Study on Effective Coverage of Low-Cost LoRa Devices

Laura García, Sandra Sendra, Jose M. Jimenez, Jaime Lloret
Integrated Management Coastal Research Institute
Universitat Politècnica de València
Valencia, Spain
e-mail: laugarg2@teleco.upv.es, sansenco@upv.es, jojiher@dcom.upv.es, jlloret@dcom.upv.es

Pascal Lorenz
Network and Telecommunication Research Group
University of Haute Alsace
Colmar, France
e-mail: lorenz@ieee.org

***Abstract*—The use of LoRa has extended to varied applications, such as precision agriculture, oceanography, or Smart Cities. The advertised long-range coverage is one of the main claims of this wireless technology. However, the effective coverage of the more affordable Long-Range (LoRa) devices may not provide the connectivity that is expected. Therefore, it is necessary to know the effective coverage of the LoRa devices available in the market in order to design a LoRa network. In this paper, a coverage test of LoRa with low-cost electronic devices is performed. The tests measured the Received Signal Strength Indicator (RSSI) and were performed with the 433 MHz and 868 MHz frequency bands, antennas with gains of 3 dBi and 5dBi, and all the Spreading Factor (SF) configurations. The results show that bad signal quality is received at distances of 1 km approximately and thus, the use of low-cost devices for larger distances is not advised.**

Keywords- LoRa; Coverage; RSSI; Spreading Factor; Gain.

I. INTRODUCTION

The introduction of wireless communications in varied scenarios, such as agriculture, oceanography, and the rise of Smart City solutions have led to the development of long-range wireless technologies, such as LoRa. LoRa is the specification of the physical layer and determines the modulation of this technology. One of the key aspects of the LoRa modulation is the Spreading Factor (SF), which indicates that the signal encompasses a bigger range of frequencies [1]. The main LoRa frequencies are 433 MHz, 868 MHz, and 915 MHz, which should be utilized according to the regulations of the location where the LoRa devices are deployed. On the other hand, the Medium Access Control (MAC) is specified by the Low Power Wide Area Network (LoRaWAN) protocol [2]. The nodes communicate with the gateway by forming a star topology. There can be multiple gateways to receive the data. Furthermore, three different device classes with variations in the amount of idle and on time are contemplated. However, as different technological solutions have different needs, new protocols and architectures for LoRa wireless communications have been designed [3]. These type of solutions substitutes LoRaWAN with the proposed protocols.

The use of LoRa has been contemplated for the detection of forest fires with systems that display the current data forwarded by the deployed nodes through a webpage [4]. The use of LoRa networks with multiple hops for Precision Agriculture (PA) is contemplated as well [3]. Monitoring infrastructures, such as a medieval aqueduct is also possible with multi-hop LoRa networks [5]. Furthermore, deploying LoRa sensing buoys [6] allows monitoring the state of the seas and transmitting the data to devices located at far distances, such as on-land stations. In order to design a deployment strategy for the aforementioned scenarios, aspects, such as coverage or energy consumption must be considered. However, the advertised transmission distances and energy consumption may not be the effective values reached by LoRa devices.

The official site of The Things Network advertises record LoRaWAN distances of 832 km [7]. Although this distance is obtained for specific LoRa settings, the advertised LoRa maximum distance is up to 15 km in line-of-sight deployments and up to 5 km in urban environments [1]. A few studies have been performed to determine the coverage of LoRa devices in different environments, such as urban areas with varied densities [8-10]. Some of them obtained results of 10 km for line-of-sight [9] or 8 km with a high Packet Loss Ratio [10]. However, these studies either do not specify the height of the transmitter and receiver nodes, or the node is located at the top of a building. Therefore, more coverage tests with other deployment configurations should be studied.

Another advertised aspect is its low cost. There are plenty of available devices in the low-cost price range. Furthermore, these devices are often coupled with low-cost antennas with low gains. Therefore, cost-effective solutions may obtain less coverage when utilizing LoRa. However, there are no studies available where low-cost devices are tested to determine the coverage that can be achieved with the use of this type of node. In this paper, the coverage of LoRa low-cost nodes considering different frequency bands, SF, and antennas. The Received Signal Strength Indicator (RSSI) was measured at different distances for each of the configurations. The tests were performed in a line-of-sight deployment where the transmitter was static, and the receiver moved to different measuring points.

The rest of the paper is organized as follows. Section 2 presents the related work. The description of the testbed is performed in Section 3. The results are discussed in Section 4. Lastly, the conclusion and future work are commented in Section 5.

II. RELATED WORK

Although more coverage studies of LoRa devices are necessary, there are some studies that have evaluated the performance of LoRa communications. Fabrizio J. Grión et al. performed in [8] a coverage study of LoRa networks in urban environments. Firstly, coverage tests were performed in cities with different densities of buildings so as to develop a model to determine the coverage of a certain area through simulations. The utilized frequency was 915 MHz with a gain of 6 dBi for the transmission antenna and 0 dBi for the reception antenna. Results show a good similarity between the tests perform in the city and the simulations. Madoune R. Seye et al. evaluated the coverage of LoRa performing tests utilizing the 868 MHz frequency band, a spreading factor of 12, and a transmission power of 14 dBm [10]. The emitter was placed at the top of a building and the receiver moved to different zones in an 8 km radius. Furthermore, the results show a packet loss ratio of 13% for distances between 0 and 2 km and up to 70% for distances between 6 and 8 km. Madoune R. Seye et al. also performed coverage tests in the Dakar peninsula to develop a path loss model for LoRa [11]. The tests were performed for the 868 MHz frequency band and a transmit power of 14 dBm. The results showed that the Dakar peninsula could be entirely on the area of coverage with a maximum acceptable RSSI of -120 dBm, which leads to a 40% Packet Error Rate. Moreover, if the maximum admissible RSSI is reduced to -110 dBm, the Packet Error Rate (PER) is reduced to 20% but the connectivity is not provided to the entire peninsula. Lastly, Jansen C. Liando et al. conducted varied tests to determine the performance of LoRa [9]. The results showed that LoRa was able to achieve a coverage of 10 km in line-of-sight deployments but is greatly affected by obstacles. Furthermore, the authors state that the reduced energy consumption is only achieved with certain parameter configurations. Lastly, the gateway was able to provide support to 6000 nodes with less than 70% of Packet Reception Ratio (PRR).

LoRa has been compared with other wireless technologies as well. Mads Lauridsen et al. compared the coverage provided by different wireless technologies, such as LoRa, SigFox, General Packet Radio Service (GPRS), and NarrowBand-Internet of Things (NB-IoT) [12] through simulation experiments. The results show the best coverage results and Maximum Coupling Loss performance for NB-IoT. However, LoRa and SigFox obtained link loss results with an average of 3dB lower values than that of NB-IoT. Lastly, outage probabilities lower than 5% were obtained for NB-IoT and SigFox. Benny Vejlgaard et al. performed a comparison between GPRS, SigFoz, LoRa, and NB-IoT in an area of 8000 km2 [13]. Both indoor and outdoor deployments were considered. For outdoor tests, all technologies obtained more than 99% of coverage. Furthermore, the results showed that NB-IoT was the only wireless technology that provided connectivity in indoor settings with a failure rate below 5%. SigFox obtained a failure rate of 12%, while LoRa and GPRS were not apt for indoor transmissions.

The interference LoRa devices cause to each other in multi-hop network deployments was evaluated by Guibing Zhu et al. [14]. Both simulations and experiments with LoRa transceivers were performed. The results showed that the higher the SF, the higher the immunity to collisions for both transmissions with the same SF and transmissions with different SF. Furthermore, the authors proposed the use of SF-pipeline and concurrent transmission in multi-hop LoRa networks to allow faster packet transmissions.

Lastly, other uses for LoRa include deploying the devices on drones or floating structures. Mario Marchese et al. presented a proposal for a LoRa Gateway on an Unmanned Aerial Vehicle (UAV) [15]. Different scenarios were considered, such as transmitting to a satellite through a UAV gateway and deploying the gateway on the base station. The 868 MHz frequency band was considered, and Arduino nodes and a Raspberry Pi gateway were the selected electronic devices. Laboratory tests were performed to determine the RSSI for different densities. Furthermore, Liu Xia et al. presented in [6] the Oriented omnidirectional perceptual coverage algorithm (VFOPCA) to increase the coverage of LoRa sensor buoys. Simulations tests were performed to compare the performance of the proposed algorithm to the virtual force algorithm. The results showed a better performance of the proposed algorithm with lower energy consumption and higher convergence speed.

Albeit there are some LoRa coverage tests, the available studies do not compare the results for different SF values, do not indicate the utilized devices, or use a very high placement of the emitter antenna. Therefore, there is a need for more studies to expand the knowledge on the effective coverage of LoRa devices. In this paper, we address this need by studying the signal quality of LoRa low-cost devices with different low-cost antennas.

III. TESTBED DESCRIPTION

In this section, the description of the utilized devices and performed tests is provided.

The utilized devices were Heltec LoRa/WiFi 32 nodes [16] for both emitter and receiver (see Figure 1). These nodes include an Organic Light-Emitting Diode (OLED) display and 36 pins. 433 MHz and 868 MHz nodes were used to perform tests with both frequency bands. The characteristics of the node are presented in Table 1.

Three different types of antennas were utilized. Two antennas for the 433 MHz frequency band were tested. The first antenna has a 3dBi gain and a Voltage Standing Wave Ratio (VSWR) below or equal to 1.5 (see Figure 2). Its working temperature range remains between -40 ºC and 85 ºC. Lastly, it has an input impedance of 50 Ω and a maximum input power of 10 W.

TABLE I. CHARACTERISTICS OF THE NODES.

Tx Power	17 dB
Frequency	433 MHz and 868 MHz
SF	7,8,9,10,11,12
Signal Bandwidth	125 KHz
Coding rate	4/5
Preamble length	8 Symbols
Height of the antenna	1.57 m

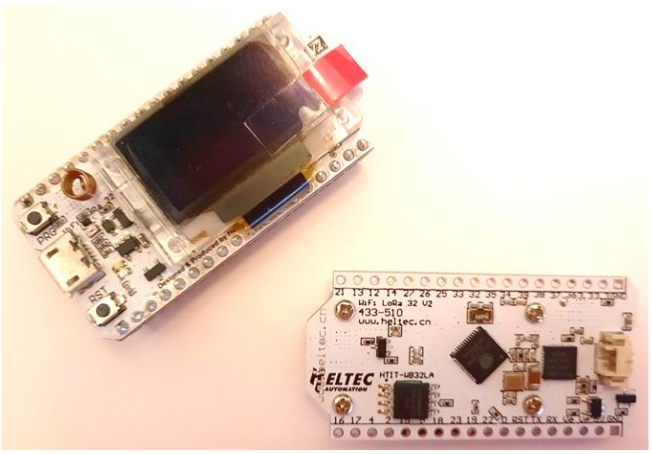

Figure 1. Utilized Heltec devices.

Figure 2. 433 MHz antenna with a gain of 3dBi.

The second 433 MHz antenna has a gain of 5 dBi (see Figure 3). It has a Sub-Miniature A (SMA) connector, a VSWR ≤ 1.5, an input impedance of 50 Ω, maximum power of 50 W, and a working temperature range between -40 ºC and 60ºC.

Figure 3. 433 MHz antenna with a gain of 5dBi.

Lastly, the antenna for the tests performed with the 868 MHz frequency band is presented in Figure 4. It has a gain of 3 dBi, a VSWR ≤ 1.5, maximum power of 10 W, and an input impedance of 50 Ω.

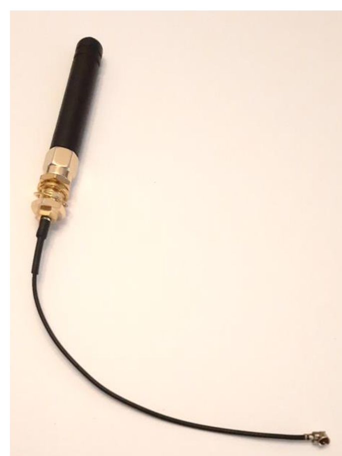

Figure 4. 868 MHz antenna.

The tests were performed on a wide street with buildings on one side and fields on the other side (see Figure 5). The satellite image of the area where the measures were taken is provided in Figure 6, with the street highlighted in yellow. The emitter was placed at the beginning of the street and the receiver moved to different measuring points.

Figure 5. Location of the tests.

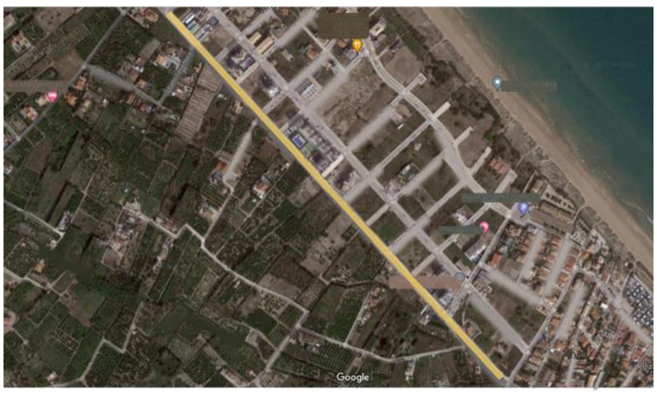

Figure 6. Satellite image of the location of the tests.

There were no obstructions between the emitter and receiver nodes. The RSSI was obtained for each of the measuring points. Moreover, the test was repeated for each of the antennas and each of the SF for the corresponding frequency band.

IV. RESULTS

In this section, the results from the performed tests are presented.

The results for the 868 MHz frequency band with the 3 dBi antenna are presented in Figure 7. As it can be seen, the RSSI values presented fluctuations for all the SF even in the absence of obstacles. The SF 7 was the one with the better signal at close distances. However, as the distance increased, other SF configurations presented better results. On the other hand, the SF 11 was the one with the overall worst RSSI values. The rest of the SF configurations have obtained similar RSSI values. Therefore, for this frequency band and this type of antenna, the selection of the SF does not seem to have a significant impact o the quality of the signal. So, other aspects should be considered for the selection of the best SF.

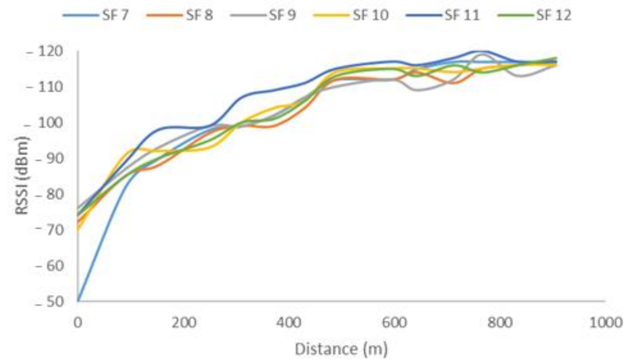

Figure 7. RSSI for 868 MHz and 3dBi antenna.

The results for the 433 MHz frequency band and the 3dBi antenna are shown in Figure 8. In this case, it is more evident that the SF 7 configuration leads to better signal quality. Although for the last measuring point, the RSSI values of SF 7 are similar to those of the rest of the SF configurations. The SF 10 is the second-best configuration, with the other SF configurations having lower signal quality. Moreover, SF 11 would be the SF with the worst RSSI values. As the difference between SF configurations is more evident for this antenna, the selection of the SF should be considered when designing a LoRa network with these devices. However, it would apply mostly for the SF 7 configuration, as the other SF present fewer differences.

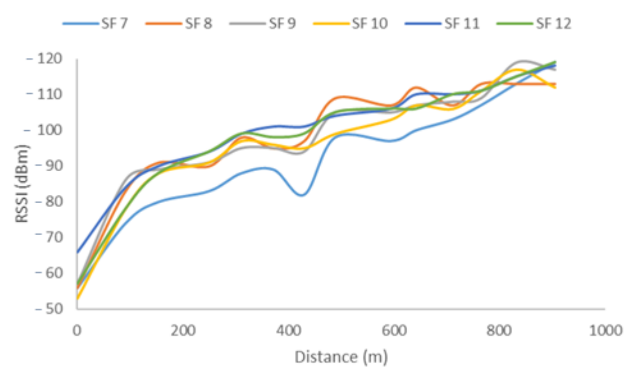

Figure 8. RSSI for 433 MHz and 3dBi antenna.

Lastly, Figure 9 shows the RSSI values for the frequency band of 433 MHz and the antenna of 5 dBi. SF 7 and SF 10 have the best signal quality. However, there is not a clear difference between SF configurations as in the case of Figure 8. On the other hand, SF 11 and 12 present the worst signal quality, with little difference between both configurations. The rest of the SF configurations present similar results to those of SF7 ad SF 10. As in the case of the 868 MHz frequency band, there is no highly noticeable difference between the different SF values, therefore, other aspects should be considered when selecting the best configuration.

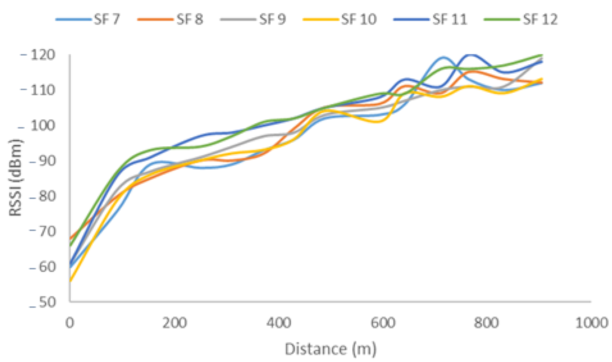

Figure 9. RSSI for 433 MHz and 5dBi antenna.

Figure 10 presents the average values of all SF values for each frequency band and antenna in order to compare the three studied cases. As it can be seen, on average, the two antennas for the 433 MHz frequency band have similar results. However, the average shows better results for the 3 dBi antenna due to the less noticeable difference between the results for each SF. Regarding the 868 MHz frequency band, the average of the RSSI values shows a lower image quality than that of transmitting with 433 MHz.

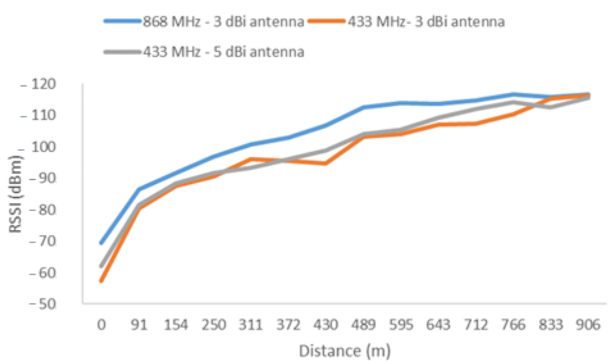

Figure 10. Average RSSI for each frequency band and antenna.

Considering the results for all the cases, we can conclude that the use of low-cost LoRa devices and antennas cannot be advised for distance requirements larger than 1 km. In those cases, other solutions such as multi-hop LoRa protocols should be employed to transmit the data to the desired location. Furthermore, the difference in the gain of the antennas for the 433 MHz frequency band was not reflected in the obtained results. For the case of the 868 MHz frequency band, the difference in SF configurations barely affects the received quality of the signal.

V. CONCLUSION AND FUTURE WORK

As LoRa gains more interest, the deployment of LoRa devices in locations such as cities, fields, or sensor buoys. LoRa transmissions have reached record distances up to 832 km. Moreover, although the expected distances range from 10 to 40 km depending on the obstructions in the area, low-cost LoRa devices do not reach those expectations. In this paper, we have performed coverage tests with cost-effective LoRa devices and antennas. The RSSI was measured for the frequency bands of 433 MHz and 868 MHz, all the SF configurations, and antennas with gains of 3 dBi and 5 dBi in line-of-sight conditions. The results show that the selection of different SF may not affect the quality of the received signal, such as for the 868 MHz frequency band. Furthermore, the combination of low-cost LoRa devices and low-cost antennas does not provide coverage greater than 1 km. Therefore, other solutions, such as multi-hop LoRa networks should be implemented when there is an interest in deploying low-cost devices.

For future work, we will perform tests with LoRa devices and antennas in the medium price range. Furthermore, tests will be performed with different types of content, such as data from sensors or images so as to assess the performance of LoRa and the devices with different traffic demands. Lastly, a multi-hop solution will be created to increase the distance achieved by LoRa networks.

ACKNOWLEDGMENT

This work has been partially funded by the European Union through the ERANETMED (Euromediterranean Cooperation through ERANET joint activities and beyond) project ERANETMED3-227 SMARTWATIR, by the "Programa Estatal de I+D+i Orientada a los Retos de la Sociedad, en el marco del Plan Estatal de Investigación Científica y Técnica y de Innovación 2017-2020" (Project code: PID2020-114467RR-C33) and by "proyectos de innovación de interés general por grupos operativos de la Asociación Europea para la Innovación en materia de productividad y sostenibilidad agrícolas (AEI-Agri)" in the framework "Programa Nacional de Desarrollo Rural 2014-2020", GO TECNOGAR. This work has also been partially funded by the Universitat Politècnica de València through the post-doctoral PAID-10-20 program.

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