Integrating LP-WAN Communications within the Vehicular Ecosystem

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Abstract

Vehicular communications are attracting the attention of both the academy and industry since some time ago. Most of the developed services rely on short-range communication technologies or on non-vehicular oriented cellular solutions such as 4G. In turn, during the last times a long-range transmission technology known as Low Power – Wide Area Network (LP-WAN) has gained great momentum. LP-WAN solutions such as LoRa (Long Range) promise long coverage ranges of about 10 km with very low power consumption. Since these features can improve the performance of many vehicular services, in this work the application of LoRa to the case of vehicular communications is explored. The two typical vehicular network architectures, namely, Vehicle-to-Infrastructure and Vehicle-to-Vehicle, are considered. The results, extracted from an experimental test-bench, show long coverage ranges never seen previously in vehicular environments. This opens the opportunity for developing novel services and applications in this growing ecosystem.

Keywords: LP-WAN, LoRa, Vehicular Networks, Intelligent Transportation Systems

1 Introduction

Vehicular communications are envisioned to gain momentum with the definitive development of the Internet of Things (IoT) and smart cities ecosystems [23]. Thus, new paradigms such as the Internet of Vehicles (IoV) are receiving great attention during the last times [19]. Under this umbrella, new services never imagined few time ago will be developed, providing vehicles and users with new functionalities and applications. These services will take advantage of the diverse capabilities offered by the different-nature Radio Access Technologies (RAT) that will be available in next-generation end-devices. Considering the 5G ecosystem, a great number of RATs will coexist within a common Radio Access Network (RAN). Focusing on the concrete case of vehicular networks, a great effort has been made for developing specific standards for achieving efficient Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications, such as IEEE Wireless Access for Vehicular Environments (WAVE) or the ISO/ETSI reference architecture for cooperative systems. Within WAVE it is proposed a modification of the common WiFi for vehicular scenarios, called 802.11p, which is also used as one of the potential technologies to include within the ISO/ETSI framework. According to our previous tests [17], 802.11p can provide in real deployments a throughput near 10 Mbps, communication ranges around 500 m, and low delays bellow 10 ms. These features are good for local communications among vehicles or with a near road-side station.

In turn, long range technologies have also been employed for providing vehicles with connectivity. So far, the de facto solution for this issue is making use of the already deployed cellular infrastructures such as 4G. Although this approach provides high data rates, especially in urban scenarios, other technologies are needed in rural and remote ones for covering large distances without needing the deployment of an expensive and complex cellular infrastructure. A new technology so-called Low Power

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– Wide Area Network (LP-WAN) has emerged during the last years, promising long coverage ranges and low energy consumption. Although the latter is not a critical factor in vehicular environments, the former entails a step towards the development of new vehicular-related services. As discussed in [4], remote maintenance or fleet tracking are highly valued applications that requires connectivity in large areas without the need of reliable connectivity and a high throughput. However, we also advocate for the usage of this technology in alert-based scenarios, which can also take advantage of a potential long-range dissemination of messages to vehicles approaching an incident (e.g., accident, roadworks, road status). As discussed in the next section, some of these services have been already deployed by using short-range communication technologies, although they present some drawbacks related to the complexity of the network management tasks, e.g., routing, medium access control, etc.

Focusing on the LP-WAN paradigm, many platforms have arisen during the last years [16]. All of them offer great transmission ranges of about 10 km in rural areas. This permits to reduce the number of base stations needed to cover vast areas. One of the solutions that have attracted greater attention within the LP-WAN ecosystem is LoRa (Long Range) [1]. This technology is a highly robust proprietary modulation that permits transceivers to have a very high sensitivity, so the transmitted information can be decoded although the received power is very low.

Due to the potentiality of LP-WAN in the vehicular domain, and the growing adoption of LoRa, in this paper we integrate this technology in vehicular communication architecture and evaluate its operation under real environments. First, by using a LoRa base station, a V2I topology is deployed. Thereafter, the case of V2V communications is also explored. By studying both cases, we provide a wide overview of the expectable performance of LP-WAN technologies, and concretely LoRa, for developing long-range vehicular services. Thus, the main contributions of this work are the following:

1. The network architecture under consideration is deeply discussed and different novel services fitting within it are identified.
2. A LoRa-based V2I testbed has been deployed. The long coverage range attained by using different LoRa configurations is demonstrated and discussed.
3. The case of V2V communications is also explored by using the LoRa technology. A performance evaluation of this system under different environmental conditions is provided.

The rest of the paper is organized as follows. Section 2 presents the most prominent related works addressing both short and long range transmission technologies applied to the case of vehicular communications. The LoRa technology is detailed in Section 3. Section 4 explores the LP-WAN-based network architecture and discusses about next-generation vehicular services taking advantage of this novel paradigm. Section 5 presents the experimental test-bench employed and examines the obtained outcomes. Finally, the paper is concluded in Section 6, remarking the most important findings.

2 Related Work

A great number of routing proposals for vehicular networks have appeared since the early 2000's [12]. However, most of them imply the usage of vehicles as forwarding nodes, which makes difficult the management of a highly mobile network. Independently of the usage of infrastructure attachment stations, communication range of WiFi-like technologies is a key limitation. Recently, another issue difficult to solve is the network congestion when using 802.11p under dense traffic scenarios. In [15], results indicate that using small data packets, such as the ones being standardised in ISO/ETSI, allow a channel allocation of up to ten close terminals sending packets at the maximum rate of 10 Hz. Solutions to this problem [20, 5] bet on reduction of transmission rates and coordination to avoid congestion, but the access to the network is still a challenge in urban scenarios. The usage of LP-WAN technologies can be a solution to offer long-range communications while consuming a low-bandwidth, this way avoiding the usage of multi-hopping in many scenarios and allowing the connection of many nodes for non-delay-critical services requiring low bandwidth.

The application of long-range transmission technologies to specific vehicular environments has also been explored in the literature [2]. Most of these solutions made use of a typical cellular architecture by considering technologies such as 4G or the upcoming 5G [22, 11, 13]. However, the cellular-based strategy presents some drawbacks related to the need of a pre-existent architecture, which is not always available in remote scenarios. Some works have considered the alternative of deploying hybrid systems (V2I and V2V) by using 4G technology [21, 8] or by gathering different-nature transmission technologies [2]. However, these solutions present restrained coverage range of about some hundreds of meters, limiting the number of reached vehicles by one-hop broadcast messages. Thus, other long-range solutions should be employed for providing direct links between vehicles. As aforementioned, LP-WAN technologies can be an interesting alternative. Although they were not designed in their inception for providing communications directly between end-nodes, recently, some authors have started to explore this possibility, even considering multi-hop transmissions [7, 3, 6]. Nevertheless, these works tackled this topic from an analytical point of view. Concretely, the authors of these studies focused on optimizing the network organization in order to find the most energy-efficient routes. From another perspective, Herrera-Tapia et al. evaluated the performance of LoRa in delay-tolerant vehicular scenarios [10]. Benefiting of the long distances covered by this transmission technology, authors demonstrated the greater number of opportunistic contacts among end-nodes in comparison with the WiFi technology. These results were not surprising, considering that the estimated transmission range for WiFi was 50 m and the one considered for LoRa was 2500 m. In addition, the results were obtained via network simulation, which not always reflects properly the real propagation conditions of highly variable scenarios. Thus, some experimental work is missed in order to confirm the attained outcomes. For that reason, in this work, a real experiment is proposed. Both network configurations discussed above are considered, namely, (i) a V2I scenario by employing a LoRa base station and a LoRa-compatible on-board unit (OBU), and (ii) a V2V architecture by using two OBU-equipped vehicles. In the following sections, a detailed overview of both network schemes and the specific real components used in this work is provided.

3 LoRa

Long Range (LoRa) is a proprietary modulation scheme promoted by the LoRa Alliance [1], composed by IBM, Cisco, and Semtech, among others. This modulation was developed following a Semtech's proprietary Chirp Spread Spectrum (CSS) radio scheme. This modulation technique trades data-rate for sensitivity within a fixed channel bandwidth. Focused on the LoRa case, this trade-off is managed by the adjustment of three different configuration parameters, namely, Spreading Factor (SF), Coding Rate (CR), and Bandwidth (BW). The spread spectrum modulation is performed by representing each bit of payload information by multiple chips of information. The number of chips representing each single bit is determined by the SF. Typical LoRa's SF values go from 7 to 12. Thus, high SF values, e.g., 11 or 12, increase the robustness of the LoRa link, but at the expense of notably decreasing the data-rate. With the aim of additionally improving the robustness of the link, LoRa also employs cyclic error coding to perform forward error detection and correction. Such error coding incurs a transmission overhead that is determined by the CR parameter. The possible range of values for the LoRa's CR is from 4/5 to 4/8. Of course, using greater amount of redundant information increases the capacity of

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[1] `https://www.lora-alliance.org/`

recovering corrupted transmissions but the time-on-air of each packet grows as well. Finally, the most employed BW in LoRa are 125 kHz and 250 kHz. Note that, as the majority of LP-WAN solutions, LoRa makes use of Industrial, Scientific and Medical (ISM) frequency bands. Concretely, it employs the 868 MHz (Europe) and the 900 MHz frequency bands (America, Asia, and Australia). Therefore, by making use of all these characteristics, LoRa permits interesting coverage ranges of several Km in both rural and urban areas [16]. This feature makes LoRa highly suitable to support long range services such as the dissemination of broadcast messages among a high number of devices or the straight connection between an end-node and a far-away base-station.

One of the strongest aspects of the LP-WAN technology is scalability, which is essential in vehicular communications, as said in the previous section. Base stations using the LoRa technology are able to listen to many different channels simultaneously. E.g., Semtech's SX1301 chipset is able to listen to eight different channels with a bandwidth of 125 kHz simultaneously in any spreading factor available without prior configuration. Also, the capability of listening to different channels with the orthogonality of the different spreading factors (even in same channel), allows communication of a large number of end-devices with the base station without problems. E.g., as shown in [14], a single base station listening to three different 125 kHz channels can serve up to 4602 end-devices sending 20-byte packets every 10 minutes, or 357 end-devices sending 1-byte packets every 30 seconds.

4 Network Architecture

Vehicular communications usually consider two well-differentiated network schemes namely, (i) Vehicle to Infrastructure (V2I), and (ii) Vehicle to Vehicle (V2V). In the former, the end-devices, i.e., the vehicles, communicate with base stations placed close to the road, i.e., road-side units. Those units send the received information from the end-nodes through a back-haul network such as the Internet, to backend servers that store and process the traffic data. On the V2V case, the vehicles are the only elements composing the network, so they have to manage and process all the information traveling through the network. Therefore, crucial management decisions regarding the amount of information to transmit and the synchronization among vehicles should be taken.

Traditionally, short-range communication technologies, e.g., IEEE 802.11p, have been employed in both V2I and V2V schemes. This fact causes that certain vehicles are not able to directly reach either the destination vehicle or the target network. Thus, multi-hop strategies are required for both V2I and V2V architectures. Following this scheme, end-devices need to function as both host and routers for relaying the received information to other elements within the network. This generates an increased complexity regarding the network management tasks, e.g., routing, medium access control, etc. Therefore, as aforementioned, other long-range transmissions technologies are explored to be applied to vehicular scenarios. For that reason, in this work, the use of LP-WAN technologies is proposed for simplifying the communication scheme for non-delay-critical services and low-bandwidth requirements. By taking advantage of the long coverage ranges provided by LP-WAN the need for multi-hop strategies is avoided, which notably relaxes the network management complexity.

The scenarios considered is depicted in Fig. 1), where both the network the architecture and the intended communication stack are shown. Regarding the V2I case, observe that the architecture is closer to that of an actual LP-WAN, with the particularity of having vehicles as end-devices. With LP-WAN radio technologies, every end-node can communicate with a base station that relays the information to the most proper backend server, which processes this information. The infrastructure can also send information back to the end-device, using a downlink transmission from the base station. Thus, critical information can be transmitted at long distances. Another benefit presented by LP-WAN technology is that, due to its long coverage range, a smaller density of base stations is required to cover vast areas, greatly reducing the costs of roadside elements. In this line, a great advance is that V2V communications can reach further distances, avoiding the need of multi-hoping with complex routing algorithms. As can be seen in Fig. 1), the low power consumption of LP-WAN technologies can also increase the battery life of communication units mounted on e-bikes or mopeds [18], which are more and more common in urban mobility scenarios.

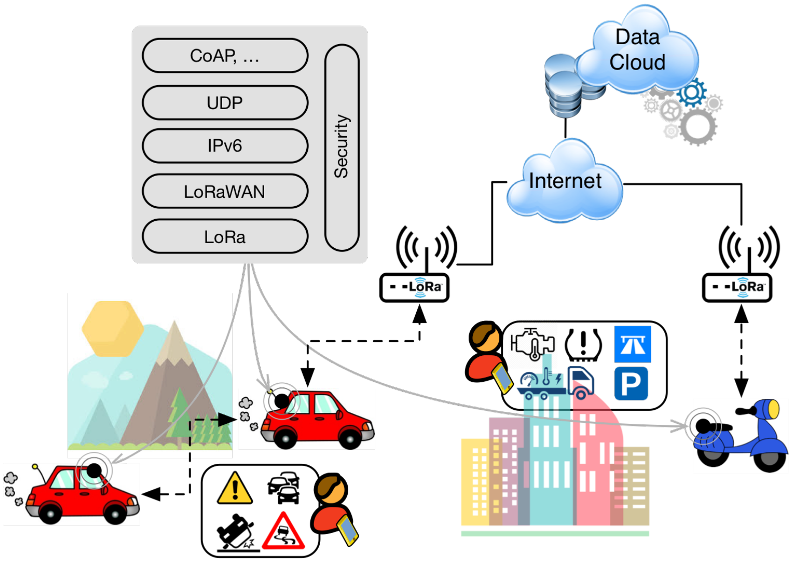

Figure 1: Target scenario and communication architecture.

The communication stack envisaged for our architecture considers the usage of the LoRa physical layer together with the LoRaWAN link layer. Over this basis, our proposal is using IPv6 to interconnect with Future Internet scenarios. For this to be done, we consider the current works within the IPv6 over Low Power Wide-Area Networks (*lpwan*) IETF working group [2], based on compacting the IPv6 and upper layers headers to reduce the payload of datagrams. In our scenario, the UDP protocols is especially considered, given the lowest overhead of this protocols as compared with TCP. As application protocol, we are currently evaluating the integration of IoT protocols such as Constrained Application Protocol (CoAP).

As indicated in Fig. 1), multiple services can be developed by taking advantage of the long-range links established between vehicles and the infrastructure. Some of the possible applications include: (i) fast electronic toll collection by which the toll payment can be performed using long-range communications, without the need of a toll booth; (ii) parking availability and reservation; this service permits travelers to reserve a free parking space when approaching a certain city or neighborhood; (iii) value-added advertisement like those of petrol stations, highway restaurants or any other entity offering its services to travelers; (iv) self-diagnosis information, by which the vehicle can send status data to the car manufacturer and, in case of detecting a problem, the manufacturer can provide the driver with useful information; (v) notification of road incidents using the global perspective from a traffic management center; or (vi) monitoring the status of a fleet, generating records of useful data, e.g., fleet tracking, information about the condition of the goods being transported by the vehicles, etc.

Considering the V2V scenarios, the benefits of employing long-range radio technologies to remove the need of multi-hop strategies are multiple, e.g., (i) avoiding the chance of having down elements in the transmission path, which would make impossible the information dissemination; (ii) delays are more

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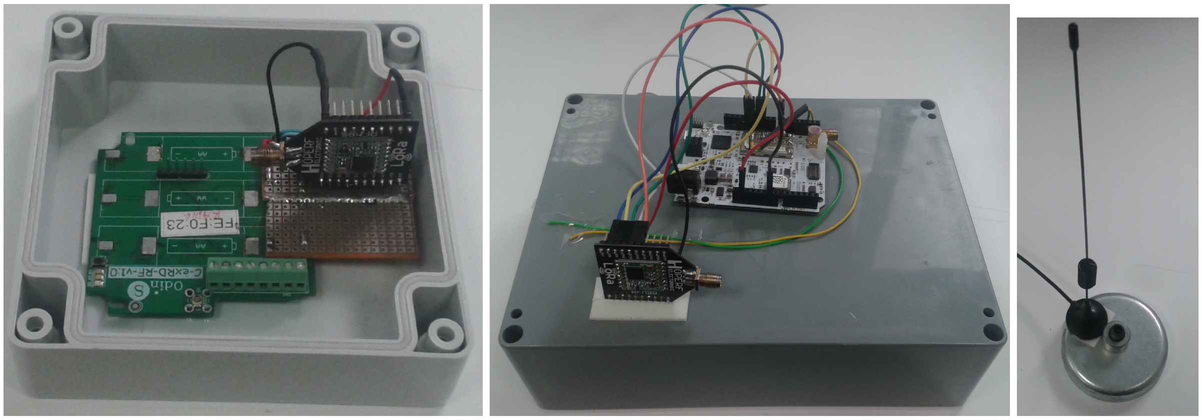
[2] `https://datatracker.ietf.org/wg/lpwan/`

controlled since the elements of the network do not need to process and retransmit data-traffic; (iii) the overhead introduced by retransmissions is avoided, permitting a clearer channel. As in the case of the V2I scenario, many services have been identified to be developed by taking advantage of the long-range V2V communications. Some examples are the following: (i) the dissemination of warning events such as traffic accidents or weather incidents, hence disseminating a fast alert in surrounding vehicles; or (ii) real-time traffic alert, by sending information about traffic status when a jam is detected, the approaching vehicles are able to take an alternative route to avoid the conflictive area.

To sum up, the benefits of using LP-WAN technologies in both V2I and V2V scenarios are multiple. The most relevant include decreasing the network management complexity as long-range direct links are established between single vehicles or with the infrastructure, or providing isolate locations with connectivity, among others. In the following, the application of an LP-WAN solution to the case of vehicular networks is deeply explored by the deployment of both discussed architectures in a real scenario.

5 Study Case

In order to test the coverage range of the LoRa technology in both V2V and V2I scenarios, an experimental test-bench has been deployed. Note that these tests make use of the capabilities of the physical layer of LoRA, i.e., just the modulation scheme; while the upper layers indicated in the previous section are left as future work. Thus, in order to implement both extremes of the communications, two different microcontroller boards were used, namely, (i) the C-exRD-RF v1.0 (Cex) microcontroller board by Odin Solutions, shown in Fig. 2a, and (ii) the SmartEverything Fox (SME) board by Arrow, shown in Fig. 2b. The Cex board runs the Contiki OS software, while the SME board is an Arduino-compatible microcontroller board. Aiming at providing both boards with LoRA connectivity, the HopeRF RFM95W radio transceiver was connected to them.



(a) Cex unit (b) SME unit (c) Antenna

Figure 2: Equipment used for the V2I and V2V communication tests.

As aforementioned, the experiments were conducted in two different scenarios: a V2I architecture and a V2V scheme. In the V2I scenario, the Cex node acted as a LoRa base-station and was installed on the rooftop of the Faculty of Computer Science at the University of Murcia, which is a 4-story building with a height of approximately 12 m. A sectorial antenna was attached to this board. This antenna presented high directionality (far-field beam-width of 65 degrees) and gain of 8 dBi. In turn, the other extreme of the communication was the SME board, which was installed on board a car. In this case, the attached antenna is shown in Fig. 2c, presenting an omnidirectional radiation pattern and gain of 2.2

dBi. For the V2V scenario, two cars were provided with this last equipment to establish a direct link between them. All the exchanged packets were transmitted at 14 dBm and had a fixed payload of 20 bytes, enough to transmit critical pre-defined messages or alerts. A free channel within the 868 MHz ISM band was used to perform the test transmissions.

In the following, the attained experimental results are shown and discussed. Focusing on the V2I scenario, i.e., that considering the presence of a LoRa base-station, a coverage study has been conducted. Concretely, the focus is on the uplink connection, as we consider a situation in which the vehicle (end-node) communicates some important information to the central system through the direct connection with the base-station (please see Fig. 1). As discussed above, potential applications for this scenario are the transmission of the vehicle status to a care service center or notifying some traffic alerts to the infrastructure, among many others. The considered area of study was a linear suburban scenario. This scenario was the same employed for the V2V case shown in Fig. 4. Regarding the LoRa configuration, the CR was fixed to 4/5 and the BW to 125 kHz. As the SF has a high impact on the performance of the system, the two extreme values for the case of LoRa, i.e., 7 and 12, were tested. Thus, Fig. 3 presents the RSSI level of the packets received by the base station. Observe that the RSSI level is similar in both configurations. Some differences were obtained in between 3 and 5 km away from the base station, in which the SF 12 presented higher level of received RSSI. Furthermore, observe how increasing the SF permits to notably increase the coverage of the system. While in the case of setting the SF to 7 the obtained coverage was 7 km, by using a SF equal to 12, the coverage was enlarged to 10 km. This behavior is explained by the better tolerance to transmission errors when using a higher SF. Thus, observe the great coverage range attained by the system when it is adequately adjusted. As discussed above, this permits to reduce the number of base stations needed for covering vast areas. The irregular level of received RSSI is explained by the varying environmental conditions of the scenario under consideration. As stated above, a suburban environment with different-nature obstacles such as tree areas, middle-height building, etc. was evaluated. Even so, the obtained coverage range is much longer than that attainable by any high-bandwidth cellular technology such as 4G.

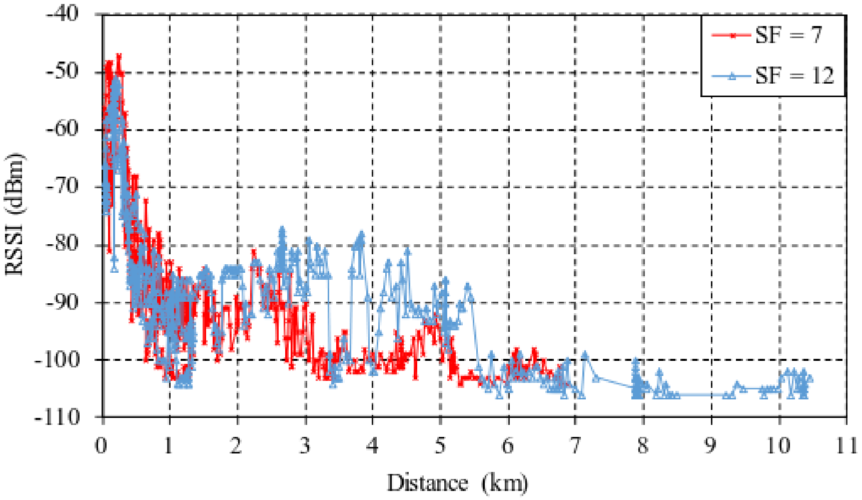


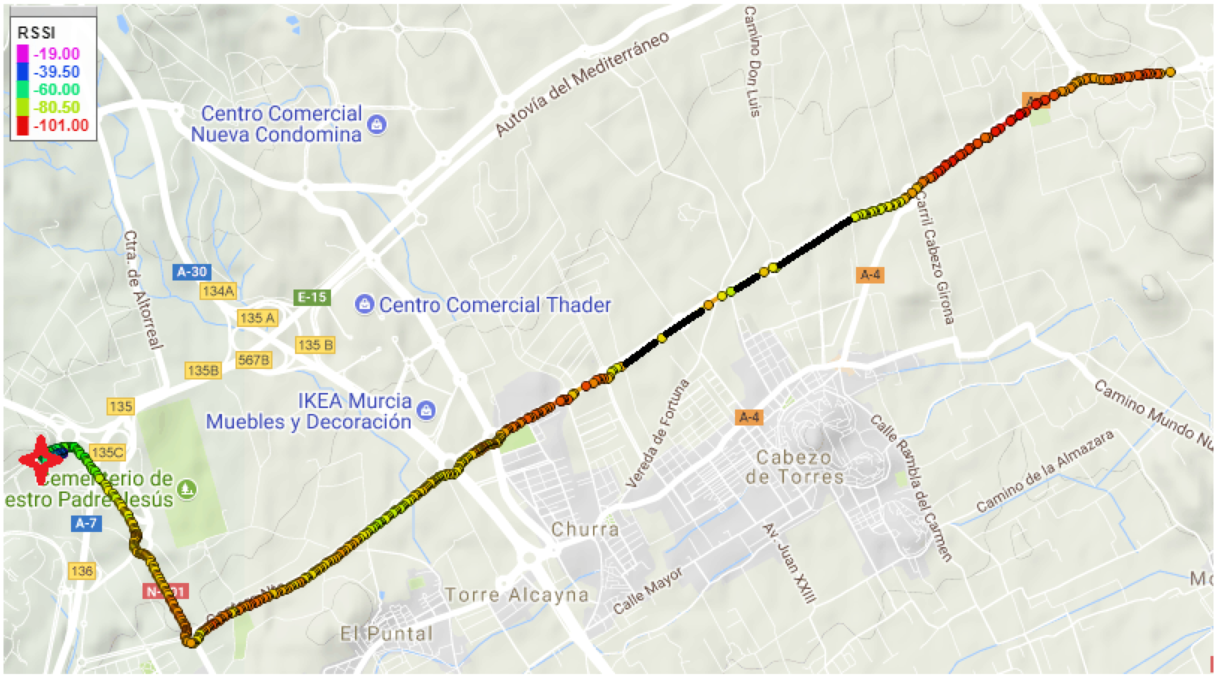
Figure 3: Level of RSSI received by the base-station in the V2I scenario by using different LoRa's Spreading Factors (SF).

After evaluating the V2I scenario, the focus is now on the V2V case. Concretely, in this experiment, one car acted as a damaged vehicle, stopped on the road and sending alert messages to the rest of moving vehicles in its surroundings. The static vehicle used the Cex unit, while the moving one used the SME one. The objective of this study is evaluating the distance covered by using just the OBU equipment in different scenarios. First, the linear suburban scenario evaluated in the V2I case was considered. Fig. 4 presents the RSSI level of the received packets by the moving vehicle. The red star represents the damaged and stopped vehicle notifying its incidence. The black lines mean shadow areas were no packets were received. In order to compare the impact of the SF on the system performance, Fig. 4a corresponds to the results attained by using an SF equal to 12, while the Fig. 4b presents the results obtained with an SF equal to 7. In the first case (Fig. 4a), observe the long distance covered of around 6 km. Although some shadow zones due to the presence of medium-height buildings were detected, in open-field conditions, the attained performance is superior to any other cellular technology, such as 4G. Observe that a distance of 6 km is more than enough for notifying approaching vehicles the traffic incident. In turn, by employing an SF of 7, observe that the performance is much poorer than in the first case (Fig. 4b). This LoRa configuration permits a V2V range of about 2.5 km. Even considering the great range decay with respect to the previous case, the results still improve the coverage attained by traditional cellular solutions.

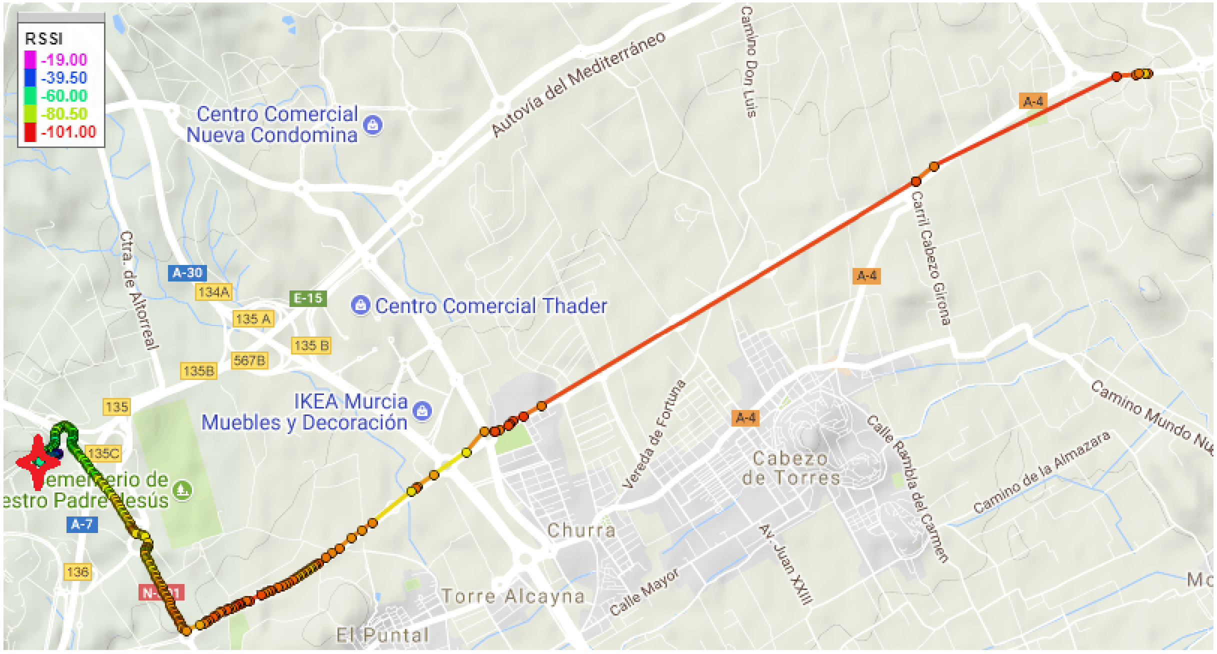
After investigating the V2V coverage range in an open-field scenario, the system behavior was also studied in a more complex scenario. In this case, the coverage study was carried out inside the University of Murcia's campus. This scenario presented dense tree areas, bulky buildings of up to 5 floors, among many other obstacles. Thus, Fig. 5 presents the coverage attained within the university campus, in terms of RSSI and using an SF equal to 12. In this case, we represent the satellite map view with the aim of showing the cited obstacles. Observe that the whole campus was completely covered with no shadow areas. This permits vehicles to report any incident to the rest of the campus community, increasing the traffic-safety within this area. Observe that in the north and south areas of the campus ring, different buildings were severely blocking the link between both vehicles. In fact, the longest link, of about 1 km, was established with the moving vehicle located in the south area of the campus. Even so, the communication was kept. Therefore, we can conclude that the use of LP-WAN technologies opens a new path to explore in order to develop novel and innovative vehicular-related applications and services.

6 Conclusion

In this paper, the application of the novel LP-WAN technologies to the case of vehicular communications has been explored. This solution reduces the complexity on the network management tasks presented by short-range technologies and notably increases the area covered by each base station in comparison with current cellular solutions such as 4G. Concretely, two different scenarios empowered by the use of LoRa modulation were studied. First, a V2I architecture was deployed for connecting a LoRa base-station with vehicles equipped with a LoRa end-terminal. Results shown a great performance of the system, with coverage ranges of about 10 km in a suburban scenario. Thereafter, the V2V case was evaluated by establishing direct connectivity between vehicles. The results shown a decreased coverage range in comparison with the V2I network due to the superior performance of the base-station's antenna. Even so, large ranges of about 6 km were attained. This range seems enough for notifying any traffic incident to surroundings vehicles, for example within a university campus. As future work, we plan to fully implement the IPv6-capable communication stack, and integrate the LoRa technology with other different RATs extending our previous work in this line [9]. The aim of this strategy is having available a set of different-nature RATs in order to select the most proper one depending on the vehicular context.



(a) SF=12



(b) SF=7

Figure 4: Heat map representing the level of RSSI received by the moving vehicle in the V2V open field scenario. The red star represents the stopped vehicle and black lines represent shadow zones.

Figure 5: Heat map representing the level of RSSI received by the moving vehicle in the V2V scenario within the university campus. The red star represents the stopped vehicle.

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