FIEE Smart Campus IoT real-time bus tracking system and web app using LoRaWAN

Arévalo Villanueva, Manuel
Research Institute of the Faculty of Electrical and Electronic Engineering
National University of Engineering
Lima, Peru
marevalo@uni.edu.pe

Aspilcueta Narvaez, Álvaro
Research Institute of the Faculty of Electrical and Electronic Engineering
National University of Engineering
Lima, Peru
alvaro.aspilcueta.n@uni.pe

Arias Obregón, Gabriel A.
Research Institute of the Faculty of Electrical and Electronic Engineering
National University of Engineering
Lima, Peru
gariaso@uni.pe

Cabrera Ronceros, Samir L.
Research Institute of the Faculty of Electrical and Electronic Engineering
National University of Engineering
Lima, Peru
scabrera@uni.pe

Bendezú Isidro, Franz
Research Institute of the Faculty of Electrical and Electronic Engineering
National University of Engineering
Lima, Peru
fbendezui@uni.pe

***Abstract* — This paper proposes the use of Long Range Winde Area Network (LoRaWAN) technology as an alternative to the General Packet Radio Service and Global System for Mobile Communications (GPRS/GSM) communication for the university bus real time tracking as a solution to improve the mobility service and the student's time organization. This solution consists of the design and implementation of a prototype and a web app where users can view the location of the bus in real time. The prototype consists of an Arduino UNO development board for control and instructions, LoRaWAN IoT technology for wireless communication is used through the RAK 811 development board, which is connected to the Arduino UNO as a shield, a Global Positioning System (GPS) module, Neo6M to obtain the location, a battery for the autonomy of the prototype as well as other components that provide protection, the possibility of recharging the prototype and charging indicators, as well as the web app was implemented with Vue.js for frontend and Firebase for backend development.**

Keywords— LoRaWAN, Tracking, Internet of Things, Arduino.

I. INTRODUCTION

The use of vehicle tracking technologies has been a developing concept for a long time, having different applications such as utility services for passengers, routing services for trips, among others. Being the most common approach for the same the use of the Global Positioning System (GPS) hand in hand with the cellular technology of the Global System for Mobile Communications and General Packet Radio Service (GSM and GPRS). However, it is not the only viable option.

This study presents an alternative for the location of the bus for the transport of students and workers of the UNI using the cellular network, since there is no dedicated service to obtain its location, users use messaging applications to share the location of the bus when traveling to their classmates to let them know if the bus has already stopped or not at a certain location. LoRaWAN is an Internet of Things (IoT) technology designed to send very small message packets over long distances (up to 5 km in urban areas and up to 15 km in rural areas) while consuming little energy, which makes it feasible for tracking solutions. That is why a solution is presented using LoRaWAN technology together with a dedicated web application that is easy to access for different types of platforms, being able to view the real-time location of the UNI bus during its trips to pick up users and give them the opportunity to take precautions when taking the bus.

It was possible to implement the prototype that will send the location of the bus with an Arduino UNO board, a LoRaWAN RAK811 V1.2 development board, a battery with a protection charging system, as well as charge and discharge indicator LEDs, a NEO-6M GPS module, and the design & printing of a 3D case. An interior LoRaWAN RAK 7258 gateway to send messages from the prototype to the internet, in addition to a web app developed with Vue.js technology to display the real-time location of the bus on the web and Firebase technology for the backend development.

II. BACKGROUND

A. Tracking Techonologies

There are two types of tracking technologies: the ones that use GPS technology and the others who use different geolocation techniques.

In the case of the traditional GPS techniques, in [1] they use a tracking system for a bus which main goal is to avoid the waiting time for the users, using GPS and GSM/GPRS technologies for the transmission of the information. [2] proposes a scalable tracking system for public transport using IoT technologies for improving the time efficiency for the users and making the information visible for the citizens.

In the case of the other geolocation technologies, there are works like in [3] where they implement the algorithm for a technique called Time of Arrival, which uses the time for a message to arrive to a base station in order to calculate distances from different bases to the node and the intersection gives the position of the node in reference to the position of the stations.

While [4] uses a technique based on the measurement of the Received Signal Strength Indicator (RSSI) that uses the levels of intensity of wireless signals to approximate the distance from a base station to the device using models for the degradation of the signal's strength. [5] presents a solution based in LoRaWAN to localize IoT modules that are meant to be carried by vulnerable population in case of emergency or natural disaster. Using techniques to approximate distance from the gateways to the devices. [6] proposes an alternative to the traditional tracking functionality that is based in wireless communication with LoRa to communicate between

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the public transport vehicle and the base station. Each vehicle is intended to be carrying an RF transmitter that continuously sends default data that the stops RF receptor receives and with PIC18F microcontrollers and Wi-Fi uses that data to track the vehicle's location.

B. Communication Technologies

The main communication technologies that can be used in IoT applications are:

1) Sigfox

Long-range, low-power area network (LPWAN) end-to-end connectivity technology based on its proprietary technologies that connects end devices to servers using an IP-based network. End devices connect to these base stations using binary phase shift keying (BPSK) modulation on an ISM band carrier, as well as LoRa, ultra-narrowband (100 Hz) sub-GHZ. Sigfox uses unlicensed ISM bands, e.g., 868 MHz in Europe, 915 MHz in North America and 433 MHz in Asia [8]. In addition, message sending is limited to a maximum of 140 messages per day.

2) NB-IoT

It is a Narrowband IoT technology specified by the Third Generation Partnership Project (3GPP). Despite having similar standards to LTE technology, it can be categorized as a new air interface. This technology seeks to keep it as simple as possible so that it reduces equipment costs and minimizes battery consumption. It uses licensed frequency bands that have the same values that in LTE are used in quad-phase shift keying (QPSK) [9].

3) LoRa and LoRaWAN

LoRa is the acronym for Long Range, as it is designed for communication over long distances. The modulation technology used is Chirp Spread Spectrum (CSS), which is used in military and aerospace communications applications because of the long distances it supports and because it is robust to interference. The data transmission rate is low, ranging from 300 bps to 11 kbps. Low-cost LoRa chips for commercial use were released in January 2015.

LoRaWAN is a software protocol that defines the formats of information packets and how they should be processed by the network. It builds on LoRa (the physical layer) the other communication layers: link, network and session (OSI model) [7]

It has the following characteristics [10]:

- Long range (up to 5 km urban, > 5 km suburban, > 50 km line-of-sight).
- Long battery life (> 1 year).
- Low data transmission rate (0.3 - 50 kbps).
- Operates in unlicensed band spectrum (depends on each region and country, according to their regulations).
- Can perform geolocation through network triangulation.
- It can work under different operating modes (A, B and C) to configure when the end node should listen to the messages sent by the Gateway.

C. Existing Solutions

Regarding the tracking of vehicles, projects have been carried out using the LoRaWAN network as in [11] where it only uses LoRa technology in transmission and reception, testing with many gateways seeking a geolocation precision of 4 meters, which leads to a halt if it is not simulated, they use a The Thing Network (TTN) network server and an MQTT client was used for data processing. In [12] the contribution of the construction of a gateway and personalized servers for more flexibility in the design of network parameters is provided, it proposes a location system with GPS but based on LoRaWAN technology, in combination with an Android application for an intelligent transportation system. [13] proposes the design and development of an integrated tracking system that uses several independent technologies such as a GPS receiver module, an RFID reader module, and a GSM network module, however, a GPS system by itself is not completely accurate (can achieve an accuracy of about 15 to 30 m). [14] presents the design and implementation of a long-range wireless sensor network (WSN) prototype for tracking the geographical location of mobile objects in real time, it is indicated that WSN is the key technology to perform the detection of geographic location in IoT, the long-distance mobility of some objects, especially animals, poses risks to the reliability of the system outside the coverage of networks. Finally, [15] proposes a vehicle monitoring and tracking system based on an Embedded Linux board and an Android application for school vehicles.

III. METHODOLOGY

A. System Requirements

This section will cover the aspects that the final prototype required in order to accomplish its principal objective. The specifications will be divided in three subsections.

1) Power Budgets

Because the prototype needs to work during the specific times that the university's bus is doing its traveling, around 6 hours a day in total, it needs to be prepared to work standalone during this period of time.

Although, considering that it will

The objective was to use the prototype during predetermined hours during the operation of the mobility of the National University of Engineering (UNI) for students, which would be a maximum of 6 hours a day, where its location is really needed, in that case the autonomy would be approximately 8 days, but the mobility is only used for 5 days a week, in that case there would be no problem with the autonomous power supply of 6000 mAh during its operation, taking into account these considerations of use, a Micro USB rechargeable system is proposed since it facilitates its recharging with a cell phone charger or through the USB ports that modern buses have in the driver's cabin. Within the LoRa protocol itself, data is expected to be sent in non-continuous and spaced time intervals, for this reason, the prototype is configured to send data every 5 minutes; in addition, while it is not sending data, the prototype is configured to be in sleep mode, which has lower power consumption.

2) Case Requirements

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In this section, the considerations for the realization of the prototype design at a general level will be discussed, from the optimization of the space of the components to the requirements of the casing for a correct operation and durability. The references shown have been obtained from [16].

Environmental considerations such as vibration, moisture protection, and temperature must be considered. Regarding vibration, the book [16] comments that vibration occurs not only in the environment where the prototype will operate, it is also considered as an environment under vibration when transporting the prototype to its final location. In the case of humidity, the prototype must have ventilation holes that allow air to enter so that the water vapor contained in the air does not condense on the electronic components. At the same time, the holes must be small to reduce the entry of dust, although since the prototype will be located inside the bus, the entry of dust is reduced since it will not be located outdoors.

Regarding the temperature, the temperatures reached by the components of the prototype inside the bus in summer can exceed 40°C, the material and the components must be able to withstand this temperature level.

3) *Web App Requirements*

The web app must be multiplatform, that is, it must work both on mobile devices and on PCs or tablets. In addition, it must be "responsive"; that is, it must automatically adapt to the screen size of each device for a good user experience. In addition, it must have the capacity to support the entry of multiple users simultaneously who enter to consult the location of the bus on a map. In addition to that, it must have a view for the drivers, and it must show the routes of the buses. Finally, you must store the information sent by the prototype in a database.

B. *System Design*

1) *Tracking prototype software*

The prototype algorithm is shown in the following flowchart in Fig. 1. The programming was done in C language using the Arduino compiler to compile and record the program on the development board.

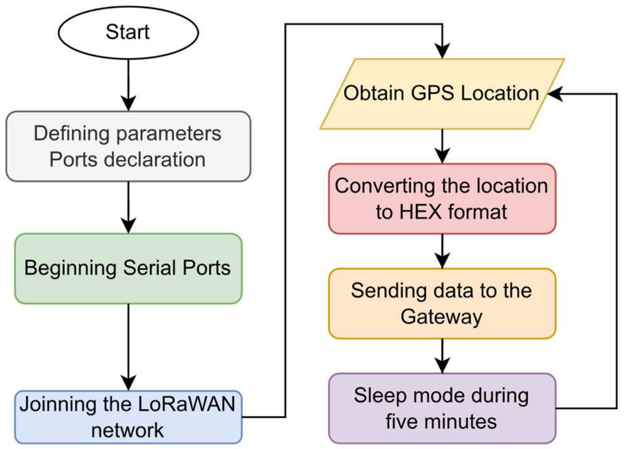

Fig. 1. Prototype Algorithm Flowchart.

Likewise, in the middle of the iterations of the code, a logic is used for the operation of the LED's that indicate the battery charge level.

There are two LEDs: Red and Green, where, according to the following energy operation modes, the following will be displayed:

- Prototype Charging (Powered): The Green LED will be in flashing mode.
- Prototype in Full Charge: The Green LED will remain on, indicating the state of full charge of the battery.
- Low Charge Level without power: The Green LED will be off, while the Red LED will enter a flashing mode, as a low battery level alert.
- Normal Operation: Outside of the cases mentioned above, both LEDs are off.

The algorithm of the operation of the LEDs is represented in the following flowchart, Fig. 2.

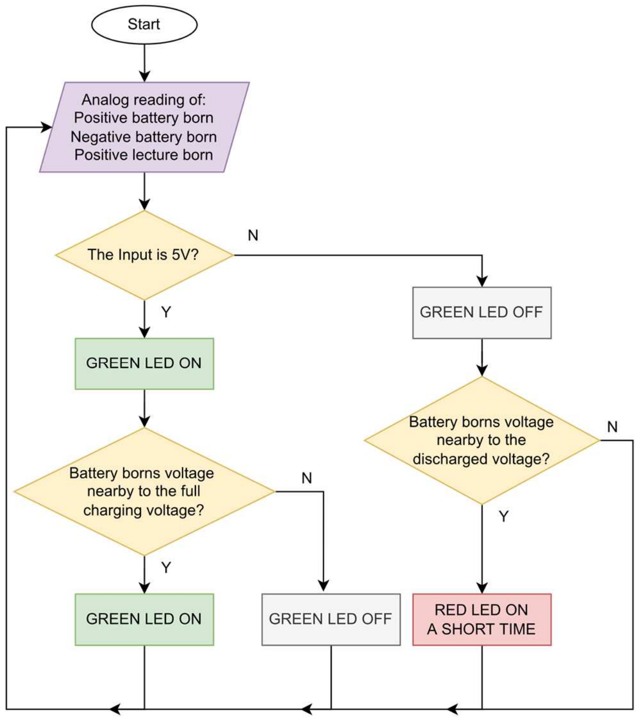

Fig. 2. Indicator lights algorithm.

The Fig. 3 shows the results of the implementation of the algorithm and the way that the data is visualized in hexadecimal format called payload of the message. This payload contains the coordinates of the latitude and longitude in grades, minutes, and seconds. Also, it contains the battery percentage of the prototype referred between the minimum and maximum battery voltage levels; in order to do an equivalence in percentage of the battery state.
Each payload is sent from the prototype to the cloud with a timestamp in hours, minutes and seconds; also, a counter for the quantity of data payloads received in the interface.

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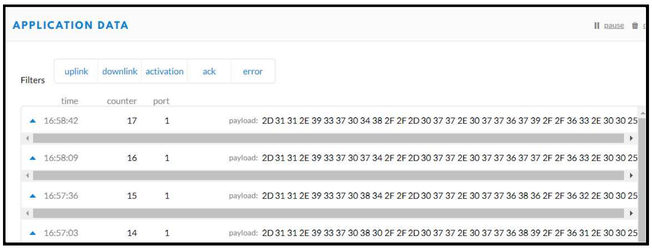

Fig. 3. Received data in the TTN interface.

The payload has a format of:
Lattitude//Longitude//BatteryPercentage
In hexadecimal form so that it sends only three data values within one message.

2) Tracking prototype hardware

The Fig. 4 shows the software's architecture in diagrams blocks in order to have a better comprehension of the prototype.

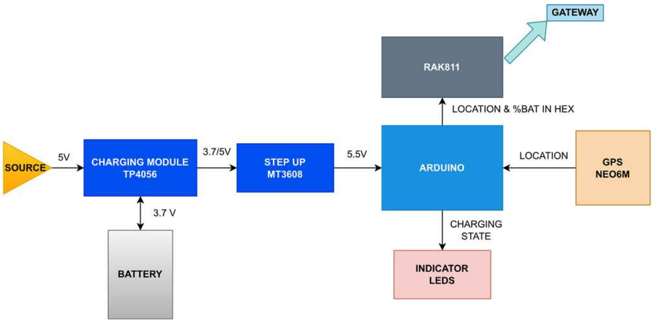

Fig. 4. Diagramm block of the prototype

3) 3D case design.

For this section, the dimensions of the different elements for the prototype had to be measured for making a good modeling for the protective case that is meant to be 3d printed.

To accomplish this, 3D real scale models are obtained from GRABCAD [21], an open access page to search for 3D models of different elements and devices. The design was made using SolidWorks [20]

In the case of the mobility and vibration, the design of the case will include wedges that won't let the prototype component's move or shake in order to avoid internal damage of the components.

Referring to the operation temperatures, the elements like the charging module or the voltage level shifter reach high temperatures referred to the other components; but that temperature doesn't exceed the ambient level. Although, the design separates these two components intentionally to avoid plastic or other elements melting within the other components of the prototype. Also, the position where the prototype is going to be settled could surpass the 40°C; even though the ABS plastic material could stand higher temperatures, the suitable choice for this work is the PLA in terms of economy and because it's the prototype's first version. Anyway, this material can stand temperature levels of 60°C.

The final design containing the prototype's elements is shown in the Fig. 5 that is the result of the 3D modeling in the software. This picture hides the top of the design to have a better view of the internal components.

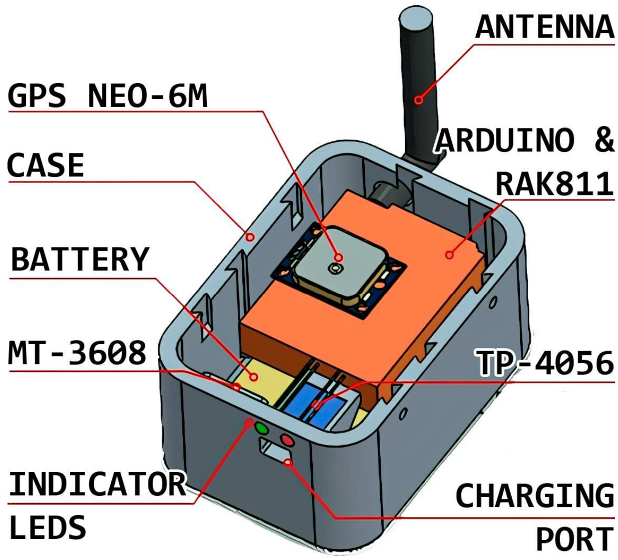

Fig. 5. Case design with internal components of the prototype.

C. Web Application Design

1) Architecture

The architecture for the communication (Fig. 6) between the web application and the LoRaWAN network server called The Things Network (TTN), the communication interface is done through HTTP Integration and Google Cloud Functions. Google Cloud Functions stores in Cloud Firestore the data collected over time and Firebase Realtime Database is responsible for storing the latest real-time data such as the location of the bus. All these data will be displayed in the application views.

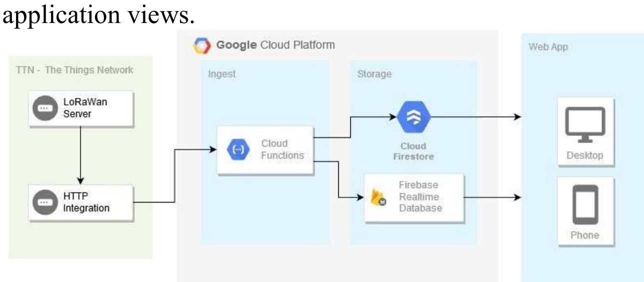

Fig. 6. Application architecture.

IV. Analysis of Results

A. Energy consumption and autonomy

Measurements of the energy consumption of the prototype were made, considering the use of its components over a period and how they behave when compared to the use of energy saving modes. For the voltage and current measurements, a conventional multimeter like the one shown in the image was used, with a resolution of 10 mV and an accuracy of ± (0.8%+2) for a range of 20V with respect to the DC voltage, and an accuracy of ± (2.5%+5) for the 10 A range with respect to DC current.

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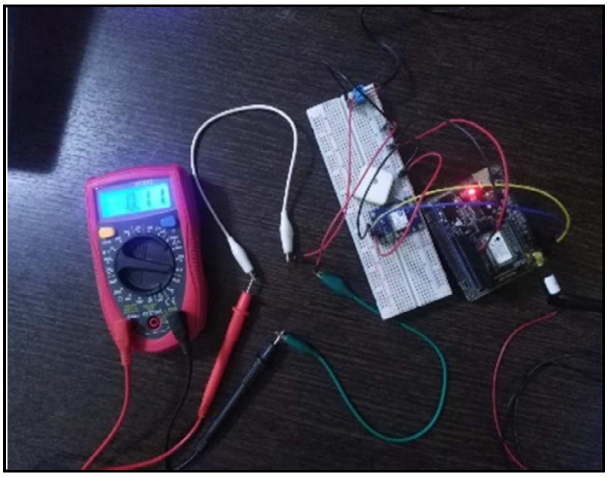

Fig. 7. Measurement of current consumption of the prototype.

Table I shows the voltage and current consumption, taking into account the different measurements for different modes of operation. Likewise, its approximate consumption is considered both in operation at full consumption and operation in low consumption mode (Sleep Mode).

TABLE I. MEASUREMENTS OF CURRENT CONSUMPTION OF SOME COMPONENTS

	Voltage (V)	*Amperes (mA)*
Total consumption	5 - 7	120 - 140
Total consumption sleep mode	5	110
Arduino only consumption	5	40 - 50
Arduino consumption in idle sleep mode	5	20 - 30
GPS only consumption	5	60

With the given premise, in order to achieve the autonomy of the prototype, research was carried out on the power supply modes of the Arduino development board. Resulting in the choice of an autonomous power supply such as a lithium battery with a 3.7V cell and a capacity of 6000 mAh. In order to supply a voltage value that allows the operation of the Arduino, a DC-DC Step-up MT3608 voltage booster is used to be able to raise the battery voltage from 3.7V to a value of at least 5.5V to be able to supply the energy. through the Vin port of the Arduino which has an internal voltage regulator. For the battery recharging system, a TP4056 single-cell battery charging module is used, which in addition to offering the possibility of recharging the battery, offers protection against overcurrent.

B. Prototype

Considering the constraints of the component dimensions and the mobility with the wedges, the design of the case printed in dark green PLA plastic is shown as shown in Fig. 8. The prototype print of the case, the lid and the wedges in Fig. 9 took a total of just over 20 hours.

Fig. 8. General view of fixed elements inside the case.

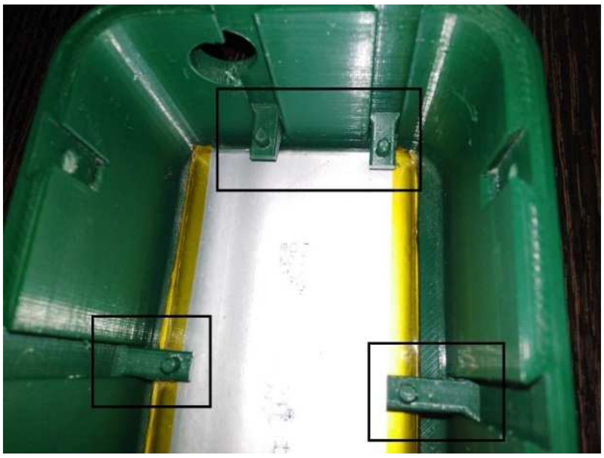

Fig. 9. Mobile wedges inside the prototype for the adjustment of the development plates.

In the case of moisture, the housing is closed by means of a cover with screw sockets, so that it is sealed. However, two holes are considered, one to be able to load the prototype and the other so that the antenna remains exposed, through this two holes ventilation will be achieved and it will prevent the humidity inside it from being stored and condensing the water of the environment on electronic components.

C. Functional Test Results

The images contained in Fig. 10 are photographs of the prototype in operation, made in the field work, which includes making measurements of the location by GPS, as well as the signal intensity parameters and others such as battery life. and analysis of the current consumption during the sampling time.

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Fig. 10. Photographs of the prototype operating in the sampling.

All the field tests carried out were in an urban area with a high population density, so all the interferences that this entails (physical and electromagnetic) must be considered, in addition to also mentioning that for these tests the sleep modes are not considered. of the Arduino UNO nor of the RAK811 module, so they have been for continuous tests of around 30 seconds and in different positions trying to make a circle around a gateway located on the fifth floor of a house, in addition the default antenna that It brought the development board with the RAK811 module, as well as highlighting that it is difficult to achieve line of sight due to the interference with the houses, which means that the real coverage of the RAK7258 LoRaWAN indoor gateway is approximately 200 meters. To increase the coverage the gateway must be placed in a higher place.

For these tests it is estimated that approximately 6% of the total battery capacity was used, taking into account its continuous use and the considerations mentioned above. The current consumption in approximately 2 hours and 13 minutes has been 287.3 mAh.

Fig. 11 shows the general connection of the internal components of the prototype as mentioned in the system design section, where it was sought to optimize the space for their interconnection.

The black and red cables are strictly for the power supply of the components that require it, as well as the white cable is for the operation of the indicator LEDs and the others are for the protection resistors, the GPS communication cables are not shown anymore. that those pins are directly connected to the development board where it is.

In Fig. 12 the prototype is shown together with its cover ready to be installed and operational.

Next, a capture is shown in Fig. 13 taken to the Google Earth Pro software where the mapping carried out with the majority of the 120 geographic coordinates, taken and analyzed from the TTN software interface, is shown, where said data can be visualized in Fig. 13. The green, blue, and red dots indicate the level of intensity of the signal that the prototype captured, indicating the level of intensity of the signal of the gateway coverage, which is good, regular, and poor, respectively. The location of the gateway is marked with the fuchsia dot.

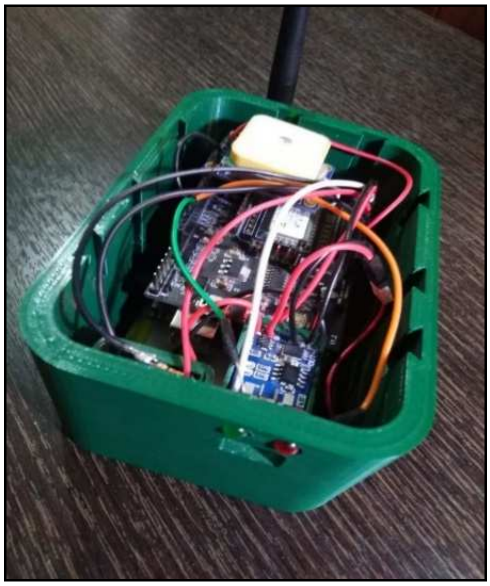

Fig. 11. Internal components and LED indicators and connection in general.

Fig. 12. General views of the built prototype.

Below is the simulation of the communication between the prototype and the gateway, this being the data collection from the point of view of the Google Earth software.

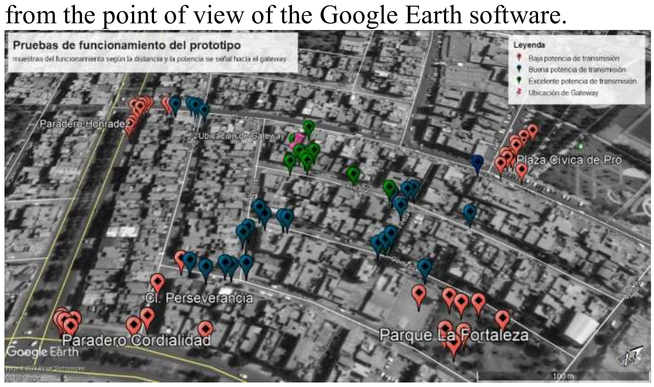

Fig. 13. Mapping of all the samples taken through the node and the gateway.

CONCLUSIONS

The design and implementation of the UNI bus tracking prototype was carried out through the development of a prototype that uses LoRaWAN IoT technology, as well as the development of its casing with 3D printing. Likewise, the web app was made for the real-time visualization of the

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bus location using the technologies of the Vue.js client side for the development of the graphical user interface and the Firebase server side. Field tests were carried out to validate the operation of the prototype and the coverage of the gateway, as well as the duration of the battery.

As future work, the dimensions of the prototype can be reduced through the design and development of a plate with the components, in addition, the casing can be redesigned to reduce the printing time by replacing the walls of the prototype with another material with aluminum plates and only printing the structural part, as well as using ABS plastic to withstand higher temperatures.

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