Received January 20, 2021, accepted January 28, 2021, date of publication February 8, 2021, date of current version February 17, 2021.
Digital Object Identifier 10.1109/ACCESS.2021.3057602

An Experimental Study on the Use of LoRa Technology in Vehicle Communication

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This work was supported in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior–Brasil (CAPES) under Finance Code 001.

ABSTRACT Among the profound changes that will come with the Internet of Things is vehicular communication. Shortly the vehicles will be connected between themselves (V2V) and their infrastructure. For the full achievement of these objectives, the challenges of new technologies are enormous due to the requirement of high reliability, high speed, and low latency. None of the technologies under development for this application has reached a satisfactory stage be assumed to as definitive. The LoRa technology, operating at frequencies below 1 GHz, presents a good signal spread and penetration in obstacles. It has a considerable range, open-source, simple, robust, and low-cost hardware, vast configuration possibilities, and applications, ranging from medicine to agriculture, do not use licensed bands. The tests proved to have good reach even in a dense urban environment. They can become a viable alternative in applications that require short message transmissions with few characters that do not require the constant sending of information packages. The purpose of this work is to evaluate the communication between V2I, V2V, and stationary vehicles using LoRa technology in field tests with measurements of signal strength, reception ratio, and signal-to-noise ratio. It will be using different SF (scattering factors) inherent to LoRa (SF7 and SF12) and evaluate the influence of the Doppler effect on communication.

INDEX TERMS Genetic algorithms, LoRa, vehicular communication, V2I, V2V.

I. INTRODUCTION

Vehicle communication is a fact, a path of no return. Vehicles, soon, will be more efficient and more connected to each other, constituting the so-called vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) communication [1], [2]. At the current stage, with the technologies available, the challenges are immense. Information exchange will require too high speeds, reliability, and extremely low latency time for networks in specific applications. Some technologies are already in satisfactory development stages, but none has yet to become the definitive solution. For several applications, DSRC (Dedicated Short Range Communications) operating at the 5.9 GHz emerges as a possible solution for vehicular communication, which has already been assumed standard in some countries [3], [4]. However, it has great limitations due to its low reach and penetration [5], [6].

The associate editor coordinating the review of this manuscript and approving it for publication was Abdul Wahid.

A technology with possibilities to minimize these effects is LoRa (Long Range), which has a greater range in signal propagation and a better penetration in obstacles since it operates at frequencies below 1.0 GHz and can be viable in applications that demand the transmission. Also, short messages, few characters, and situations in which it is not necessary to send frequent packets of information [7], [8].

LoRa technology uses Spectral Propagation Modulation with support for error correction, a technique developed mainly to operate in the ISM band (Industrial, Scientific, and Medical) at frequencies below 1.0 GHz, regulated by the International Telecommunication Union (in Brazil, the frequency is 915 MHz) [9]. The modulation CSS (Chirp Spread Spectrum) is also used on radars. Ramps form the Chirp signal. The displacement of these ramps, which do not vary in amplitude and cover the entire band, carries the information [10], [11].

LoRa hardware could be configured modifying inherent parameters to the device such as SF (Spreading Factor), CR (Code Rate), and BW (Bandwidth), to equalize the reception sensitivity, range, and transmission speed.

The SF can take values between 7 and 12 with influence on the sensitivity, robustness against interference, and transmission rate; the value 12 has the greatest robustness and the 7 the highest transmission rate. The CR, with parameterized values between 4/5 to 4/8, is used to configure the error correction. The increase in bandwidth allows a higher transmission rate but becomes more susceptible to errors; the most used bandwidths are 125 kHz, 250 kHz, and 500 kHz [10].

LoRa technology presents itself as a general solution for IoT; however, in V2V and V2I applications, few studies or research address its behavior in greater depth. Among the related works of relevance found can be cited:

The work of [12] analyzes the LoRa performance concerning the Doppler effect [12], [13], which depends on the angle of signal reception and relative vehicle speeds. It concluded that depending on the chosen hardware configuration, the vehicles' speeds could make the communication unviable. Also carried out land and sea area coverage.

In [10], a comprehensive study of LoRa is developed; in addition to conducting range tests in a suburban area with a fixed antenna on the second floor of a building and a mobile antenna installed in a vehicle, the authors also conducted sensitivity tests of signal reception with different SF; found that the reception limits obtained were slightly worse than those specified and, also, did not observe the expected difference between the chosen settings. In tests with the vehicle stopped, the reception ratio was consistent with the SF used.

The researches of [14] develop both a theoretical study of coverage of the base antenna, positioned on the roof of a building, in three different scenarios (urban, suburban and rural), and an experimental test with a moving vehicle in the same scenarios using various combinations of LoRa configuration. The results lead to suggestions on a proper configuration for each scenario.

The authors in [15] developed an end-to-end system that obtains telemetry data from the vehicle, sends it over the LoRaWAN link, and presents the information on a website through a server stored in the cloud. Validated the system with field tests carried out in a suburban environment.

The main contributions of this work are:

1. Simulate the LoRa communication channel, theoretically evaluating parameters such as the received power and the signal reception ratio.
2. Evaluate, through field measurements, the communication between the two stopped vehicles.
3. Evaluate, through field measurements, the V2I and V2V LoRa communication.

The rest of this article is organized as follows: Section II describes the configuration parameters and procedures used in the simulation and field tests. Section III presents the results and discussion. Finally, in section IV, the conclusion.

FIGURE 1. Location of the 50 initial bases.

TABLE 1. Simulation parameters.

Parameter	Value
Number of vehicles	100
Frequency	915 MHz
Antenna	Omnidirectional
Transmission power	12 dBm
Antenna gain	5 dBi

II. SET UP

A. SIMULATION

In this work methodology for the simulation in vehicular communication, it is necessary to provide information on the topology and morphology of the region, the vehicle traffic, and for the V2I analysis, the base locations. Extracted the topology and morphology of the region from the OSM (Open Street Map) [16], the traffic was simulated using the simulator software SUMO (Simulation of Urban Mobility) [17].

For the bases, the location was selected using a genetic algorithm. Initially, 50 points, presented in Fig. 1, were chosen based on buildings, obstructions, type of vegetation, and the terrain's elevation.

These points were reduced to 9, by use of a genetic algorithm, which was implemented through the fitness function, defined by equation (1).

$$z = \sum_{i,j=1}^{50} \left(Ci\right) + \left(\alpha d_{ij}\right) \quad (1)$$

where C_i represents the number of connections above the normalized reception limit, and α is the weight value varying between -1 and 1 of the normalized distances between each base, with the lowest values being attributed to shorter distances.

The use of the genetic algorithm led to the choice of the points shown in Fig. 2.

The simulation was performed according to the parameters in Table 1.

B. FIELD TESTS

For field tests, positioned each piece of equipment on the roof of a vehicle. The device is based on the

FIGURE 2. Location of the 9 final bases.

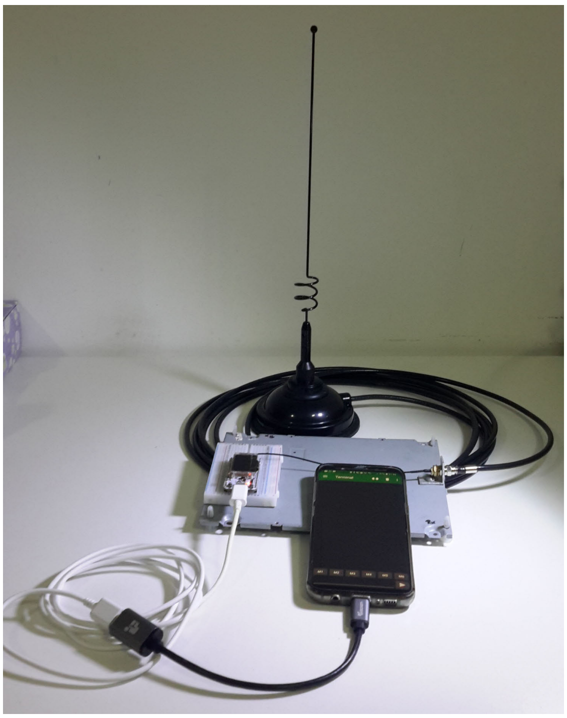

FIGURE 3. Testing equipment.

Heltec Esp32 LoRa [18] board that has the integrated LoRa SX1276 [19] chip and the ESP32 programmable microcontroller [20] and incorporates 0.96 inch OLED display. This chip operates at a frequency of 915 MHz with a reception sensitivity of −127 dBm, a 5/8 wave WHIP omnidirectional UHF antenna from the Steelbras model AP3900 [21] with a gain of 5.15 dBi was connected to the device.

Data storage and obtaining each vehicle coordinate were performed using an Android device connected to the board by serial cable, Fig. 3.

For tests with stopped vehicles, 8 fixed points with different types of obstructions, Fig. 4. The vehicle with the receiver remained parked, first at point P5, which has the lowest simulated reception ratio. The other vehicle with the

FIGURE 4. Location of the 8 points for the stopped test.

transmitter went through the rest of the points, stopping at each one long enough to transmit 150 packets. Then, the transmitter moved to the point P8, the best-simulated reception point, repeated the procedure similarly. Discarded data on vehicle movements between points. Data acquisition was performed considering parameters SF7 and SF12, thus totaling four measurement results.

In this data collection procedure, the bandwidth with the lowest susceptibility to errors and highest sensitivity (125 kHz) was considered; the CR (4/5) was used, which provides faster reception time, calibrated the transmission power to the maximum value allowed by the hardware.

Then, the V2I tests were performed with one vehicle stopped and the other circulating through the streets of the campus and surroundings. Finally, tests were made with both vehicles in free random movement (V2V) within the campus and one of the vehicles also covered its surroundings.

Data collection for V2I and V2V was performed by sending the message containing the GPS coordinates, the receiver stores the RSSI (Received Signal Strength Indicator) and SNR (Signal to Noise Ratio) of the received message. This process was repeated in a loop during the tests, and for each SF (SF7 and SF12) configuration independent tests were performed, the path and traffic situations were as similar as possible in all tests.

III. RESULTS AND DISCUSSION

In this Section, the outcomes obtained in the simulations and field tests are presented.

A. SIMULATION

1) VEHICLES STOPPED

In this stage, carried out the tests were carried out within the limits of the UFPR campus with a maximum radius of 800 m.

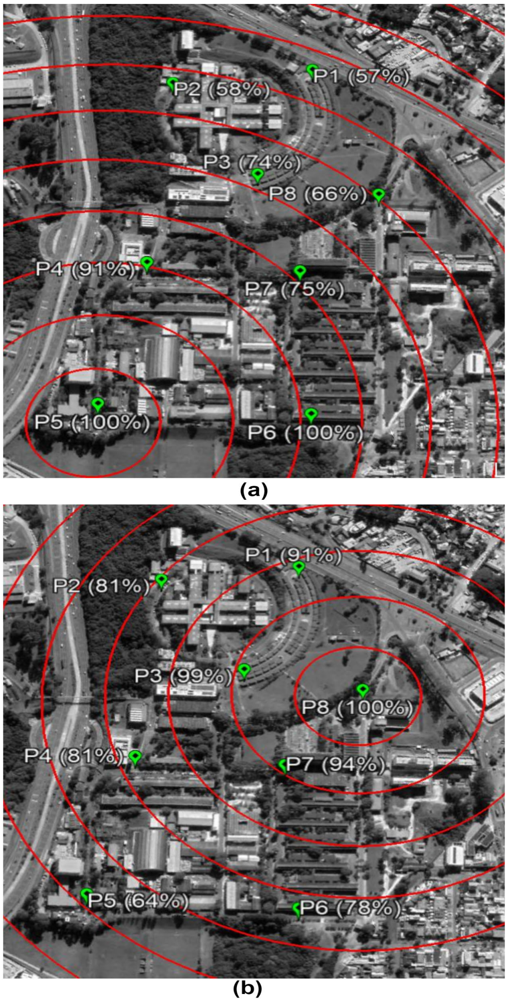

FIGURE 5. **Coverage map of the stopped simulation in different transmission bases: (a) P5 and (b) P8.**

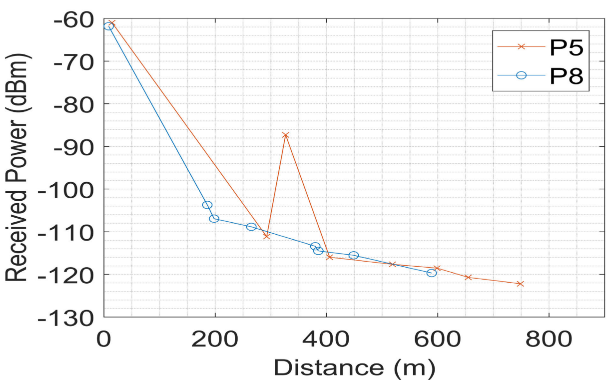

FIGURE 6. **Received power in the stopped simulation.**

In the communication between links P5-P6 and P5-P4, Fig. 5a, it is possible to recognize the influence of the type of obstruction, LOS and NLOS respectively, even at similar distances there is a decrease in the reception ratio of 9%. The same can be seen in Fig. 5b between links P8-P3 and P8-P7.

Above, in Fig. 6, is shown the simulated average of the powers received from all points transmitting to the vehicle parked first at point P5 and then at point P8. The peak power received at 326 m regarding the P5 - P6 link is due to the direct sight (LOS) between the transmitter and receiver. It should be noted that during the vehicle's movement between the points there is no measured signal.

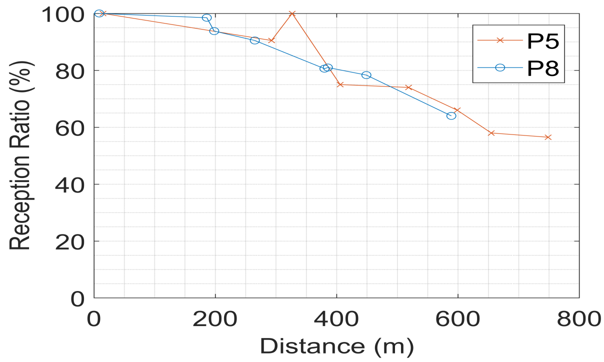

FIGURE 7. **Reception ratio in the stopped simulation.**

In the GEMV^2 simulator, it is not possible to consider the topography of the terrain. The signal decay is due to attenuation caused by the distance, environment's obstructions, and morphology; this leads to a similar curve for both P5 and P8, Fig. 7.

2) V2I

The channel simulation was carried out in the UFPR campus area, evaluating the power received as a function of the distance and each type of obstruction, as well as the percentage of the signal received above the reception threshold.

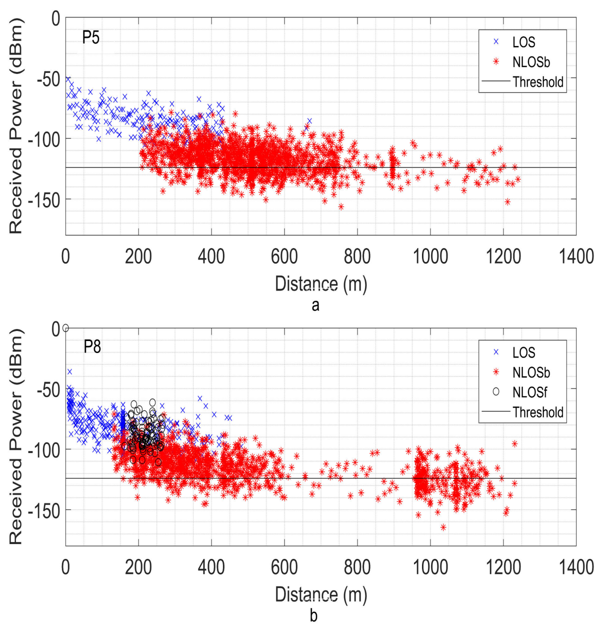

FIGURE 8. **Received power in different transmission bases: (a) P5 and (b) P8.**

It is observed that reception at points close to the base, up to approximately 200 m, is formed by signals with direct sight (LOS) and is substantially above the reception threshold.

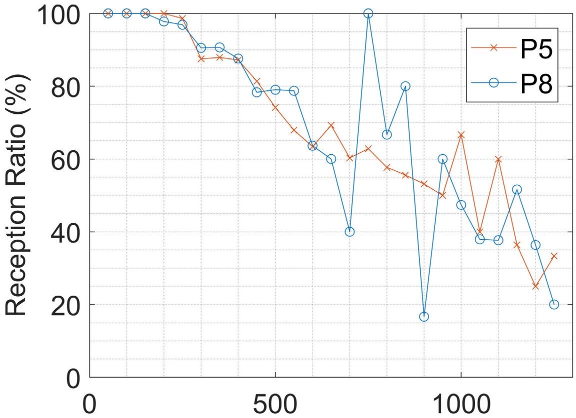

FIGURE 9. Reception ratio in the V2I simulation.

From this distance, in the simulated urban environment, the NLOS signal's effects caused by the large concentration of different types of obstructions along the link becomes dominant, as shown in Fig. 8.

In Fig. 9, the simulated level of the received signal with power above the reception threshold (−124 dBm) occurs in spaces with traffic close to the points P5 and P8 (200 m), which is perfectly compatible with the expected result, due to the attenuation of the free space ($P = 32,4 + 20\log r_{[km]} + 20\log f_{[MHz]}$). From this point on, there is a great influence of the obstructions practically eliminating the LOS condition, and the reception is done by spreading the signal over obstacles (NLOS).

3) V2V

The GEMV^2 is a channel simulator, it does not consider parameters inherent to LoRa as a SF, and CR that exert great influence on reception when vehicles are in motion. In this work, will not simulate this situation because it diverges a lot from the practical conditions of V2V communication, which will be shown only in the field measurement tests.

B. FIELD TESTS

The non-simulated part was due to measurements made on the UFPR campus, in the same simulation environment. Communication situations were considered with both vehicles stopped, with one vehicle in motion (V2I), and with both vehicles in motion (V2V). For the tests, the following parameters were used: the transmission frequency of 915 MHz, the transmission power of 12 dBm, the bandwidth of 125 kHz, the code rate of 4/5, and the spreading factor for the extremes of the value 7 and 12.

All data obtained in the field tests refer to the packets received, and the hardware provided the RSSI and SNR.

1) STOPPED TEST

For each of the 4 tests, a coverage map was generated and can be seen below.

Reception levels were consistent with LoRa's technical specifications. It can be seen in Fig. 10 that when the spreading factor increases the range of the received signal also increases and the same occurs with the reception ratio for the nearest signals, that is, it increases the equipment's robustness and sensitivity. When using SF12 there was communication between the transmitter and every all points (P1 to P8) to a greater or lesser extent, mainly influenced by the distance and obstructions in the path.

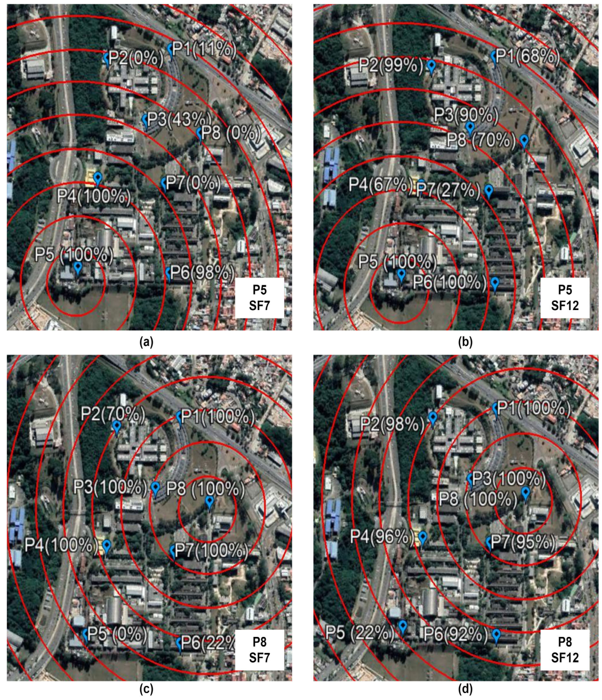

FIGURE 10. Coverage map of the stopped test in different transmission bases and parameters: (a) P5 and SF = 7, (b) P5 and SF = 12, (c) P8 and SF = 7, and (d) P8 and SF = 12.

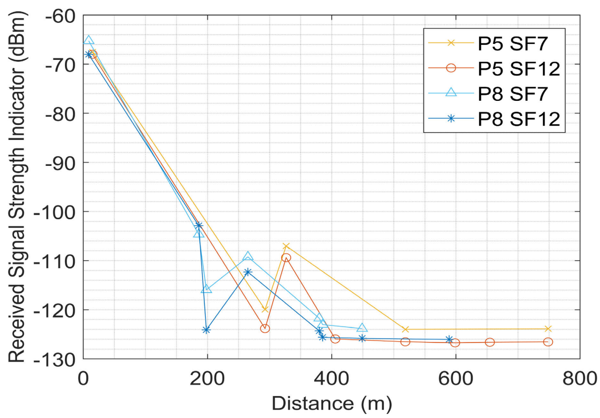

FIGURE 11. RSSI in the stopped test.

Fig. 11 shows the RSSI of packets received as a function of distance and compares the scattering factor's effect.

With SF7, RSSI tends to be higher, however, the equipment has less sensitivity than with SF12, which has greater operational gain, that is, less loss of transmitted packets and greater reception radius.

With a smaller SF, the signal/noise ratio has always been kept at low levels, which compromises the integrity of the received signal as well as the reliability of the link. With the

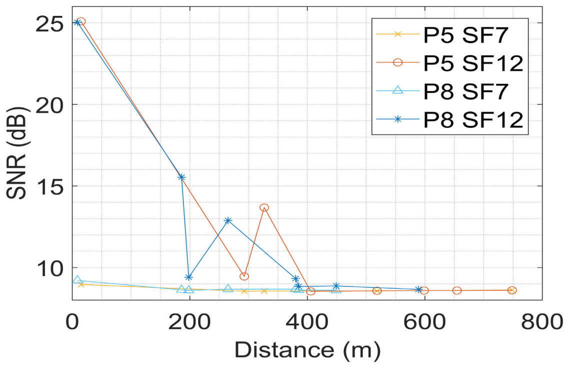

FIGURE 12. Signal-to-Noise Ratio in the stopped test.

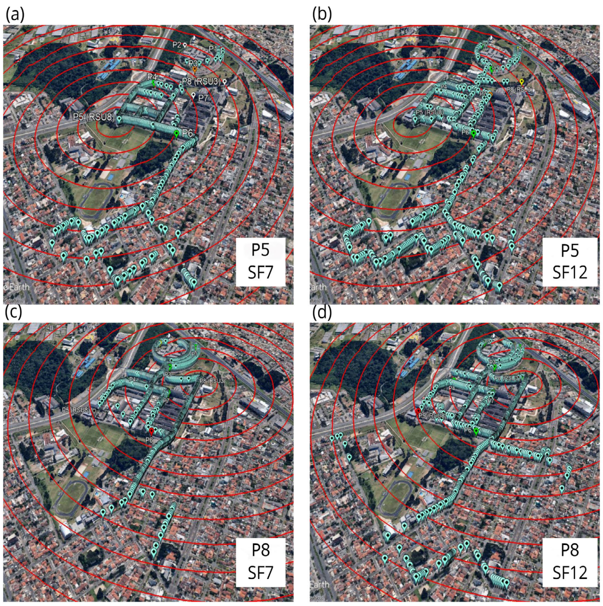

FIGURE 13. Coverage map of the V2I test in different transmission bases and parameters: (a) P5 and SF = 7, (b) P5 and SF = 12, (c) P8 and SF = 7, and (d) P8 and SF = 12.

SF (Spreading Factor) increasing, in close distances, the SNR shows itself in more reliable levels, however, there is a rapid degradation with variation in the distance and tends to match the smaller SF (Fig. 12). A lower signal to noise ratio directly impacts the BER rate.

2) V2I TEST

In the map, blue dots representing the locations where the vehicle in motion is connected to the receiver, is shown in Fig. 13.

The signal range was evaluated with a vehicle in motion; the results are shown in Fig. 13. In this test scenario, the largest Scattering Factor provided a higher percentage of packets received when the transmission was made at greater distances. However, with the increase in speed, in some points, there is no reception of packages where they previously existed (sensitivity to the Doppler effect).

The RSSI (Received Signal Strength Indicator) values for the different SFs considering each of the analyzed points are shown in Fig. 14.

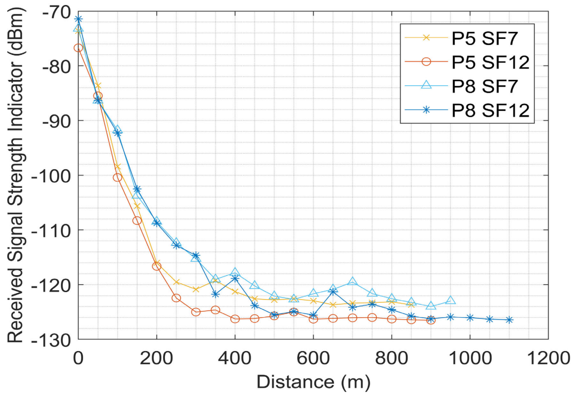

FIGURE 14. Received Signal Strength Indicator in the V2I test.

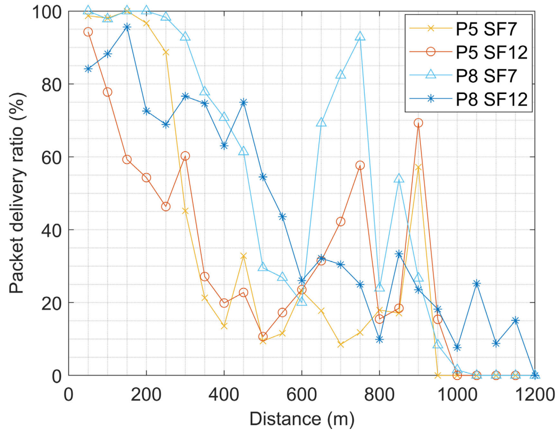

FIGURE 15. Packet delivery ratio in the V2I test.

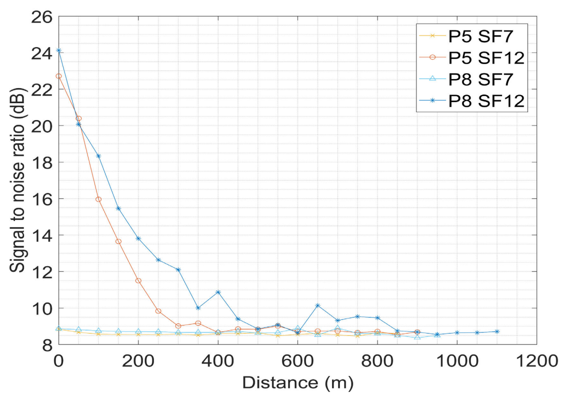

FIGURE 16. SNR in the V2I test.

LoRa proved to be sensitive to the effect of speed concerning the RSSI of the received signal; the Doppler effect can explain this. A lower SF leads to less sensitivity to this effect, which partly compensates for the higher reception threshold and practically matches the highest SF when considering the totality of measurements.

With the data measured in the field test, calculated the percentages of the transmitted, and received signals; these values are shown in Fig. 15.

In the situation under analysis, the use of SF7 decreases the signal reception ratio, but at shorter distances, the reception ratio is significantly higher than for SF12, this is due to the lower sensitivity of SF7 to the Doppler Effect. Considering

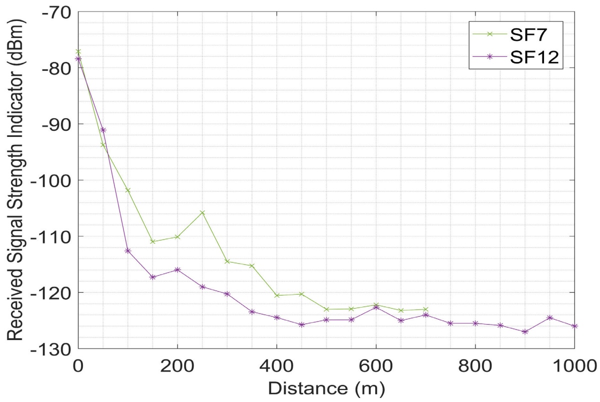

FIGURE 17. Received Signal Strength Indicator in the V2V test.

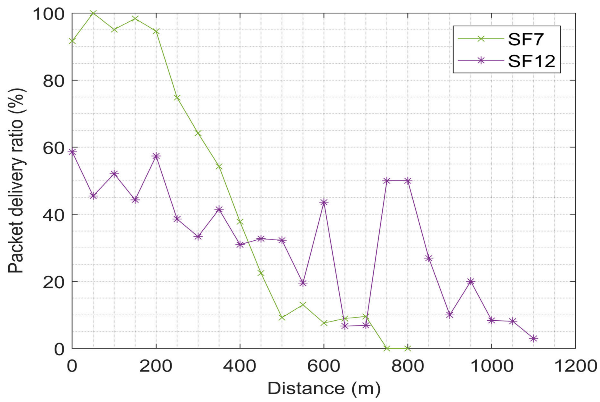

FIGURE 18. Packet delivery ratio in the V2V test.

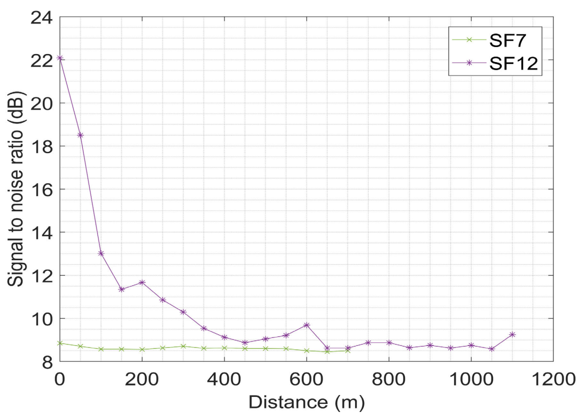

FIGURE 19. Signal-to-Noise Ratio in the V2V test.

the same parameters, point P8 maintained an average performance considerably higher than P5 concerning the number of received packets, this may be explained by the location of P5 and P8.

The SNR values for the different SFs considering each of the analyzed points are shown in Fig. 16.

The average value measured of the signal-to-noise ratio with one of the vehicles in motion (V2I) remained consistent with the values obtained compared to the two stopped vehicles. It is noteworthy that with one of the vehicles in motion the number of packets received from random points is comparatively a little higher. The analysis performed here considers the average number of packets received.

3) V2V TEST

The V2V test was performed with the vehicle with the transmitter traveling randomly within the campus, sending a message every second to the receiver positioned in another vehicle that also traveled randomly within and around the campus, going to the limit of the distance where the signal was lost.

With both vehicles in random motion and varying the spreading factor, the RSSI behaved, according to the distance as shown in Fig. 17.

The speed has more significant influence on the signal reception levels in V2V, where the vehicle speeds add up or subtract depending on the vehicles' relative displacement. The Doppler effect will have a greater influence on this condition, as seen in Fig. 17. With SF7 reception levels were significantly higher than SF12, but with a loss of range, which for SF12 was similar to V2I.

With the values measured in the field tests, the percentages of the transmitted signals that were received were obtained according to Fig. 18.

Using SF7, occurs a decrease in the range, but a significant increase in the reception ratio. Significantly greater than for SF12 in shorter distances, up to approximately 400 m; due to the lower sensitivity of SF7 to the Doppler effect and other interferences. It can be seen, in Fig. 18, that with SF12 even in small distances the reception ratio dropped dramatically, to 60%, compared with the V2I tests.

The variation of the SNR (signal/noise ratio) over the distance for the SFs analyzed is shown in Fig. 19.

As observed in the analysis for V2I, the values measured for the signal/noise ratio in V2V behaved coherently in the study with the stopped vehicles. There was a more significant decrease in short distances for SF12.

C. DISCUSSION

In this work, LoRa technology was analyzed in applications with two vehicles stopped at different points (point-to-point), V2I and V2V, by simulation and field measurements.

In the simulations carried out, the objective was to evaluate the communication channel for LoRa, that is, generate no network traffic. In measurements made in the field, limited the traffic to two vehicles.

Showed the results of the simulations and field tests coherent and in agreement with the LoRa specifications for the values of SFs in the tests with both vehicles stopped. In the V2I and V2V tests, observed that SF7 had a better reception ratio and SNR than SF 12. For the LoRa technology, the influence of speed is evident due to sensitivity to the Doppler effect, which can be attenuated by calibrating the hardware for a lower SF, but with loss in range and SNR (Signal to Noise Ratio). It is noteworthy that when both vehicles stopped, the performance when using SF 12 was significantly higher than the SF 7 in all the measured points, which corroborates the theory since in this condition there is no influence of the Doppler effect.

LoRa technology is more efficient in applications that require few characters in transmission and in situations where it is not necessary to send packets frequently due to its lower transmission rate and operational restrictions, such as accident alerts, information on the level of vehicle traffic and points of interest, especially in larger regions with a high density of buildings and obstructions.

LoRa, even with low transmission capacity and the limited size of transmitted messages, specifically in vehicular communication, has great versatility in various application possibilities such as increased traffic safety, vehicle flow optimization, vehicle network, transit area control networking. Because it has low-cost hardware, it becomes a viable solution that will possibly be used on a large scale.

IV. CONCLUSION

LoRa intends to be a technology of widespread application in several areas of the IoT and, observing some limitations and/or increasing technical solutions in the future, aiming at improvements, it may prove to be an economical and technical viable solution for use in vehicular communication in specific conditions.

The field measurements prove that the LoRa is a viable technology, both for its reach and communication reliability, even in a dense urban environment. Among the several possible applications in IoT, vehicular communication proves to be one of them. The hardware's simplicity and robustness make it an economically viable solution in mass applications such as vehicular communication.

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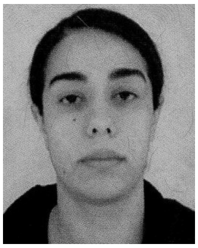

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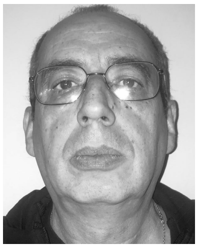

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