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Performance Evaluation of LoRaWAN SX1276 Radio in Non-Line of Sight conditions

Olaide Ayodeji Agbolade *

Department of Electrical and Electronics Engineering, Federal University of Technology Akure, Ondo State, Nigeria.

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Abstract

The study presents a comprehensive performance evaluation of the SX1276 radio module within LoRaWAN technology under Non-Line of Sight (NLOS) conditions. LoRaWAN's proliferation in IoT applications demands a thorough understanding of its performance in challenging environments. This study investigates NLOS scenarios, identifying factors influencing signal strength, packet loss, and latency. Finally, the performance of the network under LOS condition was compared to NLOS to shed light on NLOS challenges. Results showed that spreading factor and transmission power are the most critical parameters that influences the performance of the network. Results from the study also shows that in LOS condition the spreading factor 7 has the highest data rate but also the least range. Furthermore, the study revealed that using high spreading factor is more beneficial than high transmission power in non-line of sight conditions. Finally, by comparing both conditions, LoRaWAN nodes under LOS condition was found to have a range of up to 5 km as against 1 km at NLOS which further highlight the importance of LOS in LoRa transmissions.

Keywords: LoRaWAN; IoT; Line of Sight; SX1276; LPWAN; Chirp Spread Spectrum

1. Introduction

The rapid expansion of the Internet of Things (IoT) has ushered in an era of connectivity where billions of devices communicate seamlessly, enabling smarter cities, efficient industries, and enhanced consumer experiences [1]. Among the myriad of IoT wireless technologies like Wi-Fi and Bluetooth, Low Power Wide Area Networks (LPWANs) have emerged as a pivotal enabler, offering long-range, low-power connectivity for a diverse range of applications. Within the LPWAN landscape, LoRaWAN (Long Range Wide Area Network) has garnered significant attention for its ability to provide robust, energy-efficient communication [2].

LoRaWAN unlike cellular networks [3], characterized by its long-range transmission capabilities and low power consumption, has found applications in agriculture, environmental monitoring, smart cities, and industrial automation, to name a few [4]. However, the successful deployment of LoRaWAN networks hinges on understanding and optimizing their performance under various environmental conditions. One such condition that poses a formidable challenge is Non-Line of Sight (NLOS) propagation.

NLOS conditions occur when obstacles such as buildings, foliage, or terrain obstruct the direct line of sight between LoRaWAN nodes. NLOS scenarios are pervasive in urban environments, indoor deployments, and rugged terrains, rendering them critical for many real-world IoT applications [5]. Yet, the complexities introduced by NLOS environments have not been comprehensively addressed in the literature.

This study addresses this research gap by undertaking a systematic and thorough evaluation of the performance of the SX1276 radio module, a key LoRa module in many LoRaWAN deployments, under NLOS conditions. Navigating NLOS scenarios demands an in-depth understanding of the impact of obstructions on signal strength, packet loss rates, and

* Corresponding author: Agbolade O. A

latency, among other metrics. Our study seeks to shed light on these critical aspects, ultimately providing insights that can inform the design and optimization of LoRaWAN networks in NLOS-prone environments.

The objectives of this research are twofold: first, to assess the performance of the SX1276 radio module in NLOS scenarios, and second, to identify the key factors influencing LoRaWAN performance in NLOS conditions. By achieving these objectives, we aim to contribute valuable knowledge to the growing body of literature surrounding LPWAN technologies, facilitating the realization of IoT's full potential in challenging environments.

The remainder of this article is organized as follows: Section II provides a comprehensive review of related literature, Section III outlines our research methodology, Section IV presents the results of our experiments, Section V discusses the conclusion and implications of our findings.

2. Review of Past Literatures

LoRaWAN, an integral part of the LPWAN family, stands out for its ability to provide long-range, low-power wireless communication. This technology has gained prominence due to its suitability for a wide range of IoT applications. LoRaWAN operates in the unlicensed ISM (Industrial, Scientific, and Medical) bands, which enables it to offer extensive coverage and excellent penetration through obstacles, making it particularly attractive for use cases like smart agriculture, asset tracking, and smart cities [6].

LoRaWAN's key features include its long-range capability, which can extend up to several kilometers in open environments, and its low power consumption, making it suitable for battery-powered devices with extended lifespans [7]. The technology uses chirp spread spectrum modulation, allowing it to achieve an impressive link budget, making it resilient to interference and environmental challenges.

Due to the relatively low data rate obtainable on LoRaWAN, the technology has been oftentimes used with applications that are insensitive to delays and packet loss [8]. Some of these applications include asset tracking [9], pipeline monitoring [10], [11], metering [12] among several others.

Collision is a critical problem in LoRaWAN and as such as the focus of most study on the technology. Collisions occur when multiple LoRaWAN devices transmit data simultaneously on the same channel, leading to signal interference and packet loss [13]. These collisions can be caused by factors like unsynchronized timing, different spreading factors, or dynamic data rate adjustments [14]. The consequences include increased latency, reduced battery life for IoT devices, and diminished network efficiency. Efficient collision mitigation strategies, such as adaptive data rate algorithms and listen-before-talk protocols, are vital to ensure that LoRaWAN networks provide reliable, energy-efficient communication for a wide range of IoT applications. The advent of artificial intelligence like neural networks [15], [16] have been employed extensively in literature to advance LoRaWAN progress in mitigating collision-related challenges.

In LoRaWAN, Spreading Factor (SF) and transmission power are two key parameters that significantly impact the network's performance and coverage, hence several studies like [17], [18] are dedicated to optimizing the two parameters. SF determines the signal's range and robustness. A lower SF provides longer range but lower data rates, making it suitable for distant devices. Higher SFs offer faster data rates but shorter range, ideal for nearby devices. Transmission power determines the signal strength. Higher power enables longer communication distances but consumes more energy. Balancing SF and transmission power is crucial for optimizing LoRaWAN networks, as it directly affects data rates, energy consumption, and the network's ability which is why it has been used to develop business sustainability for the technology [19].

A common requirement in most wireless communication is the line of sight. Nevertheless, Non-Line of Sight (NLOS) conditions are a prevalent challenge in the deployment of LoRaWAN networks, particularly in urban environments and indoor scenarios. NLOS scenarios occur when signals encounter obstacles that obstruct their direct path between transmitter and receiver. Such obstacles can include buildings, walls, trees, and other environmental structures.

In NLOS scenarios, signal attenuation and multipath propagation become significant concerns. Signal attenuation results from the absorption, scattering, and reflection of radio waves by obstacles, leading to reduced received signal strength [20]. Multipath propagation introduces delays and phase shifts in received signals due to reflections, which can result in packet collisions and increased latency. Understanding the complexities of NLOS environments is crucial for optimizing LoRaWAN networks, as it directly impacts network reliability, coverage, and energy efficiency.

The SX1276 radio module employed in this study was developed by Semtech and is a popular choice for LoRaWAN deployments. This module operates in the sub-GHz frequency bands (typically 868 MHz or 915 MHz) and is known for its robust performance and flexibility thus making it popular among radio waves application [21]. The SX1276 offers a wide range of programmable parameters, allowing network operators to fine-tune its behavior to suit specific deployment scenarios.

Previous research involving the SX1276 module has primarily focused on its performance under ideal line-of-sight conditions. While these studies have provided valuable insights into LoRaWAN's capabilities, there is a notable lack of comprehensive investigations into its performance in NLOS environments. Understanding how the SX1276 radio module behaves in the presence of obstacles and the factors influencing its performance in NLOS conditions is essential for optimizing LoRaWAN networks in real-world applications.

3. Research Methodology

The methodology employed in this study are as described in this section. The LiLyGo LoRaWAN version 2.1 module was used for this study. The LiLyGo module features the ESP32 microcontroller and an SX1276 LoRa chip. The module has a 4 MB flash memory and a CH9102 serial chip with both Wi-Fi and Bluetooth 4.2 wireless protocol. The module also includes support for TF card and features a 3D Wi-Fi SMA Antenna with a 2 dBi gain. Also included in the module are a USB micro and LiPo battery dual power supply. Two modules were used for the experiment with one serving as a transmitter and the other the receiver. The picture of the module is as shown in Fig. 1. Different spreading factor and transmission power were configured on the module and the impacts on the performance of the module was investigated.

Figure 1 The LiLyGo LoRa SX1276 Version 2.1 Module

The location for the experiment is as shown in Fig. 2. From the Figure, the area covers a stretch of about 2 kilometers with thick foliage and plantation along the road stretch.

Figure 2 Google Map of the selected location

In all scenarios, we calculated the energy consumption of the module and the corresponding range with each parameter allocation.

4. Result and Discussion

The two critical parameters in LoRaWAN parameter allocation are the transmission power (TP) and spreading factor (SF). The current drawn during transmission by the module at different spreading factor with the transmission power fixed at 14 dB is shown in Table 1. The result showed that the spreading factor 7 has the lowest consumption at 12.52 mA while spreading factor 12 has the highest at 97.23 mA.

Table 1 Current Usage at Each Spreading Factor by SX1276 Radio

SF	current (mA)
7	12.52
8	26.26
9	41.67
10	76.55
11	90.82
12	97.23

The energy used by spreading factor 12 is further excerberated by the fact that spreading factor 12 has the highest airtime. Fig. 3 shows that the impact of spreading factor on the LoRaWAN transmission while Fig. 4 showed the energy consumption of at different transmission power. By comparing Fig. 3 and 4, it is obvious that the spreading factor has a more profound impact on the performance of LoRaWAN than transmission power since every step increase in the spreading factor leads on the average to a 211.13 percent increase in energy consumption whereas for the transmission power, a step increase in the transmission power only leads to a corresponding 11.32 percent increase in energy consumption. Fig. 4 also shows that energy consumption increases slightly as the transmission power is increased from 2 dBm up to the maximum allowable power level of 14 dBm.

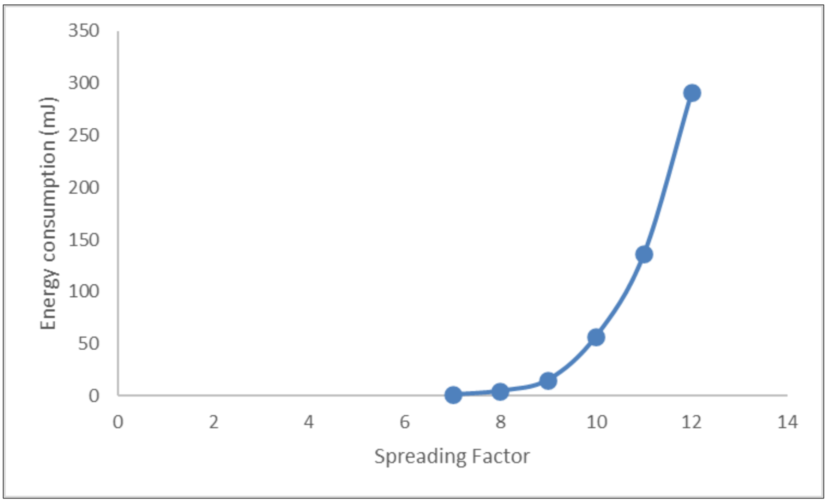

Figure 3 Energy Consumption at different SF

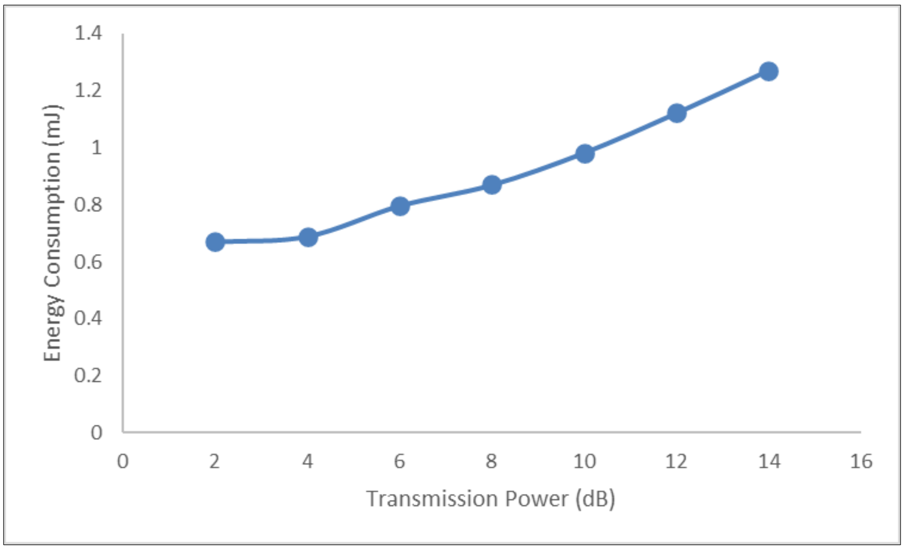

Figure 4 Energy Consumption at Different TP

To verify the impact of the spreading factor and transmission power in LoRaWAN under the non-line of sight condition investigated in this study, a range test was carried out.

The result of the range test at different spreading factor and transmission power is shown in Fig. 5 and 6 respectively.

The result presented in Fig. 5 shows a slight increase in transmission range with increase in transmission power. Each 2dB increase in transmission power produced an approximate 3.39 percent increase in transmission range.

Fig. 6 shows how transmission range changes with changes in the assigned spreading factor. From the result presented in Fig. 6, spreading factor has a much more pronounced effect on the coverage of LoRaWAN devices. The experiment could not go beyond the spreading factor of 10 due to the shortness of testing space. From the abridged result obtained in Fig. 6, each step increase in the spreading factor results in about 20 percent increase in range. This figure is expected to be far more than this in a proper line of sight condition.

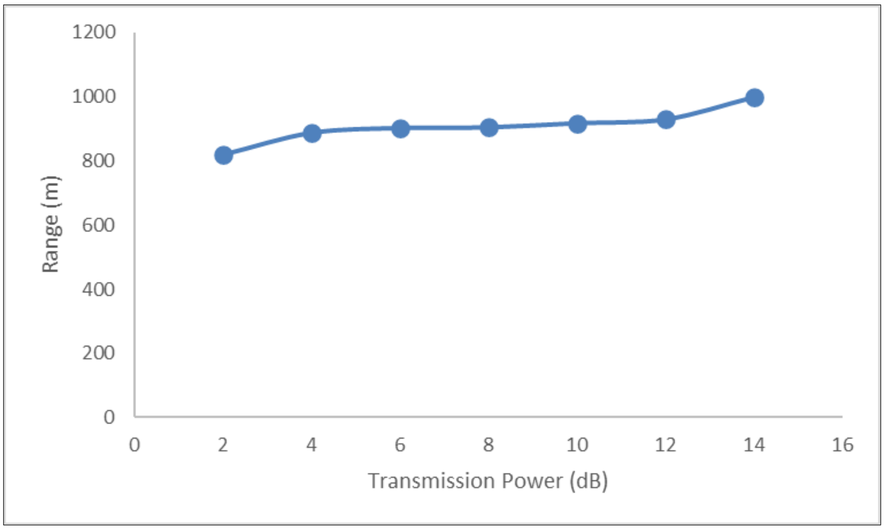

Figure 5 Range Covered by LoRa Node for Each Transmission Power

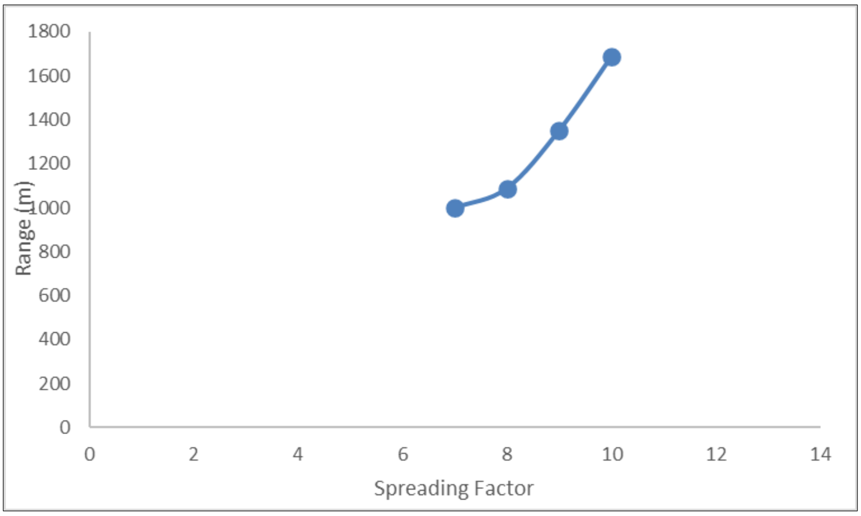

Figure 6 Range Covered by LoRa Node for Each Spreading Factor

Finally, the results obtained from this study were compared with a similar study carried out by authors in [22] under LOS condition. The authors reported at spreading factor 7, a transmission range of up to 5 km was recorded which was five times the maximum of 1 km recorded in this study under NLOS condition. This highlights the importance of maintaining LOS in LoRaWAN implementation.

5. Conclusion

In this study we employed the use of the LiLyGo module which integrates the ESP32 microcontroller and LoRa SX1276 chip into a single board. The module was used to measure the energy consumption of LoRa at different spreading factor and transmission power to highlight the importance of spreading factor and transmission power selection in LoRaWAN. Furthermore, the performance of the module in terms of energy consumption and transmission range under non-line-of-sight condition was investigated. A comparison of the result obtained in LOS condition and NLOS conditions highlight the importance of maintaining a LOS in LoRaWAN applications. However, it is always difficult to always ensure this in most applications that are installed in urban regions or densely forested areas. Consequently, this study recommends the installation of LoRa gateways on top of towers or on tall buildings to always ensure improved LOS.

Compliance with ethical standards

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Disclosure of conflict of interest

The author has no conflict of interest in this study.

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