Implementation of a LoRaWAN Network for Smart Water Consumption Monitoring in Panama

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Abstract– ***This work presents the implementation of a (Long Range Wide Area Network) LoRaWAN network in Panama for smart water consumption monitoring. By using meters equipped with Long Range (LoRa) technology, LoRaWAN gateways, and an integrated cloud platform, a comprehensive solution for the collection, storage, and visualization of water consumption data in near real-time was achieved. Field coverage studies and signal propagation simulations are currently being conducted to optimize the placement of meters, ensuring broad coverage and efficient data collection. Preliminary results demonstrate the viability of the LoRaWAN network for improving water management, supporting data-based decisions, and contributing to the of water resources in Panama. This work emphasizes the importance of integrating IoT technologies and data analysis in environmental management and water resources, proposing a replicable model for other regions with similar challenges.***

Keywords— Water management, LoRaWAN, IoT, Cloud Computing, sustainability.

I. Introduction

Efficient water management has become a global challenge, particularly in regions with limited access to and distribution of water resources [1]. In this context, Internet of Things (IoT) technologies offer innovative solutions for monitoring and smart management of water consumption. This study focuses on the implementation of a LoRaWAN network in the Metropolitan area of Panama, designed for the smart monitoring of water consumption. Leveraging LoRa technology for communication between water meters and network infrastructure, along with an integrated cloud platform for the collection, storage, and real-time visualization of water consumption data.

Panama, with its geographical and climatic diversity, represents a significant case study where water management faces unique challenges due to seasonal variations and uneven distribution of urban and rural populations.

The LoRaWAN network, known for its low energy consumption and long transmission distance, faces the challenge of adapting to densely populated urban environments [2]. This study addresses this challenge, exploring the implementation of this technology not only to improve efficiency in water management but also to facilitate decision-making based on accurate and up-to-date data.

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This work discusses in detail the technical characteristics of water meters at the communication level, the design and selection of LoRaWAN gateways, and the configuration of a cloud platform. The use of open-source solutions for data management underscores an approach focused on scalability and control, essential for the adaptability and long-term growth of the system. Coverage studies in the field and signal propagation simulations, both in controlled environments within the university campus and in selected urban areas, use advanced propagation models and consider geographical and structural factors to optimize the placement of meters.

Additionally, this paper presents the technical and operational challenges encountered during implementation. The discussion on the feasibility of the LoRaWAN network for smart monitoring of water consumption in Panama highlights its potential to improve water resource management, support data-based decisions, and contribute to environmental sustainability. This study not only addresses a local problem but also proposes an innovative and replicable model for other regions with similar challenges, emphasizing the importance of interdisciplinarity and collaboration in the search for sustainable solutions for water management.

This paper is organized as follows: Section II details the LoRaWAN network, Section III presents a study of the signal propagation, Section IV presents a simulation of the propagation channel and finally Section V presents the conclusions.

II. LoRaWAN Network Components

A. LoRaWAN meters

One of the most important elements for the smart water consumption monitoring system are the water meters (nodes). After testing some commercially available models, the SpireTap 280W-R ultrasonic meters from SpireMeters as shown in Fig. 1 was selected.

Fig. 1 SpireTap 280W-R ultrasonic water meters used in the LoRaWAN network.

The SpireTap 280W-R meters use patented ultrasonic technology to measure water flow, ensuring precise and reliable operation without any internal moving parts, making them ideal for smart monitoring applications.

Moreover, it has a stainless-steel body that meets AWWA C715 standards, ensuring durability and corrosion resistance. They offer a flow accuracy of ±1.5% throughout their normal operating range and have a warrantied battery life of over 10 years, sending updates every 12 hours [3].

The SpireTap meters are available in many inlet sizes. The ones used for this project are of 15.9 mm (5/8") and 19 mm (3/4") with NPSM threaded connections. Within this network, both meter sizes are being tested, and they are designed to handle a normal flow range of 0.05 to 8.1 m^3/h, depending on the pipe size. For real-time monitoring, these meters have been equipped with integrated LoRaWAN modules operating at 915 MHz, allowing the wireless transmission of data packets to LoRaWAN gateways within the communication range.

These data packets include the meter identification, flow rate, cumulative volume, and status flags for events such as leaks and battery level. Transmission intervals are configured according to monitoring needs. These data are encoded following the CJ188 protocol, a protocol mainly used in China [4].

B. LoRaWAN Gateway

In a LoRaWAN network, the gateway performs a critical function by acting as the communication bridge between end devices (nodes), such as water meters, and the server network. This device is essential for the reception and sending of messages as it collects the radio frequency signals emitted by the end devices and converts them into data packets that can be transmitted over the internet network to the server. Conversely, it can also receive messages from the server and send them to the end devices as seen in Fig. 2.

The importance of the gateway in a LoRaWAN network lies in its ability to manage a significant volume of simultaneous bidirectional communications, maintaining the integrity and reliability of the transmitted data. By operating on specific frequency bands and using LoRa modulation, these gateways facilitate long-distance data transmission in challenging environments, overcoming physical obstacles, and minimizing the energy consumption of the devices.

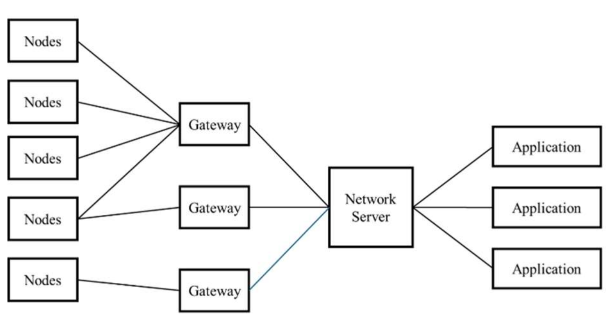


Fig. 2. LoRaWAN Architecture

Moreover, LoRaWAN gateways support communication with multiple devices simultaneously, enabling network scalability, a crucial aspect for projects covering large geographical areas or a large number of nodes. This capability is particularly relevant in applications such as water consumption monitoring, where it is essential to collect data from numerous measurement points [5].

The gateway's role is not limited to data transmission; it also plays a vital role in network security. It encrypts data before transmission and ensures that only authenticated and authorized messages are processed, thus protecting the network against unauthorized access attempts or data manipulation.

Within the framework of implementing a LoRaWAN network for smart water consumption monitoring in Panama, The Things Outdoor Gateway (TTOG) has been selected as a key component in the communication infrastructure. This device has been chosen for its robustness and ability to o3perate efficiently in outdoor environments, which is essential to ensure effective and continuous communication between the water meters and the data management platform. Fig. 3 presents the device with its basic elements.

The TTOG is a gateway specifically designed for outdoor use, offering optimal resistance to the varied environmental conditions of Panama. Its ability to support the US915 MHz frequency band allows for perfect integration with the selected water meters, which use the same band for data transmission. This consistency in frequency selection is crucial to avoid interference and ensure smooth and uninterrupted data transmission.

The installation of the TTOG is remarkably simple, allowing its placement in a variety of settings without requiring extensive maintenance. This ease of installation and maintenance ensures that the gateway can operate uninterruptedly, reliably collecting and transmitting data over time.

The gateway's connectivity is equally versatile, offering connection options via Ethernet and LTE [6]. This flexibility in connectivity ensures that the TTOG can efficiently transmit data to the cloud infrastructure, regardless of the availability of traditional network connections.

Fig. 3 The Things Outdoor Gateway

By integrating the TTOG into the system architecture, a robust and efficient link is established between the SpireTap ultrasonic meters and the AWS platform, enabling the collection, transmission, and analysis of water consumption data in real-time.

C. Cloud Platform

The cloud platform plays an important role in this ecosystem as it is responsible for collecting, processing, and storing the information generated by the LoRaWAN devices in the network. The system is hosted on a virtual machine in the cloud with two cores, 4GB of RAM, and 60GB of storage, which allows it to run all the essential services for communication and data processing between the LoRaWAN gateways and the data management platform.

The monitoring system uses The Things Network Community Edition, an open and distributed platform for IoT devices, providing the key infrastructure for the interconnection between LoRaWAN devices and the data management platform. Its open-source model and collaborative community are crucial aspects that facilitate the efficient integration and management of the network. Through The Things Network (TTN), the configuration and centralized management of gateways and devices are facilitated, optimizing the monitoring and operability of the network. This centralized capability is vital for real-time tracking and rapid adaptation to the network's needs. [7].

Once the data is collected by the LoRaWAN gateways, it is sent to TTN, where initial processing takes place. This includes the decryption and formatting of the data for proper interpretation. TTN provides an API that allows the extraction of these processed data for use in external applications or storage and analysis platforms. On the platform, when data from a meter arrives, a webhook is triggered and sends the decoded data in JSON format to a microservice that is responsible for storing these data in a database; in this case, we use InfluxDB as the database.

InfluxDB is a time series database optimized for the fast and efficient storage of data sequences over time. It is particularly useful in contexts where performance, availability, and the accuracy of historical data are critical, as is the case with this water consumption monitoring platform using the LoRaWAN network.

Thanks to InfluxDB, we can store the data collected by the LoRaWAN meters, where each data point includes a timestamp, the instant water flow, the cumulative water flow, and other tags or identifiers that facilitate the organization of the data. Then, these time series of data can be queried and visualized to analyze trends, detect anomalies, and support decision-making in water management.

Finally, for the visualization of the data stored in InfluxDB, Grafana was employed as an advanced tool that allows us to build interactive and highly informative dashboards. With Grafana, visual representations of the instant and cumulative water flow, as well as other key metrics, are generated, presenting them in a graphical and intuitive manner.

On these dashboards, the user can not only monitor the behavior of water consumption in real-time but also perform historical, comparative, and trend analyses. Grafana's ability to integrate natively with InfluxDB facilitates the creation of customized panels that can include line graphs, bar charts, histograms, and heat maps, among others, allowing for a clear and quick interpretation of the data.

III. Signal propagation study

To understand the behavior of the LoRaWAN network, we started by installing a Gateway at the top of a building on the university campus, placed approximately 20 meters above ground level. Subsequently, measurements were taken at various points across the campus, within a 1km radius, with points spaced 50 meters apart. These tests were carried out in a metal box at ground level, like the ones used in Panama to protect meters in residential areas, as presented in Fig. 4. At each location, 3 samples were collected to average certain parameters like Signal-to-Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI).

In LoRa networks, SNR is crucial for assessing the quality of the wireless signal. As SNR increases, there's an enhancement in signal quality, which boosts the network's ability to transmit and receive data efficiently. The spread factor (SF) is another critical aspect that directly has an impact on the communication efficiency and signal range. A higher spread factor results in broader coverage, though it also means more time is needed for data transmission.

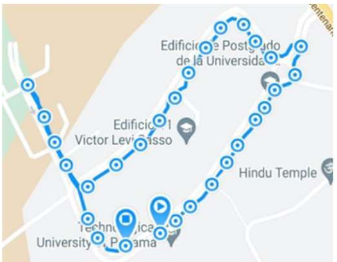
It's essential to acknowledge that these indicators can vary based on environmental conditions, such as interference, background noise, and antenna quality. Equipment manufacturers and LoRa service providers might have specific recommendations or standards to ensure reliable transmission in their setups.

As illustrated in table 1, for each spread factor value, the corresponding SNR is displayed along with additional details like symbols per second, airtime, and bit rate.
For instance, SpireTap water meters use a spreading factor of 7 [3]. Therefore, it is important to note that the SNR threshold is -7.5 as observed in table I. This is a crucial factor to consider since receiving an SNR lower than this threshold likely indicates errors in the transmitted payload.

This entire study was conducted with the aim of creating an empirical propagation model to provide estimates of the areas with the best reception and to position the meters in these areas.

The measurements behaved as expected, as observed in Fig. 5. As the meter moves away from the Gateway, the received signal strength decreases. Moreover, even though both the gateway and the meter promise transmission distances of up to 5KM, in this environment with large trees, buildings, and vehicles, the maximum distance achieved was about 500 meters.

These data were compared with various deterministic and empirical propagation models, with the Hata-rural model yielding values closest to those obtained in the field tests.



(a) (b)

Fig. 4 a) Sampling area within the Technological University of Panama. Each point represents 3 samples. b) Metal box where the meters were placed in each sampling.

TABLE I
LORA SPREAD FACTORS [8]

Spreading Factor	Symbol/second	SNR Limit (dB)	Bit Rate (bps)
7	976	-7.5	5469
8	488	-10	3125
9	244	-12.5	1758
10	122	-15	977
11	61	-17.5	537

The Hata model is an empirical model used to calculate signal attenuation in urban and suburban environments. It is widely used in telecommunications to estimate radio signal propagation in urban settings with buildings and obstacles. The Hata model equation varies depending on the operating frequency and antenna height, but it generally relies on the distance between the transmitter and receiver, the frequency, and a series of correction factors [9].

For the Hata model, the following equations were used:

- Hata Model for Urban Environments

$$PL_{urban}(d)dB = 69.55 + 26.16\, log_{10}(f_c) - 13.82\, log_{10}(h_t) - a(h_r) + (44.9 - 6.55\, log_{10}(h_t)\,)\, log_{10}(d) \quad (1)$$

- Hata Model for Suburban Environments

$$PL_{suburban}(d)dB = PL_{urban}(d)dB - 2\left[log_{10}\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \quad (2)$$

- Hata Model for Rural Environments

$$PL_{rural}(d)dB = PL_{suburban}(d)dB - 4.78[\, log_{10}(f_c)]^2 + 18.33\ log_{10}(f_c) - K \quad (3)$$

In Fig. 6, we generate graphs of (1), (2) and (3). The path loss is very close to that of the Hata Rural model (3) with a K value of 30, which is why this model will be used in future simulations in areas near the university campus.

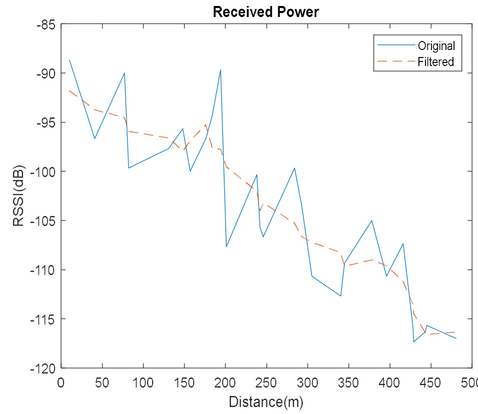
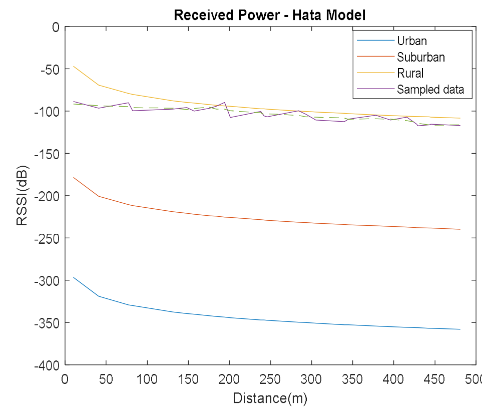
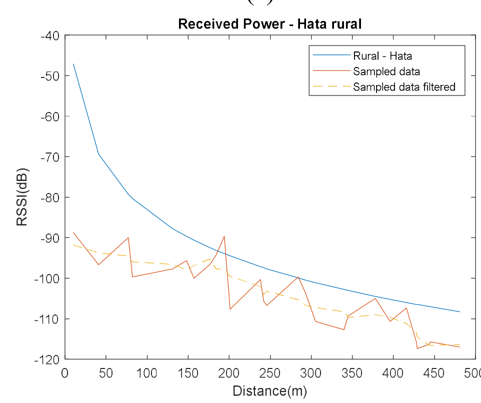


Fig. 5. RSSI taken with water meters inside a metal box at ground level over 500 meters.



(a)



(b)

Fig.6 a) Comparison between the Hata model and the data collected on the university campus. b) Comparison between the Hata rural model and the data collected on the university campus.

IV. Simulated wireless channel propagation models

Due to the extensive preparation time required for field studies in channel propagation, varying conditions in each area that needs different models, and the challenges of conducting such studies in uncontrolled environments as discussed in the previous section, simulations were developed using field data. These simulations enable quick estimation of

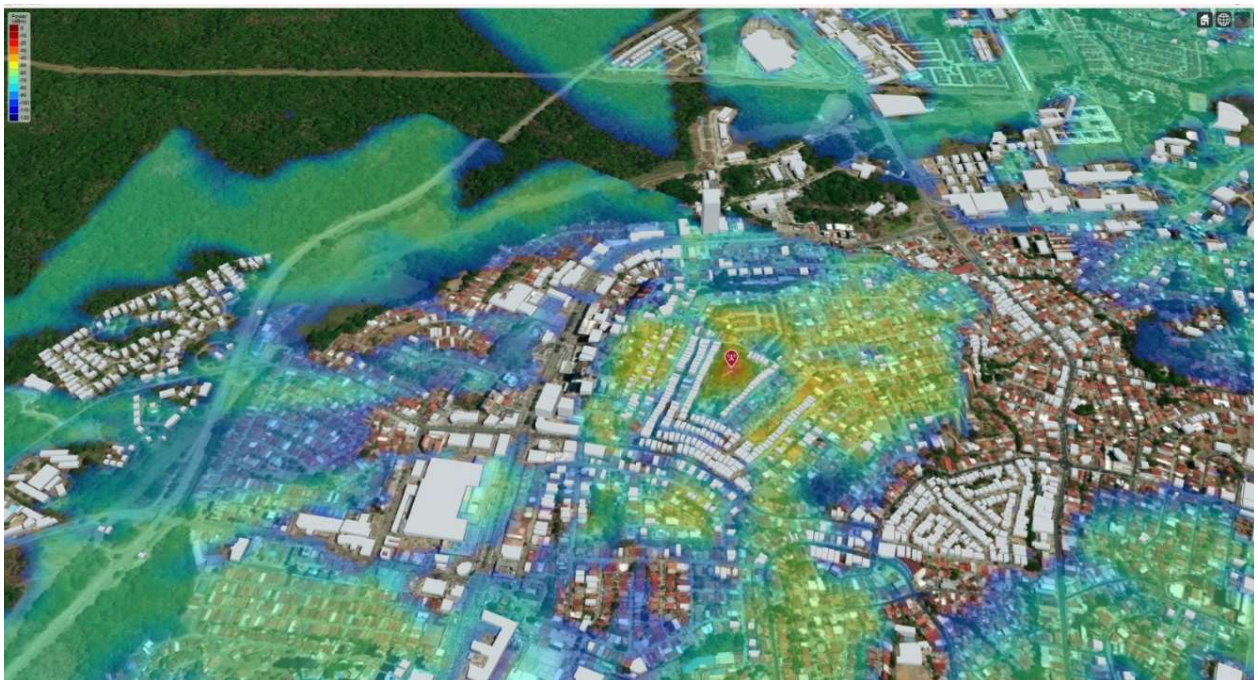


Fig. 7 Simulation obtained with MATLAB of the Bethania area considering DEM data and the OSM (OpenStreetMap) building data.

the most suitable locations for meter installation. To generate accurate channel propagation simulations, precise data on terrain elevation, buildings, and a propagation model that closely mirrors reality are essential.

Bethania, a primarily residential urban area, was selected as the study site, where we have access to one of the highest points in the area located on a water tank owned by IDAAN (Instituto de Acueductos y Alcantarillados Nacionales, by its acronym in Spanish). A gateway was installed there to set up smart meters for a pilot study.

MATLAB was used for the simulations along with the Antenna Toolbox and the Mapping Toolbox. These tools allow for the simulation of wireless channel propagation, considering the terrain. It's important to note that Matlab uses the DTED format to acquire DEMs (Digital Elevation Models).

Initially, elevation data were sourced from the United States Geological Survey (USGS) databases. However, the low-resolution data for the Panama region resulted in inaccurate simulations. Therefore, data from IGNTG (Instituto Geográfico Nacional Tommy Guardia, by its acronym in Spanish) were used instead, as it is the official mapping information source in Panama.

IGNTG provided the information in shape files containing already interpolated contour lines. With these lines, a georeferenced map was created using ARCGIS Pro with UTM17N coordinates, and the contour lines were introduced.

Subsequently, raster-type files were generated to create a DEM map, which was converted to the DTE2 format, compatible with MATLAB's tools.

Furthermore, to enhance the accuracy of our simulations, we incorporated data on the area's buildings obtained through OpenStreetMap. Including urban structures allows for a more faithful simulation of the interaction between radio signals and the built environment, a crucial factor for determining optimal locations for meter installation and gateway positioning.

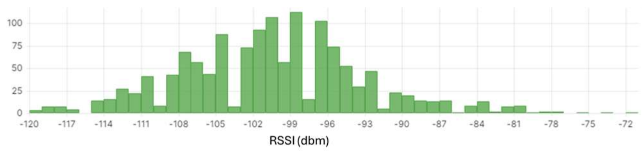
With this data, simulations were conducted to identify areas with better reception. Additionally, considering the terrain helped us understand why, in certain zones, some meters failed to communicate with the Gateway due to terrain or building obstructions. Fig. 7 presents the simulation results in the Bethania area. The areas closest to red have the best reception. Thanks to these simulations, we can easily evaluate the behavior of other areas or find better locations to place the gateways without having to visit the sites directly. This facilitates the scalability of the LoRaWAN network and allows for the optimization of gateway usage within the network.

V. Field Test

Approximately 250 meters are planned to be deployed, distributed at 50 meters per Gateway. To verify that the meters can transmit data to the Gateway without mutual interference, a test was conducted on the university campus, where 48 meters were spaced 10 meters apart, with each meter transmitting data every 15 minutes. This setup simulates the distribution typically found in a neighborhood in Panama, as illustrated in Fig. 8.

Fig. 8 Meters (marked in red) spaced 10 meters apart throughout the university campus.

The test results were satisfactory, demonstrating the feasibility of scaling up the meter deployment. Statistical analyses such as histograms were conducted; Fig. 9a shows that most of the meters recorded received signal strength indicator (RSSI) values ranging from -111 to -90 dBm. Within this range, the signal-to-noise ratio (SNR) values remained robust, between 5 and 11 dB, as depicted in Fig. 9b. Finally, the majority of the meters were able to transmit data within a 30-minute period, confirming the success of the test, as depicted in Fig. 9c.



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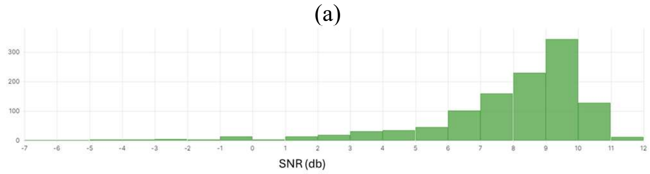

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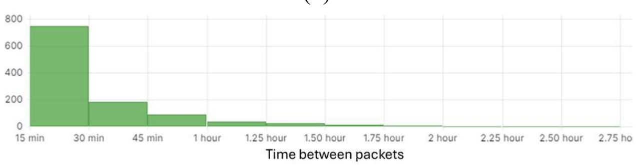

(c)

Fig. 9. Histograms of the performance obtained from the 48 meters installed on the university campus a) RSSI b) SNR c) Time between packets.

Additionally, the proper utilization of the communication channel was confirmed. The meters randomly used the eight available frequencies, resulting in a uniform distribution as displayed in Fig. 10.

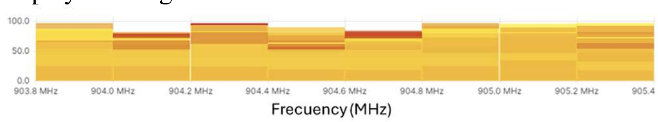

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Fig. 10. Histogram of the use of the 8 available frequencies in LoRaWAN sub-band 2 during the field test.

VI. Conclusions

By using LoRa technology equipment and an integrated cloud platform, a LoRaWAN network in Panama for intelligent water consumption monitoring has been developed. This network allows a solution for the collection, storage, and visualization of water consumption data in near real-time. Coverage studies and signal propagation simulations are currently being conducted to improve the network. The results demonstrate the viability of the LoRaWAN network for improving water management, supporting data-based decisions, and contributing to the of water resources in Panama.

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