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A miniature IoT-based Ground Station at 433 MHz for reception of telemetry packets from LoRa satellites

Una estación terrena en miniatura basada en IoT a 433 MHz para la recepción de paquetes de telemetría de satélites LoRa

Jorge Simón[1], **José Ricardo Gómez-Rodríguez**[*2], **Marco Cárdenas-Juárez**[3], **Víktor Iván Rodríguez-Abdalá**[2], **Remberto Sandoval-Arechiga**[2], **Salvador Ibarra-Delgado**[2], **José Luis Álvarez-Flores**[4], **J. Villanueva-Maldonado**[2], and **Jorge Flores-Troncoso**[2]

[1] *Investigadoras e Investigadores por México, Consejo Nacional de Humanidades, Ciencias y Tecnologías*
Zacatecas, Mexico,
jsimonro@conahcyt.mx
[2] *Universidad Autónoma de Zacatecas (UAZ), Unidad Académica de Ingeniería Eléctrica,*
Posgrado en Ingeniería para la Innovación Tecnológica, Zacatecas , México.
{jrgrodri,abdala,rsandoval,sibarra,juvenal.villanueva,jflorest}@uaz.edu.mx
[3] *Universidad Autónoma de San Luis Potosí, Facultad de Ciencias*
San Luis Potosí, Mexico,
marco.cardenas@uaslp.mx
[4] *Universidad de Colima, Facultad de Ingeniería Mecánica y Eléctrica*
Colima, Mexico,
alvarez_jose@ucol.mx

Abstract

In this article, a miniature Internet of Things-based ground station operating at 433 MHz for the reception of telemetry packets from LoRa satellites is presented. The ground station is composed of a turnstile antenna, an ESP32-based LoRa reception system, and a rechargeable battery. Connected to Internet via a WLAN router, the ground station offers monitoring capabilities through a web page interface. The website provides a console to track the coordinates of the target satellite, allowing telemetry packets to be downloaded and displayed. The goal of this project is to have a low-cost telemetry ground station for educational and radio amateurs purposes, solving the issue of bringing youth closer to STEM careers, this by means of building a ground station using COTS components that is able to be connected to LEO-orbiting satellites.

Keywords— IoT, Ground Station, LoRa
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Resumen

En este artículo se presenta una estación terrena en miniatura basada en el Internet de las cosas que funciona a 433 MHz para la recepción de paquetes de telemetría desde satélites LoRa. La estación terrena está compuesta por una antena turnstile, un sistema de recepción LoRa basado en ESP32 y una batería recargable. Conectada a Internet a través de un enrutador WLAN, la estación terrena ofrece capacidades de monitoreo a través de una interfaz web. La página web proporciona una consola para rastrear las coordenadas del satélite objetivo, lo que permite descargar y mostrar paquetes de telemetría. El objetivo de este proyecto es contar con una estación terrena de telemetría de bajo costo para fines educativos y de radioaficionados, solucionando el tema de acercar a los jóvenes a carreras STEM, esto mediante la construcción de una estación terrestre hecha a partir de componentes COTS que es capaz de conectarse con satélites en órbita LEO.

Palabras clave— Internet de las Cosas, Estación Terrena, LoRa

I. Introduction

An increasing number of companies worldwide have been developing networks utilizing LoRa technology for satellite applications. Mainly, the applications that are being developed for these satellites with LoRa technology are designed to serve a variety of purposes, asset tracking, weather monitoring, environmental monitoring, maritime communications, and terrestrial links from space. Interestingly, in different parts of the world, there are ongoing developments utilizing LoRa technology for space applications, particularly for real-time environmental monitoring, as well as vehicle and animal tracking [1]. Table 1 summarizes information on some satellites (different sizes) using LoRa technology and belonging to the Tiny Ground Station (TinyGS) project, providing details about their country of origin and designated applications [2].

Table 1: *Satellites using LoRa Technology*

Name	Country	Organization	Application
Norby [3]	Russia	Moscow University	Geophysical monitoring
FEES [4]	Italy	Italian GPAP	Validating electronics
FossaSat-1 [5]	Spain	FossaSystem	Democratizating space
Satish Dhawan [6]	India	Space Kidz India	Ionising radiation
GaoFen-7 [7]	China	Chang Guang	High resolution imaging

Particularly, ground stations are a core part of accessing and controlling the space segment, facilitating communication with satellites primarily located in low earth orbits (LEO). Commonly, ground stations include modules such as antennas, receivers, transmitters, data processing equipment, and satellite control equipment [8].

In this context, the TinyGS project is an open network of ground stations around the world with the purpose of receiving and communicating with LoRa Satellites, which use inexpensive, versatile, and efficient modules. This project started in 2019 using an ESP-32 to receive LoRa telemetry from the FossaSat-1 satellite [9]. The TinyGS network can share the downloaded information with all users around the world, using web servers, and transceivers. The frequencies at which TinyGS project work are within the UHF band, this is because they imply telemetry links, although there are other applications not considered in the project, for example, data transmission using small satellites, that work at S band frequencies [10] [11].

In this article, the integration of a low-cost miniature Internet of Things (IoT)-based ground station (i.e. a TinyGS) at 433 MHz for reception of telemetry packets from Lora satellites is presented. The ground station is equipped with a turnstile antenna, an ESP32-based LoRa reception system, and a rechargeable battery to fulfill its functions. Linked to the Internet via a WLAN router, this ground station offers comprehensive monitoring capabilities accessible through a user-friendly web page interface. On the web page, users can access a console that allows them to track the precise coordinates of the targeted satellite and download telemetry packages. Furthermore, the platform provides real-time satellite trajectories and displays the retrieved packages, all within the same intuitive interface. The aforementioned ground station is a relatively good alternative for educational or radio amateurs purposes.

*Correspondence author

The rest of the article is organized as follows: Section II presents a detailed description of the ground station, which includes the antenna system and the LoRa receiver. Then, in Section III, the functionality tests regarding the antenna system and telemetry packet reception are shown. Finally, Section IV presents the conclusions.

II. Ground station

II.1. Antenna system

The antenna system is based on a turnstile antenna or crossed-dipole antenna that works optimally at 433 MHz, which is one of the frequencies of interest for receiving telemetry packets from LoRa small satellites. A turnstile antenna is a radio antenna that consists of pairs of two identical dipole antennas mounted at right angles to each other and fed in phase-quadrature [12]. In this work, a Yagi-type turnstile antenna was built, consisting of 3 pairs of crossed half-wave dipoles: a pair of reflectors (up), a pair of directors (down), and a pair of fed ones (center). Each of the six dipoles measures 34.64 cm in length, with a separation of 17.32 cm between each pair of crossed dipoles.

The antenna is circularly polarized, this is because some satellites do not have attitude control, which means that the satellite is not stable in space and consequently neither is the onboard antenna that transmits to earth [13]. Their lack of attitude control causes losses due to polarization mismatch, an effect that can be minimized by having a circular polarization antenna in the ground station which is achieved using crossed dipoles. Figure 1 shows the antenna, which was designed and built using low-price metallic and plastic materials.

II.2. LoRa receiver system

The receiving system is based on a LILYGO TTGO LoRa32 433 MHz V1.6.1 development board which mainly contains an ESP32 and a LoRa receiver [14]. The receiving system captures telemetry packets from LEO small satellites [15], which, by containing an ESP32, connects to Wi-Fi (WLAN router) and can be monitored from a web page. The information contained in telemetry packets includes transmitted power, the distance at which the

Figure 1: *Turnstile antenna used for satellite telemetry reception.*

satellite was listened, elevation angle, RSSI (Received Signal Strength Indicator), SNR (Signal-to-Noise Ratio), among others. Figure 2 shows the LILYGO TTGO LoRa32 433 MHz V1.6.1 development board, whose programming and configuration are available on TinyGS project website [2].

Figure 2: *LILYGO TTGO LoRa32 433 MHz V1.6.1 development board.*

II.3. An IoT ground station

As it was mentioned before, the ground station is monitored via Internet through the TinyGS project website. TinyGS is an open network of Ground Stations worldwide distributed to receive and operate LoRa satellites, weather probes, and other flying objects, using cheap and versatile modules. The website allows monitoring all ground stations registered in TinyGS network. On the website, it is possible to find out the trajectories and positions of small satellites belonging to the network, which at the moment are 17. The project includes 1309 active ground stations and more than 4 million telemetry packages downloaded.

In the case of the ground station for this project which is named "Tuna_Potosina" and as the rest of the ground stations, it can be monitored via website and via a Telegram bot. It is possible to know what satellites are passing near the ground station soon and what the elevation and azimuth angles are to orient the turnstile antenna. Nonetheless, the antenna is directed towards the zenith, so that is why elevation angles near 90° are chosen. On the TinyGS project website, descriptions of the satellites and ground stations belonging to the network can be seen, as well as all the information about the packages downloaded by the ground stations and from which satellites the information was downloaded.

Figure 3 shows a map including ground stations and satellites belonging to the network, stations online are in green, while the ones offline are in red. In addition, satellites are shown in blue with their corresponding real-time location.

III. Functionality tests

In this section the elements functionalities that make up the ground station are described, so below, before describing each of them separately, a block diagram of the architecture of the ground station is shown in Figure 4.

III.1. Antenna tests

Antennas are crucial for ground station satellite reception purposes. In this case, the type of antenna used has a relatively acceptable gain for the application, since common 3-element linearly-polarized Yagi antennas exhibit gains around 6.5 dBi, which leads us to think of a similar gain. The parameter S_{11} (reflection coefficient), shows a value at 433 MHz of -12.9857 dB, implying relatively low losses (5 % of reflection due to impedance mismatch), and making it an antenna that worked acceptably for this kind of terrestrial satellite receptions at UHF frequencies, this characteristic can be noticed in Figure 5 [16].

It is worth mentioning that although the best antenna behavior is shown at 370 MHz, a bandwidth at -10 dB (less than 10 % of reflection due to impedance mismatch) from 410 to 490 MHz is ensured, a range that includes frequencies commonly used for reception from LoRa satellites [17].

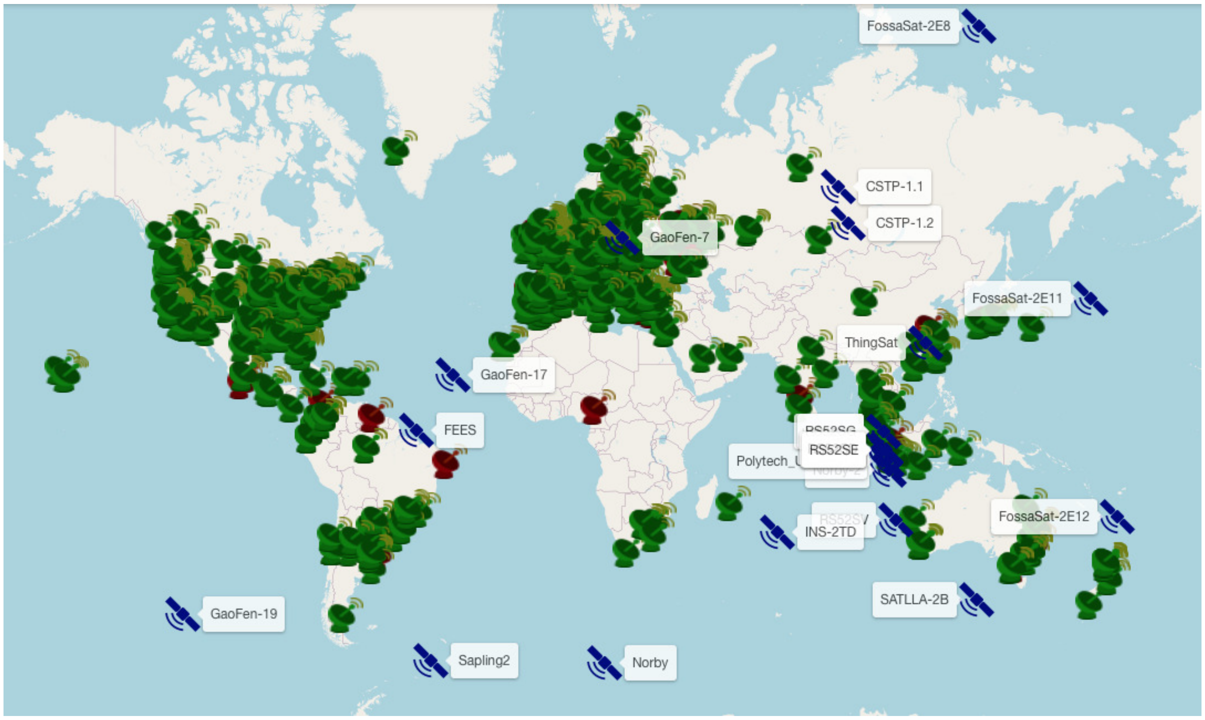

Figure 3: *World map showing the stations and satellites of the TinyGS project.*

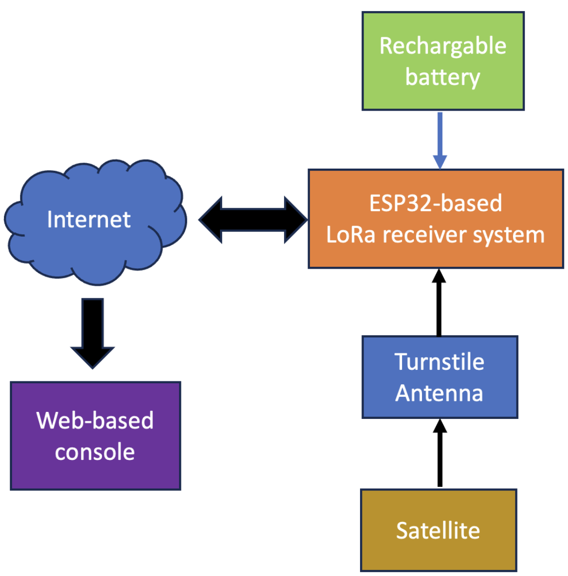

Figure 4: *Architecture of the ground station.*

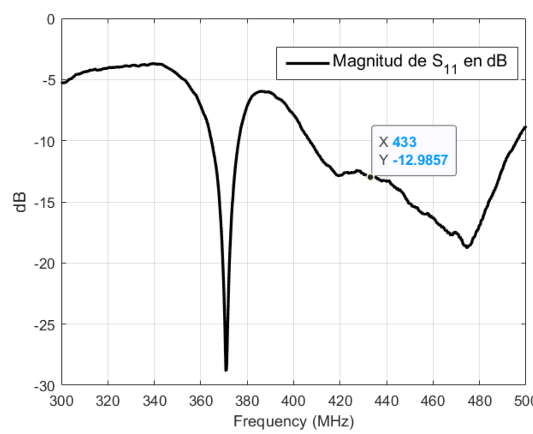

Figure 5: *Parameter S_{11} (reflection coefficient) at 433 MHz.*

III.2. Telemetry packets reception

Once the ground station was fully assembled including its antenna (Figure 6) and also programmed and configured, telemetry packets could be downloaded. Telemetry packets are free to access, and the information they contain is presented and available on the TinyGS website in different formats available to be downloaded, such as hexadecimal and raw parsed views.

Figure 7 shows hexadecimal and condensed raw parsed views of telemetry downloaded from one of the satellites belonging to the network. In addition and regarding each ground station, as it is for "Tuna_Potosina" ground station, a console is available registering the packets downloaded and all the information about it and about the satellite it listened to. Figure 8 shows evidence of reception using the aforementioned ground station.

Figure 6: *The whole ground station: antenna (in green), LoRa receiver system (in gray), and battery (in red).*

IV. Conclusions

In this work, a miniature IoT-based ground station, designed to receive telemetry from small satellites as a part of the TinyGS project, was built and presented. The LoRa reception system was assembled using commercial electronics, while the antenna was designed and built using low-cost materials. The antenna receives signals around 433 MHz and with circular polarization to avoid polarization losses.

Telemetry packets reception was successful which allows us to conclude that the aforementioned ground station is a relatively good alternative for educational or ra-

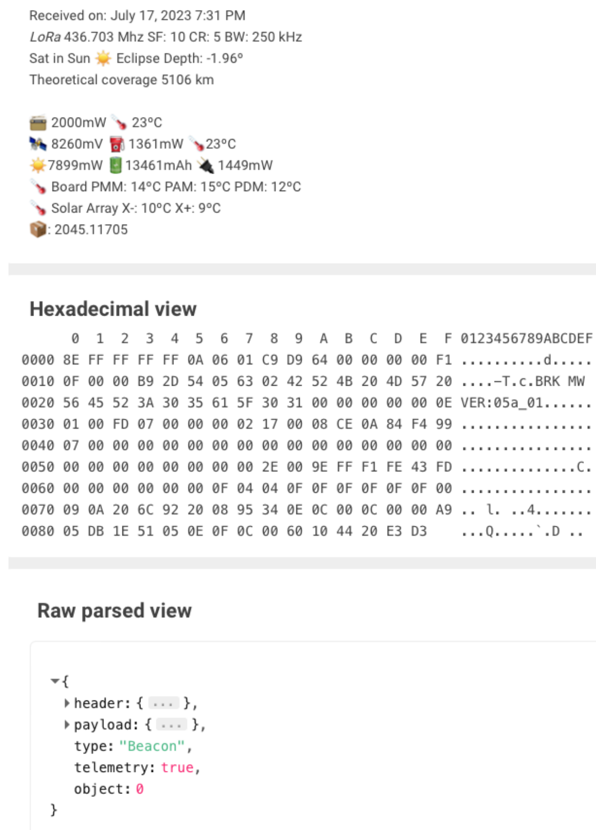

Figure 7: *Hexadecimal and condensed raw parsed views of telemetry downloaded from a satellite.*

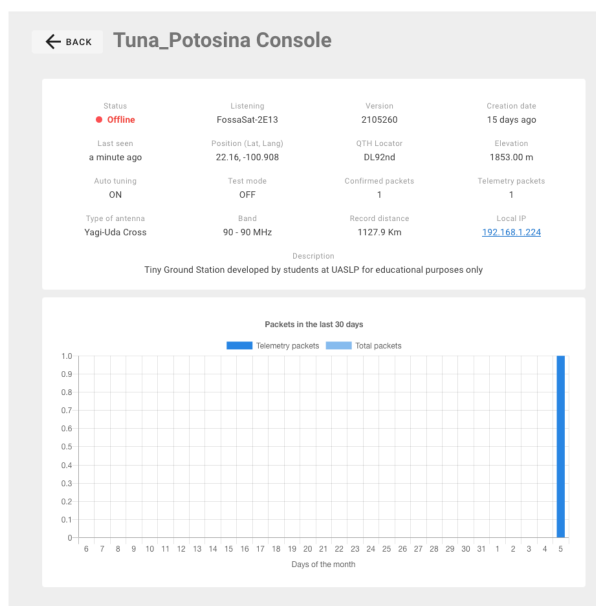

Figure 8: "*Tuna_Potosina*" *ground station console.*

dio amateurs purposes. The ground station is connected to Internet and can be monitored and controlled through a web-based console.

The goal of this project is to have a low-cost telemetry ground station, that solves the issue of bringing youth closer to STEM careers, this by means of building a ground station using COTS components that is able to be connected to LEO-orbiting satellites.

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