devices. An OBU inside a stationary vehicle transmits to an RSU placed on the edge of the road (Figure 1(a)). The road is divided in 10 segments of 100 m and the transmissions are performed by the OBU targeting the RSU. Initiating transmissions at 100 m from the RSU, after a given number of BSMs are sent, the vehicle is repositioned in steps of 100 m until it reaches 1,000 m of distance from the RSU, the expected maximum range of IEEE 802.11p.

Scenario 2: Moderate mobility – the goal is to compare simulated and experimental performance of IEEE 802.11p with moderate vehicle speeds, using V2I communications. A vehicle traveling at 20 km/h, 50 km/h and 80 km/h communicates with a fixed RSU (Figure 1(b)). The vehicle starts 1 km away from the RSU and continuously transmits BSMs to it. The transmissions performed during the entire route between the vehicle and the RSU are accounted for.

Scenario 3: Intense mobility – the objective here is to verify the effect of higher speeds on IEEE 802.11p. Two vehicles moving in opposite directions toward each other communicate using V2V (Figure 1(c)). The two vehicles start from opposite ends of the road at the same time and with same speed, producing relative speeds up to 160 km/h. As in Scenario 2, the transmission of BSMs is continuous.



(a) Maximum range.
(b) Moderate mobility.



(c) Intense mobility.
(d) IEEE 802.11p devices.

Fig. 1. Experimental scenarios and used devices.

IEEE 802.11p defines eight modulations: BPSK ½, BPSK ¾, QPSK ½, QPSK ¾, 16 QAM ½, 16 QAM ¾, 64 QAM ⅔ and 64 QAM ¾, associated, respectively, to 3, 4.5, 6, 9, 12, 18, 24 and 27 Mbps rates. We test only the 6, 12, 18 and 24 Mbps PHY rates. There are two reasons for this choice: the large number of permutations (in the experiments, the vehicles traveled approximately 480 km); and the expectation that, between nearby PHY rates, the results are close. Table I summarizes the evaluated scenarios.

TABLE I
EXPERIMENTAL SCENARIOS.

Scenario	Investigation	Tx	Rx	Speed (km/h)	PHY Rate (Mbps)
1 (V2I)	Maximum range	OBU	RSU	Stationary (0)	6/12/18/24
2 (V2I)	Moderate mobility	OBU	RSU	20/50/80	6/12/18/24
3 (V2V)	Intense mobility	OBU	OBU	40/100/160	6/12/18/24

A. NS-3 Configuration

Since the most recent versions of NS-3 (up to NS-3.27) have no model that considers the Doppler effect, it was necessary to use the module *PhySimWiFi* [15], a derivation of NS-3 based in the IEEE-802.11 standard. Incorporating sophisticated channel models, this module considers multipath effects in a more precise way compared to the standard implementation of NS-3, in addition to the Doppler effect. In this work, BSMs are transmitted every 100 ms in the CCH (Control Channel). The channel bandwidth is 10 MHz and the frequency range DSRC's 5.9 GHz.

The OBU and RSU specifications define an EIRP (Effective Isotropic Radiated Power) of 23 dBm, with an antenna gain of 6 dBi (if the receiver is a RSU) or 5 dBi (for an OBU). The threshold of received signal energy was set to - 99 dBm. As mentioned before, we use four modulation schemes: QPSK ½, 16 QAM ½, 16 QAM ¾, and 64 QAM ⅔ (for 6, 12, 18, and 24 Mbps PHY rates, respectively).

To simulate the signal attenuation, which is proportional to the distance between transmitter and receiver, the *LogDistance* propagation loss model was set. The attenuation exponent was defined based on the maximum range results for the 6 Mbps rate. Integrated to the *LogDistance*, the *RicianPropagationLoss* model, responsible for applying the fast-fading Doppler effects, was also set.

To generate realistic vehicle mobility, the IDM (Intelligent Driver Model) [16] was used. The characteristics of the simulated road were based on the physical characteristics of the real scenario. The duration of each simulation run was 2,000 seconds and transmitted packets, 1,500 B long.

B. Practical Experiments Configuration

The real measurements were performed using OBUs and RSUs model MK5 from Cohda Wireless (Figure 1(d)). The devices have IEEE 802.11p-compliant radios, 24 dBm transmit power, GPS with 2.5 m precision, and antennas with sensitivity of -100 dBm, and run an embarked Linux OS.

The BSMs include the geographic coordinates of the node (obtained through GPS every 200 ms), its current speed, a timestamp, and other vehicle information. BSMs are sent every 50 ms over CCH 178. Again, BSMs are 1,500 B long.

For metrics gathering, the transmitter node stores the timestamp and geographic coordinates of BSMs it sends. The receiver node stores the position update and BSM reception events, the time of their occurrence and received content. Outliers are removed from the PDR and PIR measurements: values whose differences from the mean were greater than two standard deviations.

The field measurements were made in a deactivated airport located at Leopoldina - MG, Brazil. With a 1.2 km runway, the location was ideal because it does not suffer with interferences from other networks and, given it is an open area, there are LoS conditions. Figure 2(a) shows the aerial view of the site, while Figures 2(b) to 2(f) show the devices and photos from experiments in the three evaluation scenarios.

IV. RESULTS

This section presents the simulation and real measurement results. For each configuration, 10 rounds are performed.

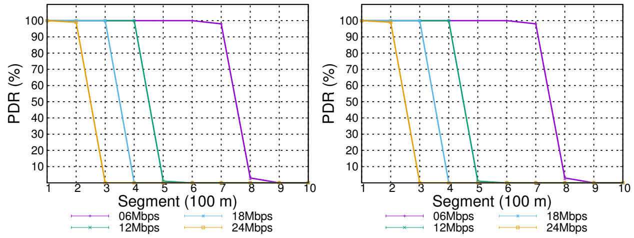
(a) Aerial view. (b) Fixed RSU. (c) OBU in the vehicle.

(d) Maximum range. (e) V2I scenario. (f) V2V scenario.

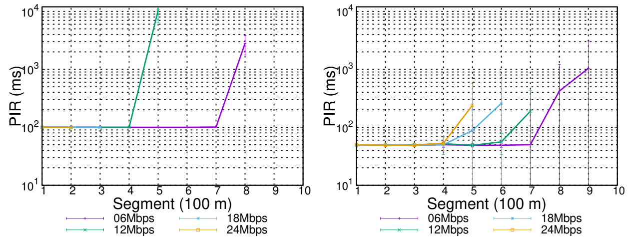
Fig. 2. Practical experiments scenario.

A. Measuring the Maximum Communication Range

This set of experiments investigates the maximum range supported by IEEE 802.11p devices. Figures 3(a) and 3(b) present the PDR in each 100 m segment in the simulations and real measurements, while Figures 3(c) and 3(d) show the PIR obtained under the same conditions.



(a) PDR (simulation). (b) PDR (practical experiments).



(c) PIR (simulation). (d) PIR (practical experiments).

Fig. 3. PDR and PIR obtained in the Scenario 1.

We note that the theoretical maximum range of 1,000 m was not achieved for any of the chosen modulations. The maximum range of approximately 800 m was reached with the 6 Mbps PHY rate, in both environments. Even so, the PDR at this distance was extremely low: 3.9% in simulation and 2.2% in real measurements, unacceptable for safety applications. Nonetheless, at 700 m the PDR is notably better, above 90% in both environments. This behavior of the PDR with the distance between transmitter and receiver is similar to the real measurements of [14]. In that work, at 1,000 m, the PDR was approximately 25% for the 6 Mbps PHY rate, but increased to about 94% at 700 m.

The PDR obtained with the highest PHY rate (24 Mbps) shows that this modulation can only be used when transmitter and receiver are close, as expected. Nevertheless, the behavior is more perceptible in simulation. Starting at 200 m, the PDR goes from 99.9% to approximately 0.2%, while in real experiments the PDR goes from 88.9% to 11.1% starting at 400 m. Again, the practical results obtained in [14] present similar behavior. In that work, for the 24 Mbps PHY rate, the PDR drops from 75% at 200 m to 25% at 400 m, approximately. In this work, this behavior can also be seen in both environments for 18 Mbps and 12 Mbps rates, being, however, more pronounced in the simulations. Also note that, despite that both graphics present the same behavior, only the results related to the modulation associated to the 6 Mbps rate (referral value) are equal in value. For the other modulations, the obtained PDR indicate that the communication range is larger in real-life than in NS-3 simulations.

Nevertheless, relating to the PIR obtained in simulation, analyzing the 6 and 12 Mbps PHY rates for segments 8 and 5, the values obtained disrupt when compared to values for other segments. On the other hand, comparing Figures 3(c) and 3(a), we note that these results are in accord to the PDR obtained in the same segments for the same modulations. The explanation is that, for lower PHY-rate modulations, communication distances are longer. At the same time, the greater the communication range, the worse the transmission quality, impacting the PDR and, consequently, the PIR. This behavior can also be noted in the practical experiments. Nevertheless, differently from simulations, in this environment the PIR is affected in all scenarios (despite of modulation), indicating a stronger relation between PDR degradation and PIR increase, as seen in [4].

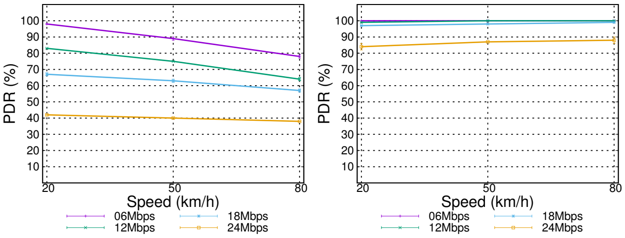
As expected, the results in this first set of experiments show a notable PDR degradation in both simulation and practical environments, as the distance between OBU and RSU increases. The combination of long distance and high PHY rate may imply low PDR and produce situational awareness blackouts, as mentioned in [4].

Finally, to check if the theoretical maximum range of the IEEE 802.11p standard could be achieved, we have also tried with the lowest possible PHY rate, of of 3 Mbps. Three rounds for each 100 m segment were executed. As in [14], it was possible to have communication in distances above 1,000 m. Nevertheless, the PDR was 46% at 1,100 m and only 3% at a 1,200 m, unaffordable for any kind of application.

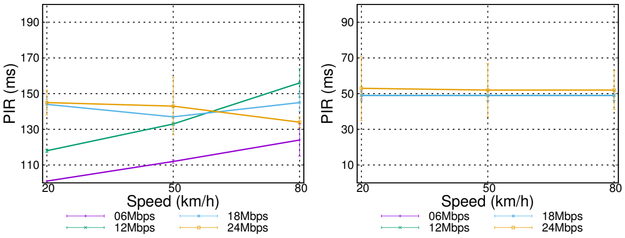
B. Moderate Mobility Scenario

Differently from the previous experiments, in this set of experiments, PDR and PIR metrics are computed for the whole duration of each run. We ignore transmissions made by the OBU when not in range of the RSU. We define the range of the RSU as the maximum communication range obtained by the lowest PHY rate considered in our experiments (6 Mbps). Therefore, both in simulation and practical experiments, the PDR and PIR calculations in the V2I scenario are considered only if the transmission occurs within 700 m or less.

Figures 4(a) and 4(b) present the effect on the PDR of V2I communications and moderate vehicle speeds. The same as



(a) PDR (simulation). (b) PDR (practical experiments).



(c) PIR (simulation). (d) PIR (practical experiments).

Fig. 4. PDR and PIR obtained in the Scenario 2.

in [14], it is possible to perceive the negative effect provoked by the increase in data rate on the PDR in both environments, despite it being more intense in simulation. Also in simulation, we note that for any modulation, increasing speed of the vehicle is accompanied by the degradation in the evaluated metrics. This result can be attributed to the impact of the Doppler effect. Such degradation is more subtle in the 24 Mbps PHY rate results and more severe in the lower PHY rates. In the real experiments, unlike what happens in [14], surprisingly this degradation is not observed: the results in this environment show that the PDR is not affected by the vehicle speed. As expected (based in previous scenarios results) the PDR results obtained in this environment are substantially better than those acquired through simulation. Therefore, there is no consistency among the results of the simulations and real experiments when the moderate mobility effect on the V2I communication PDR is considered.

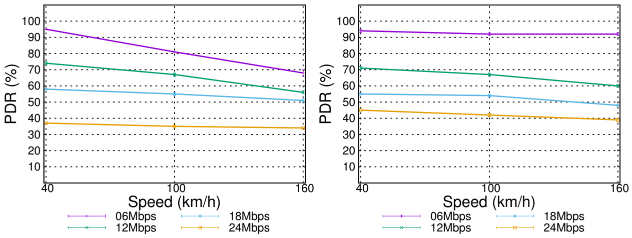
Figures 4(c) and 4(d) plot the PIR. In simulation, we observe that, for the modulations associated with 6 Mbps and 12 Mbps rates, the PIR is directly impacted by the Doppler effect, correlating to the PDR. Nevertheless, this behavior is not observed for 18 Mbps and 24 Mbps, since those PHY rates are not impacted by the speed increase (even if the PDR follows this pattern). The explanation is that, increasing the speed to 50 km/h, few packets arrive at the receiver (as Figure 4(a) has shown). These packets are, however, received in bursts, almost continuously, due to the faster approximation between the nodes caused by the speed increase. Such a scenario implies a PIR almost proportional to the packet transmission rate, even if the PDR is low. The same hypothesis was made in [10].

As for the practical experiments, we observe that the PIR is not influenced by the different data rates, or by the increase in the vehicle speed, as the PIR values obtained in each modulation and speed are in a very close interval, of approximately 50 ms. Despite that, the results obtained in the practical experiments are more coherent than their simulated counterparts. In this environment, the results point to a slight tradeoff between PIR and PDR in V2I communication, given that, as the PDR increases, the PIR slightly reduces. This behavior is not dependent on the modulation, even if it is more clearly perceived at 24 Mbps.

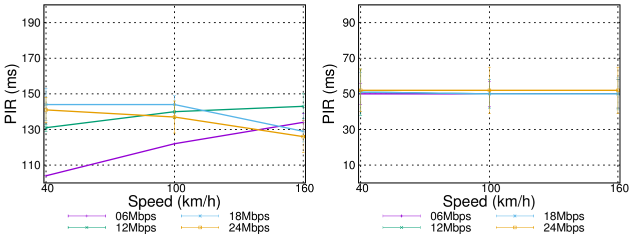
Comparing the environments, it was not possible to obtain a total equivalence in term of the PIR results. In the simulations, only the modulations associated with 6 Mbps and 12 Mbps PHY rates show results matching the expected. The results also show that, as identified in [10], it may not be possible to estimate the PIR values directly from the PDR results. Beyond that, the absence of a packet delivery pattern of the transmitted packets under the effect of the propagation loss models in the NS-3 suggests the need to review the referred models.

C. Intense Mobility Scenario

In the last set of experiments, two vehicles traveling in opposing directions vary their speeds from 20 km/h to 80 km/h, producing relative speeds between 40 km/h and 160 km/h. Again, the PDR and PIR are calculated as overall averages.



(a) PDR (simulation). (b) PDR (practical experiments).



(c) PIR (simulation). (d) PDR (practical experiments).

Fig. 5. PDR and PIR obtained in the Scenario 3.

The PDR results simulation and practical experiments are presented in Figures 5(a) and 5(b). Compared to the previous scenario, the higher relative speeds definitely lead to worse PDR for both environments, regardless of the modulation. In the simulations, in some cases this difference goes up to 10% (e.g. for 6 Mbps PHY rate and 160 km/h), whereas in the practical experiments the difference reaches up to 51% (18 Mbps PHY rate and 160 km/h). Despite some differences, such as the PDR degradation being more intense at the 6 Mbps rate in simulations while in practical experiments the opposite occurs, we observe that the curves shown in the graphics of both simulation and real environments are similar in terms of their behavior. This time, these results agree with those obtained in [14], even though, in the present work, the curves representing the highest rates (12 Mbps, 18 Mbps and 24 Mbps) are not as close. In the case of transmissions at 24 Mbps and the vehicle traveling at 40 km/h and 160 km/h, a PDR of approximately 92% and 75% was achieved, respectively. In the present work, for the same rate the PDR was about 45% and 39%, respectively.

Figures 5(c) and 5(d) present the PIR obtained in the simulations and practical experiments. As Figure 4(c) has shown, in the simulations, the PIR was directly influenced by the mobility for the 6 Mbps and 12 Mbps PHY rates. Again, for these rates, the greater the vehicle speed, the greater the packet inter-reception time. Nonetheless, based on the same explanation described in the previous scenario, at 18 Mbps and 24 Mbps PHY rates, the PIR is not impacted by the speed increase. As for practical experiments, as shown Figure 4(d), it can be considered that the PIR is not influenced by the data rate increase, nor by the increase in vehicle speed. Nevertheless, in this scenario, it is not possible to perceive a tradeoff between PIR and PDR in communication. As in the V2I scenario, there is no equivalence among PIR results obtained through simulation and practical experiments considering V2V communication.

V. CONCLUSION AND FUTURE WORK

This work has compared the results from the evaluation of IEEE 802.11p through simulation made in NS-3 and real device measurements. The impact of different modulations and speeds was analyzed in V2I and V2V communication scenarios, considering the packet delivery rate and packet inter-reception time. Moreover, static experiments evaluated the maximum range obtained in both simulation and real life.

As expected, the results in both scenarios show that only the modulation associated with the 6 Mbps PHY rate offers a satisfactory range of 700 m. As for the other modulations, the range was greater in the real world. The impact of increasing distances and of PHY data rates in the PDR is clear. As for the moderate mobility effect on communication, there is no equivalence between the results obtained in simulation and practical experiments. While the increase in speed in the simulations causes a degradation in PDR, the same was not observed in the real measurements. On the other hand, intense mobility affects communication in both environments.

With respect to the PIR, the values obtained in the maximum range evaluation indicated a tradeoff with the PDR (more evident in practical experiments). As for the moderate mobility scenario, the equivalence was incomplete. In simulation, only the 6 Mbps and 12 Mbps PHY rates present consistent results, with the PIR being influenced by mobility. As for the real measurements, we observe that the PIR was not influenced by different rates or speeds. These results are also obtained in both simulation and real experiments in the intense mobility scenario, again showing the difficulty to estimate the PIR based on the PDR.

The differences found in the results from both environments indicate the need to enhance the models used in NS-3 simulations of vehicular networks. As future work, we intend to investigate the impact of a denser vehicular network, beyond LoS and NLoS (Non-Line-of-Sight) conditions. We also want to compare these results with those of the Veins (Vehicles in Network Simulation) simulator.

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