UNIVERSIDAD AUTÓNOMA DE ZACATECAS FRANCISCO GARCÍA SALINAS

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Hecho en México
Made in Mexico

Contenido

Editorial

La revista **DIFU$_{100}$ci@** es una revista cuatrimestral que comenzó su publicación oficial en 2005. En mayo del 2012, la revista **DIFU$_{100}$ci@** adquirió el ISSN.
Desde entonces, se pretende contribuir a la difusión del conocimiento de la comunidad académica tanto nacional como internacional mediante la difusión de resultados de investigación de alta calidad. La Revista se centra en obras originales, que incluyen principalmente los estudios experimentales, análisis numéricos, estudios de casos y revisiones bibliográficas que proporcionan una significativa contribución a las áreas de ingeniería y tecnología en todas las disciplinas (Electrónica, Eléctrica, Ciencias de la Computación, Mecatrónica, Robótica, Telecomunicaciones, Procesamiento de señales, Ingeniería Industrial, Ingeniería de Control, y Bioingeniería).

Desde el comienzo, la revista ha buscado la mejora de los artículos aceptados para su publicación por un proceso de evaluación por pares o árbitro de los manuscritos recibidos. Estas evaluaciones son llevadas a cabo por expertos de reconocido prestigio por sus conocimientos y logros académicos, con el objetivo de asegurar que las publicaciones seleccionadas están contribuyendo al estado del arte en diferentes áreas de interés. Además, desde su inicio, la revista se ha abierto a los estudiantes y académicos a través del Sistema Open Journal, facilitando todo el proceso de presentación y publicación.

Agradezco a los autores y revisores, que se esfuerzan para mejorar la calidad de los manuscritos. Exhorto a todos los investigadores, académicos y estudiantes en las áreas de ingeniería y tecnología para que continúen sometiendo sus artículos en nuestra revista y contribuir a la noble difusión de la ciencia y la tecnología.

Jorge Flores Troncoso
Editor en Jefe, Revista **DIFU$_{100}$ci@**
Universidad Autónoma de Zacatecas

Test flight using LoRa based telemetry subsystem for stratospheric balloons

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Abstract

This article presents a stratospheric balloon telemetry subsystem based in wireless communication protocol LoRa, which is a long-range and low power consumption protocol mainly used for Internet of Things. The stratospheric balloons are great devices for research, they are mainly used to measure climatic variables, although they can also be used to test flight for satellite instruments because the atmospheric conditions in the stratosphere are similar to those experimented by a low orbit satellite. The goal is to ensure a reliable point to point communication link, between the stratospheric balloon and the ground station to track the real-time location and store the latitude, longitude and altitude information in a database for post-processing data analysis and plotting.

Keywords: LoRa, stratospheric balloon, GPS.

1. Introduction

A stratospheric balloon is a platform that allows to develop scientific experiments at the atmosphere with a specific mission like radiation measurement, link performance measurement or system stability at that conditions.

The stratospheric balloon's mission can only be fulfilled by successfully integrating all its subsystems, they being usually: balloon and structure; onboard data handling and payload; power; communication and telemetry.

The stratospheric balloons can reach heights between eleven and thirty-seven kilometers and travel typically two hours until they burst, where the traveled distance depends on the climatic conditions. Once they have landed the payload can be retrieved to further analysis.

A Global Positioning System (GPS) can be used to track in real time stratospheric balloons as part of the telemetry subsystem, delivering latitude, longitude and height among other the device location's parameters.

Traditionally, a stratospheric balloon telemetry subsystem uses narrowband analog modulation schemes, the use of digital modulation schemes allow increasing the system transmission capacity but, the communication scheme needs to have a long range and high interference immunity.

Actually, IoT (Internet of Things) networks offer long range, high interference immunity, narrowband, low power consumption and low cost, these characteristics are ideal for the telemetry subsystem of a stratospheric balloon.

This article shows the telemetry subsystem implementation as part of the balloon's payload, this device can establish a long-range link through LoRa in a one-way communication link, in order to send geographic position data.

The position information can be obtained either from the data stored in the balloon payload or from the ground station, this data is used for a graphic interpretation in real-time and also the flight path.

2. IoT networks protocols

Choosing the proper communication technology is imperative in an IoT ecosystem that tolerates such extreme climatic conditions and long distance, the options are limited by the technology available, among them NB-IoT (Narrowband IoT), LoRa, and Sigfox, each involves many technical and economic differences to consider for the flight logistic.

- Sigfox is a low power narrowband Internet of Things network that uses BPSK (Binary Phase Shift Keying) modulation, using unlicensed ISM (Industrial, Scientific, and Medical) bands ($<$ 1GHz), with a bandwidth of 100 Hz. This network has a maximum number of messages per day limit of 140 uplink and 4 downlink, that means a wait of 10 minutes between messages arrival for the uplink. Each message is transmitted at a maximum of 100 bps. The range is a notorious advantage due to the long distance range provided by the network of 10 km in urban areas and 40 km in rural areas [1].

- LoRa is a physical layer technology that modulates the signals using a proprietary spread spectrum technique, uses unlicensed ISM bands ($<$ 1GHz) with a bandwidth of 250 kHz and 125 kHz, maximum data rate 50 kbps, an unlimited number of messages per day, usual range of 5 km in urban areas and 20 km in rural areas, and very high interference immunity.

- NB IoT (Narrow Band IoT) can coexist with GSM (global system for mobile communications) and LTE (long term evolution) under licensed LTE frequency bands, has QPSK (Quadrature Phase Shift Keying) modulation scheme with 200 kHz bandwidth, 200 kbps, and unlimited maximum messages per day, the usual range in urban areas is 1 km, and for rural areas is 10 km. It is equipped with encryption. At the time this technology is not available in Mexico.

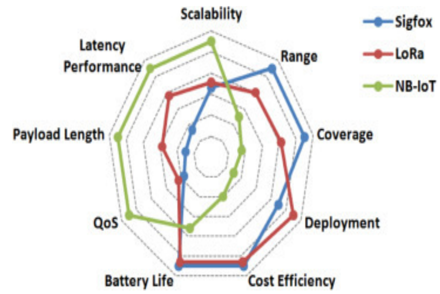

Figure 1. Comparison of IoT technologies

As shown in Fig. 1 we can see the clear advantages for this particular application, the key points to consider are: range, battery life, cost efficiency and latency performance, which LoRa and Sigfox excel.

The excellent range provided by Sigfox is the reason why the network has been used previously by the Faculty of Electrical Engineering of Czech Technical University in Prague. Despite the network proved the capability for tracking the stratospheric balloon through 350 base stations in three countries (the Czech Republic, Slovakia, and Germany), the online platform was not designed originally for this application and showed several problems causing a monitoring failure and therefore made the endpoint estimation for the rescue insufficient[2].

On account of the messages limitation of Sigfox and due to NB IoT is not yet available in Mexico, the more convenient clear choice is LoRa for this particular application, considering it is desirable to know the balloon's position at any given time.

3. LoRa IoT protocol

LoRa is a communication protocol developed by Semtech that offers a powerful combination of long range, low power consumption and secure data transmission. The networks created with LoRa technology can provide coverage in range compared to cellular networks [3].

This protocol uses the unlicensed radio spectrum in sub-GHz ISM bands to provide a low power consumption, wide area communication between remote sensors and gateways connected into a network. The ISM free band in Mexico is surrounding the 915 MHz frequency.

According to [3], some LoRa's key features that are ideal for the experimental flight are:

- Enables free GPS for low power tracking applications.

- Reduces costs in infrastructure investment and node sensors.

- Specifically designed for low power consumption.
- A single base station provides deep penetration in dense urban/indoor regions, plus connects rural areas up to 50 kilometers away.

4. Telemetry subsystem architecture

The telemetry link sends the data of the balloon's health to the ground station, like the position, velocity and acceleration and other critical parameters from other subsystems. In this project, the telemetry subsystem is conformed by a LoRa transmitter (HOPERF RFM95 module) and the GPS sensor (L80 GPS module).

4.1. HOPERF RFM95 Module

The RFM95 module has the FSK (Frequency Shift Keying), OOK (On/Off Key) and LoRa modulation schemes, a sensibility of -148 dBm and power transmission of 7 dBm up to 20 dBm with high-power PA output. The operation frequency bands are 868 MHz and 915 MHz, which is programmable through software, is possible to choose the spreading factor between 6 and 12, which is directly related to the transmission's bit rate and bandwidth, the bandwidth is between 7.8 and 500 kHz with an effective bit rate of 0.018 to 37.5 kbps. The HOPERF RFM95 Module is connected to a single-board computer via UART (Universal Asynchronous Receiver/Transmitter) [4].

All messages are sent and received conform to this packet format:

- 8 symbol PREAMBLE
- Explicit header with header CRC (handled internally by the radio)
- 4 bytes HEADER: (TO, FROM, ID, FLAGS)
- 0 to 251 bytes DATA
- CRC (handled internally by the radio)

4.2. L80 GPS Module

The L80 GPS module has an embedded patch antenna and an integrated LNA (low-noise amplifier) allowing a high sensibility and low power consumption, bearing various localization and navigation systems like GPS (Global Positioning System), SBAS (Satellite-based augmentation systems), QZSS (Quasi-Zenith Satellite System) and AGPS (Assisted GPS). The L80 GPS module and the single-board computer communication is through the SPI protocol (serial peripheral interface), that is a synchronous serial communication interface.

The GPS information delivered is composed of different kinds of NMEA (National Marine Electronics Association) standard sentences. The kind of GPS NMEA sentences are: GPRMC, minimum data recommended for GPS; GPVTG, tracking vector and ground speed; GPTXT, this message is used to show information of transmitted messages or if an error exists; GPGGA, GPS adjustment information; GPGSA, general satellite data; GPGSV, detailed satellite data; GPGLL, latitude and longitude data.

The NMEA standard sentence necessary to the balloon's tracking is GPGGA because this establishes the balloon's latitude, longitude and altitude. The GPGGA sentence means the Global Positioning System Fix Data. The structure is shown in Fig. 2.

```
Enviando [3] al node #1 => $GPGGA,231953.000,2246.0743,N,10234.0883,W,1,4,2.12,2
386.7,M,-15.0,M,,*50
```

Figure 2. Sent packages structure

Where the fields are:

1. UTC of Position
2. Latitude
3. North or South
4. Longitude
5. East or Weast
6. GPS quality indicator (0=invalid; 1=GPS fix; 2=Diff. GPS fix)
7. Number of satellites in use [not those in view]
8. Horizontal dilution of position
9. Antenna altitude above/below mean sea level (geoid)
10. Meters (Antenna height unit)
11. Geoidal separation
12. Meters (Units of geoidal separation)
13. Age in seconds since last update from diff.
14. Diff. reference station ID number
15. Checksum

5. Balloon mission

The balloon mission is endeavoring the tracking by the telemetry subsystem through the whole flight, landing, and subsequently to secure the payload's rescue. The telemetry data of interest are latitude, longitude, UTC (Coordinated Universal Time) and altitude.

In Fig. 3 can be observed the project structure, these are the payload of the stratospheric balloon and the

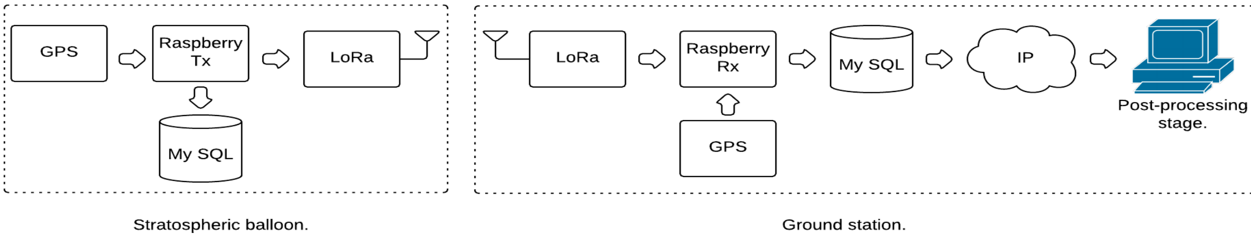

Figure 3. Project Structure

ground station next to the post-processing stage. A Raspberry Pi is the stratospheric balloon payload with a GPS module and a LoRa transmission module in it, the GPS module data is captured and stored into a database for its transmission to the ground station.

The ground station is a Raspberry Pi with a GPS sensor and a LoRa reception module, its function is to receive the stratospheric balloon transmitted data and store it in a database together with the receiver position to determine the distance and height regarding the ground station.

5.1. Transmission and reception parameters

The link frequency between the stratospheric balloon and the ground station was set at 912.88 MHz with a transmission power of 14 dBm using the power amplifier (Pa boost) of the RFM95 module, the sensibility at the receiver was set at -136 dBm. The link bandwidth was 125 kHz with a spreading factor of 12, a code rate of $4/5$ and a 16 bit CRC [5].

Due to the balloon payload's limiting factors the ground station must compensate the wireless link requirements like an antenna with high gain and directivity in this way the receiver sensibility will increase and decrease the packet error rate.

The link is set in only a one-way communication because the navigation balloon is not controlled, it is not contemplated to correct the balloon's direction during the flight, the telemetry subsystem's interest is only for tracking the balloon.

The device's time operation was tested and it can function about sixteen hours, the device's independence device depends directly on the battery capacity.

In both the real-time tracking and the travel's path mapping the information used was latitude and longitude, the altitude was saved in an independent record.

5.2. Payload

The balloon payload is a Raspberry with a LoRa GPS hat module, and an omnidirectional coil antenna with 1 dBi gain, the telemetry subsystem is described in Fig. 4. The GPS information is both being sent and saved in a database.

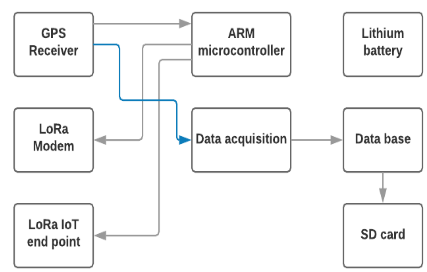

Figure 4. Balloon's payload block diagram

The payload's weight that includes the MODEM, GPS receiver, the single board computer, antenna, the battery and the structure is about 300 grams, as shown in Fig. 5.

Figure 5. Balloon's payload

5.3. Ground station

The ground station consists of two main parts: a Raspberry with a LoRa GPS hat module as receiver, the antenna was upgraded with a 9 elements 9 dBi gain Yagi antenna, as shown in Fig. 6, the received data is stored into a database that can be accessed remotely via IP (Internet Protocol); a personal computer shows a map and markers that represents the balloon's position.

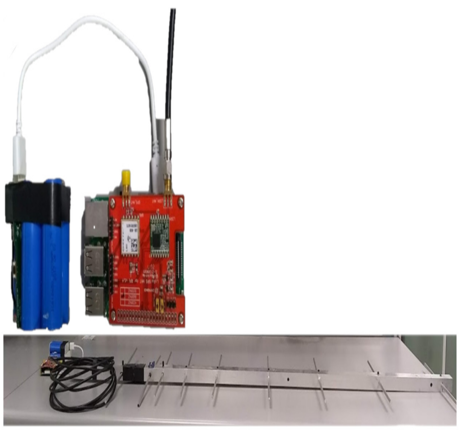

Figure 6. Ground Station

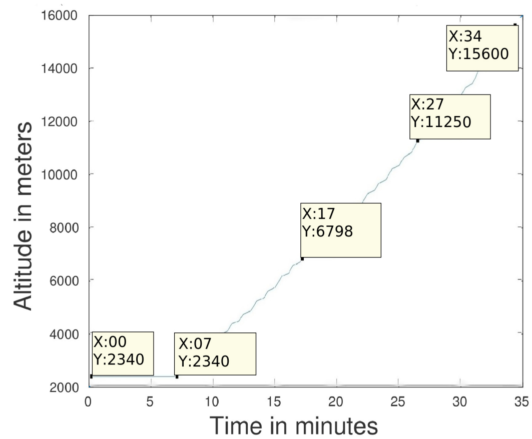

Figure 7. The stratospheric balloon's altitude(Time vs. Altitude)

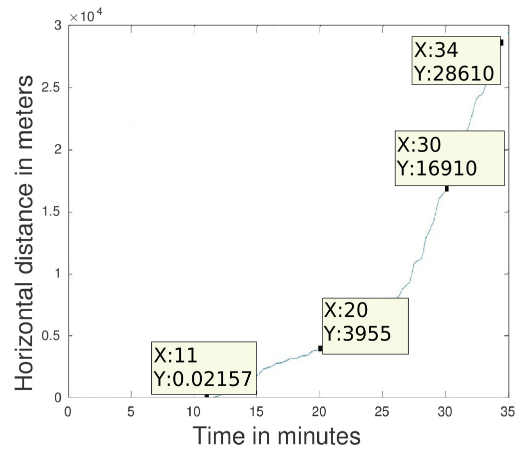

Figure 8. Horizontal distance (Time vs Distance)

6. Flight results

6.1. Performed route

The stratospheric balloon was launched from the coordinates $22^o47'08.2''$N, $102^o36'47.3''$W at an initial height of $2,329.2$ m. The last received data were the coordinates $22^o47'01.6''$N, $102^o19'44.7''$ W, to determine the horizontal distance d_h the formula of haversine is used (1), it calculates the maximum circle's distance between two points in a sphere given its longitudes and latitudes [8].

$$d_h = 2Rarcsin\sqrt{\sin^2(a) + cos(lat_s)cos(lat_c)\sin^2(b)} \quad (1)$$

where R is the Earth radius equal to $6,371,000$ m, lat_c and lon_c correspond to the stratospheric balloon's latitude and longitude equal to $22^o47'01.6''$N, $102^o19'44.7''$ W and lat_s and lon_s correspond to the ground station's geographical coordinates which are $22^o47'08.2''$N, $102^o36'47.3''$ W, so $d_h = 29,106.4$ m; $\Delta lat = lat_c - lat_s$ and $\Delta lon = lon_c - lon_s$; $a = \Delta lon/2$ and $b = \Delta lat/2$.

To determine the real distance is necessary to take into consideration the stratospheric balloon's height in regard to the ground station shown in Fig. 7 and the previously calculated horizontal distance shown in Fig. 8 , using the Pythagorean theorem, is obtained (2).

$$d = \sqrt{d_h^2 + (h_c - h_s)^2} \quad (2)$$

where d_h is horizontal distance, $h_c = 15,596.0$ m is the stratospheric balloon's height and $h_s = 2,329.2$ m the height of the ground station, both heights above mean sea level, obtaining $d = 31,987.7$ m.

The Fig. 9 shows the real-time tracking by the ground station, the green marker shows the ground station's position and the blue marker the last position sent by the stratospheric balloon.

The tracking was successful during 23 minutes, there were 76 received valid data packages, after that the device aboard the stratospheric balloon suffered a malfunction. As shown in Fig. 9 and Fig. 10 the last valid GPS balloon's information is the same, in the real-time tracking and in the device that was part of the balloon's payload, it can be inferred that it was not a communication problem.

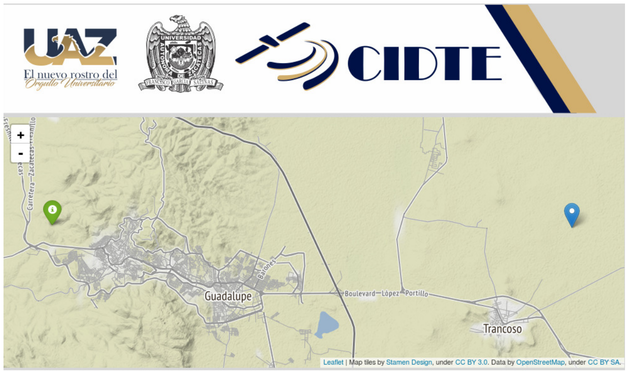

Figure 9. Last known position

Figure 10. Flight path

7. Conclusions

The LoRa IoT protocol has promising results considering that it was used only one ground station, the reception can be improved using additional ground stations to secure the tracking during the whole flight. The structure onboard the balloon has to have a thermal insulation structure because the SD card technology and power subsystem are especially vulnerable to extreme temperatures found in the stratosphere that oscillate between 0^oC and -55^oC.

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