Performance Analysis of LoRa and Zigbee for Application in Industry 4.0

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Abstract. The Industry 4.0 concept has been progressively consolidated worldwide and much of its success is due to the use of LPWA communication technologies. Among them, LoRa and Zigbee have stood out since, in addition to low power consumption and long-range, they are low cost and use spread spectrum technique to increase the system's robustness to interferences. In this context, this work presents a study of these technologies' performance for indoor and outdoor environments to analyze the feasibility of their use in Industry 4.0.

Keywords: Industry 4.0 · IoT · LPWA · LoRa · Zigbee

1 Introduction

In recent years, the world industry has undergone a real revolution. The concept of Industry 4.0 has been deployed to offer Internet of Things (IoT) technologies for the monitoring and control of industrial processes [1]. One reason for its rapid growth was the adoption of wireless LPWA (Low Power Wide Area) communication technologies. Among them, the LoRa (Long Range) and Zigbee technologies have shown to be very promising since they offer devices with affordable prices and of easy acquisition, reduced deployment costs and good immunity to interference (spread spectrum techniques), in addition to low consumption (e.g., in the order of 10 years) and long-range (e.g., few km) [2–4].

The performance of these technologies in different radio propagation environments, such as those found in industrial plants, is currently a very important issue for the successful implementation of the Industry 4.0 concept and, as a result, several works have been published recently in the scientific literature [1, 5–7].

In this context, this work aims to present a comparative study between LoRa and Zigbee technologies based on experimental measurements carried out in both indoor and outdoor environments to verify their feasibility in Industry 4.0. The analysis will use the measured values of RSSI (Received Signal Strength Indication), PER (Packet Error Rate), and the estimated maximum range as performance references.

In addition to the introduction, this text is divided into four additional sections. Section 2 presents a brief description of the evaluated technologies. Section 3 shows the

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measurement tests. Section 4 shows a radiopropagation model analysis. Finally, Sect. 5 concludes the work.

2 Technologies Overview

LoRa uses Chirp Spread Spectrum (CSS) and has been specified to operate on some specific ISM (Industrial, Scientific, and Medical) bands. In this work, the 915 MHz band standard was chosen as it uses the frequency band adopted in Brazil. LoRa has a very interesting feature: it allows the adjustment of some important parameters of the system, such as SF (Spreading Factor), BW (Bandwidth), and CR (Coding Rate), which can vary, respectively, from 7 to 12, 125 to 500 kHz, and 4/5 to 4/8 [8]. According to these parameters, the data rate can vary from 0.3 to 50 kbps.

On the other hand, Zigbee employs Direct Sequence Spread Spectrum (DSSS). It has been standardized to operate on three different ISM bands, each with very different characteristics [9]. In this work, the 2.4 GHz standard will be employed, as it is the most used standard in Brazil. It employs quasi-orthogonal modulation based on OQPSK (Offset Quaternary Phase Shift Keying) and can achieve data rates in the order of 250 kbps [6].

3 Performance Analysis

This work aims to evaluate and compare the performance of LoRa and Zigbee technologies from the point of view of quality (RSSI and PER) and transmission range. Due to industrial plants' characteristics, the performance of the systems will be analyzed for both indoor and outdoor environments.

For LoRa performance analysis, two ESP-LoRa devices based on the SX1276[1] chip operating at 915 MHz and positioned 2.0 m from the ground were used, one acting as a transmitter (TX) and the other as a receiver (RX). The research was based on the eight possible LoRa operating configurations presented in Table 1 for the different possible combinations of SF, BW, and the transmission power (P_{TX}) [1].

For Zigbee analysis, two Xbee-Pro devices (TX and RX) operating at 2.4 GHz were used. Each device was connected to an embedded Arduino Mega system for the control and transmission of packets and, as in the LoRa tests, both were positioned at 2.0 m from the ground.

3.1 Indoor Environment

The indoor environment tests were carried out in the basement of the A building of the Federal University of ABC (UFABC), Santo André. The performance of LoRa and Zigbee was analyzed from the measurements of the RSSI and PER parameters. During

[1] https://semtech.com/products/wireless-rf/lora-transceivers/sx1276.

the measurements, the TX was kept fixed and the RX was moved from 10 to 10 m until reaching 100 m. It is important to note that the systems were exposed to different interferences on the site, such as, for example, cochannel interference from WiFi (Wireless Fidelity) networks in operation. Specifically for LoRa, measurements were performed for all configurations presented in Table 1.

Table 1. LoRa configurations.

Configurations	SF	BW (kHz)	P_{TX} (dBm)
Config 1	7	125	14
Config 2	12	125	14
Config 3	7	125	20
Config 4	12	125	20
Config 5	7	500	14
Config 6	12	500	14
Config 7	7	500	20
Config 8	12	500	20

The indoor environment where the tests were performed is presented in Fig. 1.

Fig. 1. Indoor environment.

Figure 2 presents the RSSI variation as a function of d for the analyzed indoor environment. It can be seen that for LoRa, the measured values of RSSI was between –60 and –96 dBm. For Zigbee, it can be seen that up to 50 m, the RSSI was higher than –50 dBm, while, above 50 m, it was higher than –65 dBm.

In turn, Fig. 3 presents the results of PER as a function of *d* for Lora (Config 1 and Config 6) and Zigbee in the analyzed indoor environment. In the tests, three different measurement points were defined (10, 50, and 100 m) and, at each point, 10.000 packets were transmitted. It can be seen that up to 100 m, the LoRa presented a maximum PER of 2.2% for Config 1 and 1.8% for Config 6. For the Zigbee, the maximum PER was 0.4% between 10 m and 50 m. However, for 100 m, there was a significant increase in PER, which was around 22.5%.

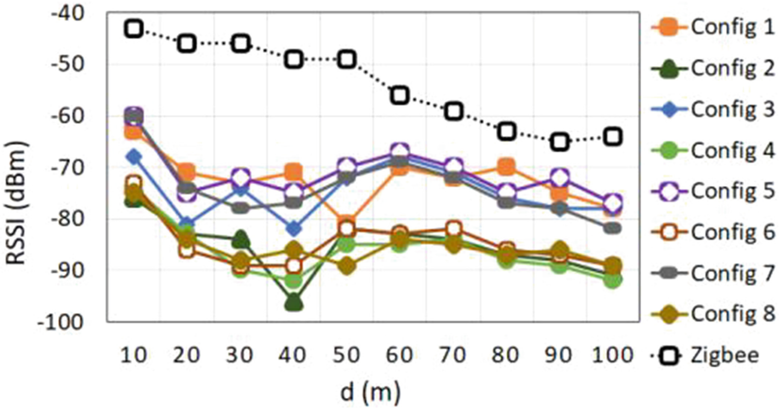


Fig. 2. RSSI as a function of *d* in the indoor environment.

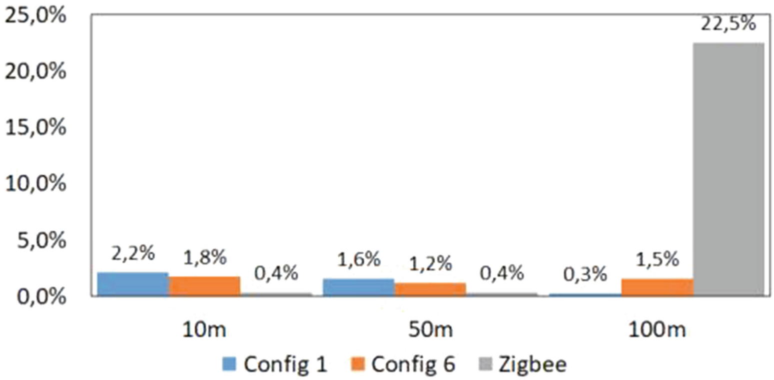
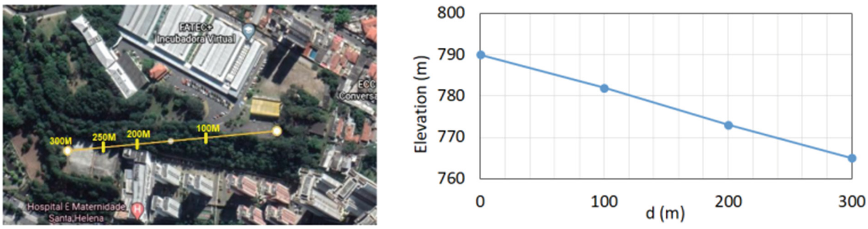


Fig. 3. PER as a function of *d* in the indoor environment.

3.2 Outdoor Environment

The outdoor measurements were carried out at the Faculty of Technology (FATEC), São Bernardo do Campo. Figure 4 shows the environment where the tests were performed. During the measurements, the TX was kept fixed and the RX was placed at 100, 200, 250, and 300 m away from TX, both at a height of 2.0 m from the ground. For simplicity, LoRa measurements were performed only for Config 1 and Config 6. Figure 5 shows the measurement points (a) and the terrain's elevation profile (b). It can be seen that the maximum slope between TX and RX is of 22.0 m.

Fig. 4. Outdoor environment.



(a) Distances (b) Elevation

Fig. 5. Measurement points and terrain elevation of the outdoor environment.

Figure 6 presents the RSSI as a function of *d* for the analyzed outdoor environment. For LoRa, it can be seen that the RSSI varied from –80 to –110 dBm for Config 1 and from –85 to –110 dBm for Config 6, for distances between 50 and 300 m. As the reception sensitivity of LoRa devices is –148 dBm, the system operated properly within the analyzed range (making it possible to cover even greater distances, by the margin shown). In the case of Zigbee, the RSSI varied from –57 to –83 dBm, between 50 and 250 m. However, it was not possible to measure the RSSI in 300 m, since all packets were received with errors, indicating the level of the received signal was below the reception sensitivity of –102 dBm of Zigbee devices.

On the other hand, Fig. 7 presents the results of PER as a function of *d* for Lora (Config 1 and Config 6) and Zigbee in the analyzed outdoor environment. For Lora, it can be seen that up to 300 m, Config 1 presented a maximum PER of 3.0%, while Config 6 showed a maximum PER of 2.5%. For the Zigbee, the PER at 200 m was 34.71%, a value worse than 6.17%, measured at 250 m. This is mainly due to the environment's dynamic characteristics, such as the circulation of people and vehicles around the tests. However, at 300 m, Zigbee stopped working properly and all data packets were received with errors (corresponding to a PER of 100%).

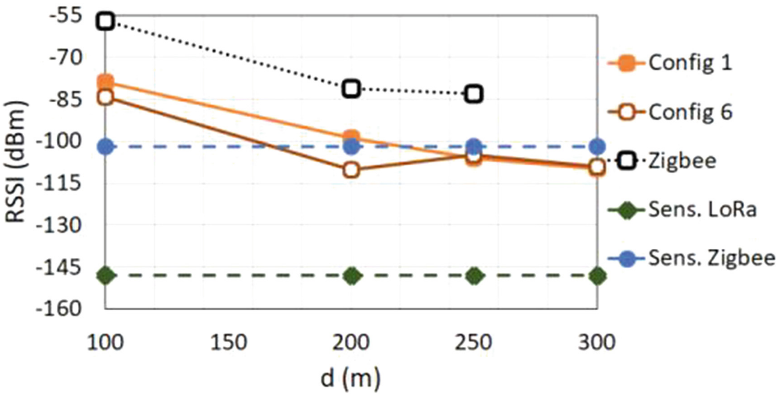


Fig. 6. RSSI as a function of d in the outdoor environment.

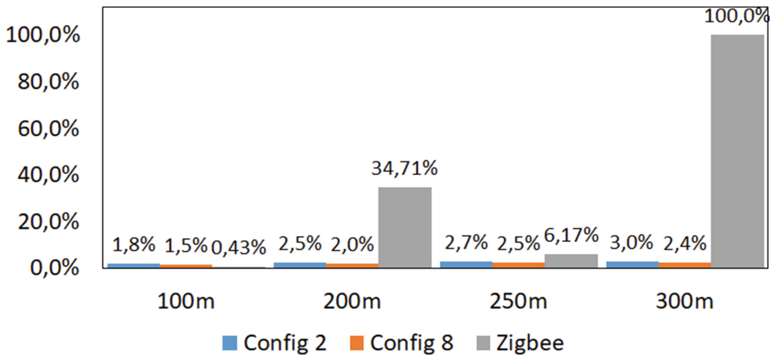


Fig. 7. PER as a function of d in the outdoor environment.

4 Shadowing Propagation Model

To estimate the mean received power (P_{RX}) as a function of d, the Shadowing Propagation Model (SPM) was used due to its flexibility, simplicity, and possibility of application when practical measures are taken. This model is based on the modified free space model and uses a log-normal random variable X_{SH} to represent the shadowing effect of the environment, which can be quantified by the value of its standard deviation σ_{SH}, expressed in dB [6, 10]. The P_{RX} for the SPM can be represented by:

$$P_{RX}(d) = P_{RX}(d_0) - 10 \cdot \gamma \cdot \log_{10}\left(\frac{d}{d_0}\right) + X_{SH} \tag{1}$$

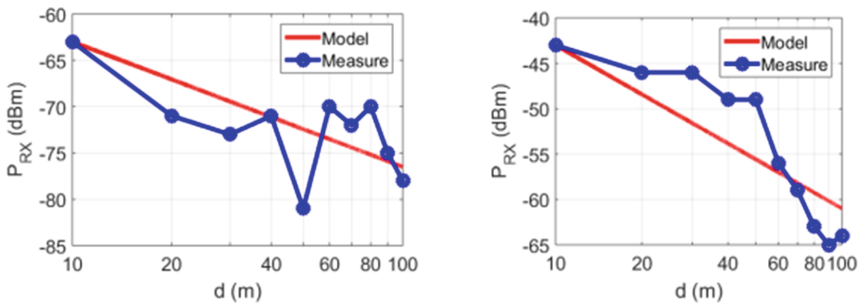
Where: d_0 is the reference distance, $P_{RX}(d_0)$ is the mean power received at d_0, $P_{RX}(d)$ is the mean power received in d, and γ is the propagation coefficient of the environment.

Table 2 shows the values of γ and σ_{SH}, determined by a logarithmic regression method [6], for LoRa (for all configurations analyzed) and Zigbee frequency bands in the indoor environment.

Table 2. Obtained γ and σ_{SH} of the indoor environment.

Configurations	γ	σ_{SH}
Config 1	1.35	3.86
Config 2	1.35	4.38
Config 3	0.9	5.10
Config 4	1.74	4.07
Config 5	1.57	4.54
Config 6	1.60	4.60
Config 7	1.97	4.86
Config 8	1.45	3.13
Zigbee	1.8	3.9

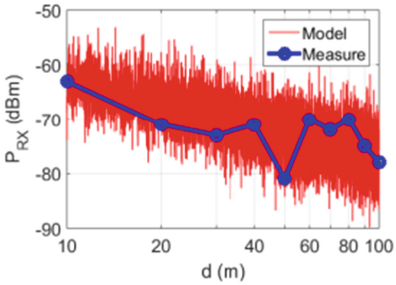
Figure 8 shows the measured P_{RX} and the P_{RX} obtained through SPM for the analyzed indoor environment. In order to make the LoRa analysis clearer, without loss of generality, only Config 1 curves were presented in the figure. Analyzing the results, it is possible to verify that the P_{RX} shows some variations along d, mainly caused by cancellations of multipath components of the order of multiples of half the wavelength of the transmitted signal. For Zigbee, it can be seen that the measured P_{RX} also varies due to the cancellations of the multipath components. It is important to note that, due to the physical limitation of the environment (i.e., 100 m), it was not possible to obtain an estimate of γ and σ_{SH} for distances greater than the critical distance (D_c) [6]. In turn, Fig. 9 shows the random effect of the shadowing component on the P_{RX} curve obtained by SPM in the indoor environment for LoRa (Config 1) and Zigbee. The measured P_{RX} curve is also shown as a reference.



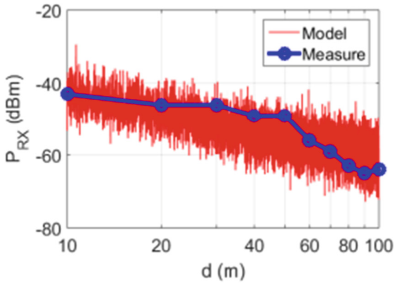
(a) LoRa (Config 1) (b) Zigbee

Fig. 8. P_{RX} as a function of d for the indoor environment.

Table 3 presents the obtained values of γ and σ_{SH} for Lora (Config 1 and Config 6) and Zigbee in the analyzed outdoor environment. It can be seen that high values of γ were obtained due to the characteristics of the analyzed environment (e.g., slope between



(a) LoRa (Config 1)



(b) Zigbee

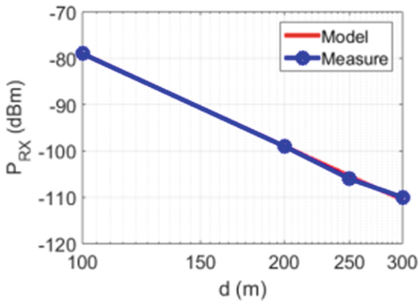
Fig. 9. P_{RX} as a function of d for the indoor environment, considering the shadowing effect.

TX and RX, path obstructions) and the measurements use some points with distances greater than D_c (e.g., after D_c, γ change to a higher value due to ground reflections) [6].

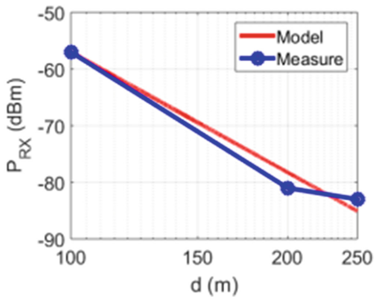
Table 3. Obtained γ and σ_{SH} of the outdoor environment.

Configurations	γ	σ_{SH}
Config 1	6.62	0.44
Config 6	5.8	4.73
Zigbee	7.06	2

Figure 10 shows the values of the measured P_{RX} and the P_{RX} obtained by the SPM for the outdoor environment. For simplicity, only the LoRa results for Config 1 are shown. It can be seen that a good fit was obtained between the model used and the measured values for both systems. On the other hand, Fig. 11 shows the effect of shadowing on the P_{RX} curve obtained by the SPM for LoRa (Config 1) and Zigbee in the outdoor environment. The measured P_{RX} curve is also shown.

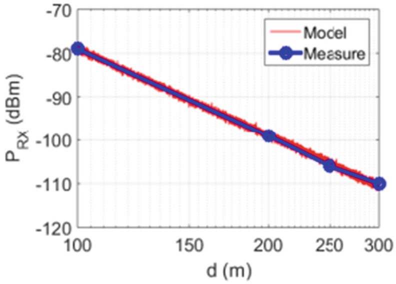


(a) LoRa (Config 1)

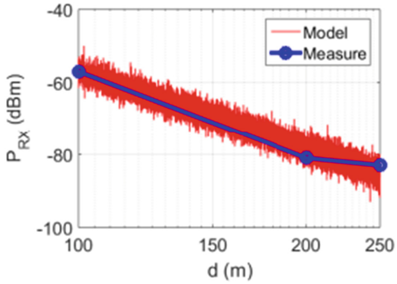


(b) Zigbee

Fig. 10. P_{RX} as a function of d for the outdoor environment.



(a) LoRa (Config 1)



(b) Zigbee

Fig. 11. P_{RX} as a function of d for the outdoor environment, considering the shadowing effect.

An estimate of the analyzed systems' maximum range can be obtained (according to the reception sensitivity) by extrapolating the P_{RX} curve obtained from the SPM. In this way, it can be seen that the maximum range of LoRa (Config 1) is 1.1 km, while the range of Zigbee is limited to 433.9 m.

5 Conclusions

The results obtained indicate that the evaluated Zigbee system has a better performance than the LoRa system used for a range of up to 50 m for indoor and outdoor environments. However, in a more in-depth analysis, also considering coverage above 50 m, the LoRa proved to be the most suitable choice for low rate, low consumption, and long-range applications. Operating in the 915 MHz frequency band, which is less congested than the 2.4 GHz band, and having a better reception sensitivity, the LoRa offers wider coverage with better signal quality, which is ideal for use in Industry 4.0.

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