Performance assessment of a Low-Power Wide-Area wireless network based on LoRa technology using IoT devices in different Bolivia areas

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Abstract— This project focuses on the implementation and performance analysis of a Low Power Wide Area Network (LPWAN) using IoT devices in an urban environment. We develop an IoT Node and a Gateway designed to emulate the behavior of a LoRa network architecture. The technical parameters of these devices have been rigorously validated through extensive measurement campaigns and theoretical simulations using advanced radio propagation simulation software. The collected data and simulation results provide a comprehensive assessment of the LoRa technology's performance, demonstrating its effectiveness and reliability in the specified urban and rural context.

Keywords— AWS, IoT, LoRa, LoRAWAN, LPWAN

I. INTRODUCTION

The Internet of Things (IoT) connects the physical and digital world, revolutionizing business operations. Smart objects, equipped with processing and communication capabilities, interact either directly or through cloud servers[3]. This connectivity enhances process automation and problem resolution. We have investigated technologies that optimize IoT device performance, focusing on energy efficiency, frequency reuse, extended coverage, and reduced network costs.

Smart devices are characterized by limitations in processing power and energy, making wireless communication a significant challenge. Recently, numerous technologies and standards for radio frequency communication have emerged. This work focuses on Low Power Wide Area Networks (LPWAN), particularly LoRa (Long Range) technology. LoRa is designed to address the challenges of long range, low power communication by implementing its own protocol, known as LoRaWAN, which defines the system architecture and communication parameters[4].

In this project, we conduct a coverage analysis by modifying the propagation factor, transmission power, and bandwidth of LoRa transmitters. We describe the properties, network architecture, capacity, and limitations of LoRaWAN technology.

Low Power Wide Area Networks (LPWAN) are an emerging paradigm in IoT networks, designed to meet three key requirements of IoT applications: low cost, large scale deployment, and high energy efficiency[5]. LoRa networks have garnered significant attention in both research and industry due to their open standard, which enables the construction of autonomous LPWANs without relying on third-party infrastructure.

It is necessary to evaluate the fundamental characteristics of LoRa technology to maximize the capacity and efficiency of IoT devices that use this technology[6]. Previous projects [1] [2] have evaluated the behavior of LoRa technology, transmission speed, and the Doppler effect in both indoor environments, such as large buildings, and outdoor environments, such as base stations located on university campuses abroad. These studies have assessed performance in various settings.

This project evaluates key parameters of the LoRa physical layer, propagation factor, transmission power, and bandwidth in both urban and rural environments. We assess the potential for large-scale deployment of LoRa networks across Bolivia using commercial boards and analyze how these parameters impact network performance, ensuring that the system operates within the technology's specifications.

II. IMPLEMENTATION OF THE MEASUREMENT CAMPAIGN

This section outlines the project execution and details the development of the IoT Gateway. It starts with enabling the device, installing the necessary libraries, and executing the code for linking with Amazon Web Services (AWS). It has also described the prototype and discussed the characteristics of the communication modules.

The chapter subsequently details the development of the IoT Node, which includes 3D modeling and the tests performed. It then analyzes the obtained data and contrasts it with the simulated data.

The large scale implementation of the Internet of Things (IoT) is becoming a reality, with networks being deployed to support smart city applications, intelligent transportation systems, and environmental monitoring, among other uses.

Many of these IoT installations rely on Low Power Wide Area Networks (LPWANs) [7].

Emerging LPWAN technologies, such as Long Range (LoRa), enable energy efficient wireless communication over extensive distances. LPWANs typically form single hop networks where each node communicates directly with one or more gateways connected to the Internet. Network operators find this advantageous as it eliminates the need for constructing and maintaining multi hop networks. However, because LPWANs cover wide areas and all devices communicate directly with a limited number of gateways, a large number of nodes must share the communication link.

A. *Planning*

The project focuses on LoRa technology, which has become the most widely adopted emerging LPWAN technology and is viewed by many industries as a key enabler for IoT applications. To support scalability, LoRa offers various communication parameters (frequency, spreading factor, bandwidth, and transmission power) that can be adjusted on the transmitter.

The methodology employed is experimental, involving intentional modifications to the variables of LoRa transmitters and receivers. This approach is illustrated in the graphical representation shown in Figure 1.

Fig. 1. Graphic description of the project

Block 1 consists of the IoT Node, which transmits geographical coordinate data (latitude and longitude) to the IoT Gateway. It features a TTGO T-BEAM transmitter module with an integrated ESP32 processor and the SemTech SX1276 communication module. This setup has been used to send data at a frequency of 915 MHz, which is authorized in Bolivia [8]. The IoT Node is installed in a vehicle that travels through various streets in Cochabamba and La Paz. It collects random data during the journey, allowing for an analysis of its performance.

Block 2 is the IoT Gateway, composed of a Raspberry Pi 4 Model B. This Gateway processes the data and transmits it to the internet. A TTGO T-BEAM module is used as the receiver to collect all messages from the IoT Node. The IoT Gateway is equipped with a 5 dBi omnidirectional antenna, positioned at different heights depending on the area.

Block 3 involves Cloud Computing, which enables the IoT Gateway to access on-demand IT resources such as storage and networking via an internet connection. A local internet service provider provides the internet access. Public cloud services are available for purchase or rental, with the three major providers being Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform. AWS has been selected for this project due to its status as a leading cloud computing service provider in recent years.

Block 4 involves the AWS IoT servers, which receive and process the data through their servers for interpretation. AWS IoT Core is used for this purpose, as it connects devices to AWS services and enables applications to interact with endpoints. AWS has offered a broad range of cloud functions and services that continuously evolve, greatly facilitating the management of connected endpoints and proving ideal for IoT applications.

Block 5 represents the Remote Terminal, which consists of a remote PC connected to the internet. In this block, users have visualized the AWS IoT interface from any remote PC, allowing them to access the data sent by the IoT Node for subsequent analysis.

B. *IoT Node and Gateway development*

The primary goal of the design of the IoT Node is to protect the electronic board from manipulation during the measurement campaign.

For the final assembly of the gateway prototype, we have assembled the Raspberry Pi 4 Model B and the TTGO T-BEAM board and have connected them via a USB cable to the Serial 0 port of the Raspberry Pi.

For the final assembly of the gateway prototype, we have assembled the Raspberry Pi 4 Model B and the TTGO T-BEAM board and have connected them via a USB cable to the Serial 0 port of the Raspberry Pi. We have also installed the LoRa 915 MHz 5dBi NB-IoT SMA omnidirectional antenna, as illustrated in Figure 2.

Fig. 2. Gateway Prototype and Data Collection IoT Node

In Figure 2, the IoT Node in operation is shown on the right side, configured to collect power level data in a tropical zone. It has been installed on the roof of a vehicle to facilitate driving through various streets and conducting tests across different study zones.

III. TESTING PHASE MEASUREMENT CAMPAIGN

Each test zone in this project features distinct geographical characteristics, which require the gateway to be positioned at the highest available point. Table 1 details the five specific test zones across Bolivia. We have performed data collection by mounting the IoT Node on the roof of a vehicle, which follows designated routes to gather information for analysis. For data reception and transmission, each module is set with a spreading factor of SF12, a bandwidth of 125 kHz, and a transmission power of 20 dBm.

AWS IoT is utilized to monitor all received parameters on the platform. The data, exported in JSON format—a lightweight data interchange format—are then transferred to Google Earth to provide distance references for each data sample.

TABLE 1 DESCRIPTION OF THE TEST ZONES

TEST ZONE	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
TEST LOCATION	La Paz - Sorata	El Alto - Zona Mercedario	La Paz - Zona Obrajes	Cochabamba - Zona Norte	Cochabamba - Ivirgarzama
COORDINATES	Lat: -15.775° Long: -68.650°	Lat: -16.524° Long: -68.233°	Lat: -16.522° Long: -68.111°	Lat: -17.350° Long: -66.169°	Lat: -17.060° Long: -64.875°
TERRITORY CONDITIONS	Surface surrounded by mountains and hills	Flat and slightly undulating surface	Surface with hills and tall buildings	Flat surface with medium-sized buildings	Tropical zone, flat surface
GATEWAY INSTALLATION HEIGHT	5 meters	6 meters	15 meters	6 meters	8 meters
SPREADING FACTOR	SF12	SF12	SF12	SF12	SF12
TRANSMIT POWER	20dBm	20dBm	20dBm	20dBm	20dBm
BANDWIDTH	125KHz	125KHz	125KHz	125KHz	125KHz
MAXIMUM DISTANCE BETWEEN GATEWAY AND NODE	2970 meters	1354 meters	1226 meters	2000 meters	3055 meters

To determine the distance between the gateway and the IoT node, the Haversine formula (1) has been applied, as AWS only provides the geographic coordinates of the IoT Node. The calculation requires two sets of data: latitude and longitude for both points. The gateway's coordinates are Latitude: -17.350218° and Longitude: -66.169532°. The average Earth radius of 6371 km, denoted as r, is used in the formula. The formula for calculating the distance between two points on the Earth's surface is shown below.

$$d = 2 * r * \arcsin\left(\sqrt{sin^2\left(\frac{\emptyset_2-\emptyset_1}{2}\right) + (\cos(\emptyset_1) * \cos(\emptyset_2) * sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)}\right) \quad (1)$$

Where Ø_1 is the latitude of the gateway,

λ_1 is the longitude of the gateway

Ø_2 is the latitude of the Node

λ_2 is the longitude of the Node

r is the average radius of the Earth

d is the distance between the two points in meters

This approach allowed for the collection of distance values for each sample throughout the measurement campaign in both urban and rural zones. Figure 3 provides an overview of the data, plotted in relation to the received signal strength indicator RSSI, which varies from level 7 to level 12 of the device's spreading factor.

Each test utilized a transmission power of 20 dBm with a bandwidth (BW) of 125 kHz, powered by 3.7V, 2600mAh batteries. The maximum distance achieved was 2000 meters between the node and the gateway in an urban area, and 3055 meters in a tropical zone. The communication modules were configured with a transmission power of 20 dBm and a bandwidth (BW) of 125 kHz to achieve these distances.

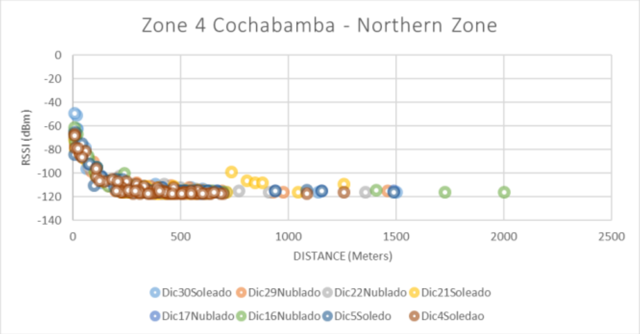

Fig. 3. Measurement campaign carried out over a one-month period

To conduct the initial measurement campaign, it was necessary to vary the spreading factor (SF) for both the transmitter and receiver, ensuring that the devices operated with the same transmission configuration. This process involved adjusting the SF six times, from SF7 to SF12, while maintaining a power of 20 dBm and a bandwidth of 250 kHz. For subsequent analysis, the devices were then configured with the maximum allowable SF of SF12, a transmission power of 20 dBm, and a bandwidth of 125 kHz [9][10].

As shown in Figure 4, increasing the spreading factor (SF) and reducing the bandwidth improve coverage, while adjusting the transmission power significantly extends the coverage area.

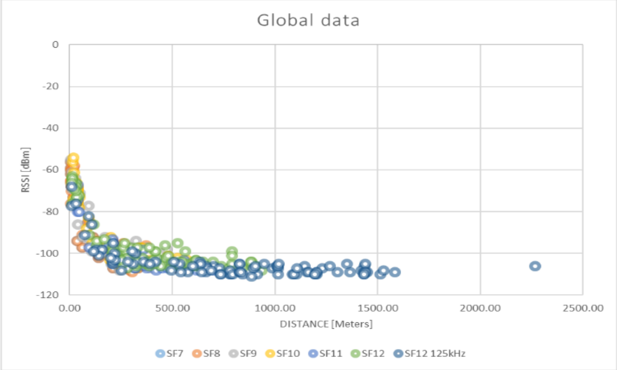

Fig. 4. Data obtained in measurement campaign with different SF

It is important to note that in Urban Zone 4, the gateway was installed at a height of 6 meters. This height, combined with obstacles such as three-story houses, vegetation, and awnings, interfered with the line-of-sight between the devices. As a result, increasing the gateway height improved coverage.

In the tropical zone, the gateway was positioned approximately 8 meters high on the top floor of a building, which is the highest point in the area. This setup allowed the communication distance between devices to exceed 3000 meters, demonstrating significantly enhanced coverage in this environment.

Measurements taken in the Mercedario area of El Alto, where buildings typically ranged from 2 to 3 floors of building, showed that the direct line-of-sight obstruction with the gateway limited the maximum distance to 1354 meters.

In La Paz city, the gateway was placed on the top floor of a new building at UCB University. Here, the maximum distance achieved was 1226 meters. The dense urban environment resulted in limited direct line-of-sight with the gateway.

Data from Sorata showed that maximum distances between the node and gateway reached up to 2970 meters. The site, located at the foothills of a mountainous area, also experienced a lack of direct line-of-sight with the gateway.

To compare these results with theoretical expectations, we utilized Radio Mobile software, which is designed for calculating long-distance radio links across various areas.

For this analysis, Zone 5 (Cochabamba – Ivirgarzama) was chosen due to its extensive coverage area and positive social impact. The gateway was installed at approximately 8 meters high on the highest point of a house, with no surrounding obstacles. Figure 5 overlays images from the practical data collection with the simulated coverage obtained.

The orthogonality of spreading factors enables the simultaneous transmission of multiple LoRa signals on the same channel frequency and within the same time interval. To ensure comprehensive coverage of the study area in this project, the gateway is configured with a spreading factor of SF12, a bandwidth of 125 kHz, and a transmission power of 20 dBm.

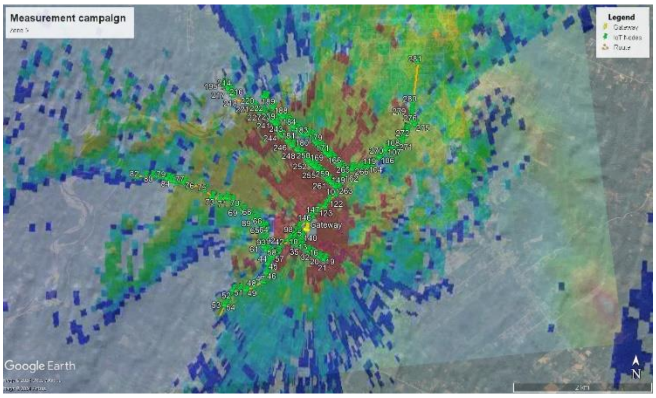

Fig. 5. Coverage of Zone 5 with Tx/Rx power of 20 dBm

IV. CONCLUSIONS

This study has demonstrated the effectiveness of LoRa technology in various urban and rural environments, utilizing TTGO T-BEAM modules and integrating with the AWS IoT platform for remote data reception. The research highlights the capability of LoRa for low cost, large scale, and long range applications, with Zone 5 (Cochabamba – Ivirgarzama) achieving a maximum communication distance of 3055 meters.

The findings confirm that increasing the spreading factor within a fixed bandwidth enhances link gain and sensitivity, though it also extends transmission time. Conversely, expanding the bandwidth reduces receiver sensitivity. LoRa's ability to transmit multiple signals simultaneously on the same frequency and time interval, due to spreading factor orthogonality, is a significant advantage.

LoRa technology proves highly suitable for projects needing extensive coverage. However, it is important to manage power consumption, as higher spreading factors increase energy usage. For optimal network performance, nodes should be configured with lower spreading factors closer to the gateway and higher factors as the distance increases. Multi-channel gateways are available for supporting such network configurations.

Recommendations for future projects include conducting detailed coverage area studies, accounting for environmental factors such as buildings and vegetation, and placing IoT nodes with appropriate spreading factors based on their distance from the gateway. Elevated installations and outdoor gateways are advised to enhance coverage.

Future work will focus on developing functional applications within the LoRaWAN ecosystem, applying insights from this study to deploy practical IoT networks. The study's results contribute valuable knowledge for the advancement and implementation of LoRa technology in diverse scenarios.

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