# Real-Time Geolocation Approach through LoRa on Internet of Things

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***Abstract*— Internet of Things (IoT) and wireless technologies like LoRa brought more opportunities for application development in a plethora of different fields. One of these is location estimation of real-time objects and people. In this study, we focus on monitoring user's location through a wearable IoT device with LoRa connectivity. The paper presents the development and integration of an loT ecosystem (Hardware and Software) which can be used in Search and Rescue (SAR) use cases. The proposed IoT ecosystem is evaluated and deployed in real-scenarios with established gateways. After that we compare the existed location-estimation methods in terms of attenuation problem, cost and operation as well to conclude to the most suitable solution that can be integrated in LoRaWAN environments. Finally, the conclusions of this work and improvements for possible future activity are described.**

***Keywords—IoT; LoRaWan; swift programming language; mobile application; wearable sensor nodes;***

## I. INTRODUCTION

Nowadays global national and regional networks connect billions of wireless devices. Even at home, multiple devices are connected, send and receive hundreds of messages every day. People are now able to monitor and control any device that's connected to the Internet. These devices form the already known Internet of Things (IoT) that refers to millions of network connected intelligent devices which contain sensors able to collect data and communicate with cloud services.

LoRa is a proprietary spread spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS) and which trades data rate for sensitivity within a fixed channel bandwidth. It's also a long range, low power wireless platform which can be used for building IoT networks worldwide. It enables smart IoT applications that solve some of the biggest challenges such as energy management, resource reduction, pollution control, infrastructure efficiency and etc. However it enables data communication over a long range while using very little power. The above technology fills the gap of cellular and Bluetooth and Wi-Fi based networks that consume high power, either high bandwidth or have a limited range. IoT introduce improvement in quality of life by providing cost effective solutions, through manage, monitor and control of physical objects. Smart IoT objects gather useful data from sensors and modules and process them through Gateway (GW) to remote application servers for further consideration.

To meet IoT requirements industry has invented and incorporated various technologies such as Near Field Connection (NFC), Wi-Fi, Bluetooth and etc. These technologies allow the implementations of modern applications which are health-oriented to monitor patients and vulnerable groups. These applications are based on emerging technologies such as Bluetooth Low Energy (BLE) and the Wide Body Area Networks (WBANs) such as LoRa [1]. In [2] authors implement a monitoring system using LoRa and real hardware for energy generation renewable facilities together with the system architecture. Moreover, a system that provides an access for a wide variety of low-speed and high-speed IoT devices following IEEE 1451.2 standard has been proposed. The system in [3] integrates both LoRa and WiFi module that makes the system using Message Queuing Telemetry Transport (MQTT) server for the data handling to combine the long-distance transmissions and power requirements. Also in [4] a mobile application for health monitoring is developed to handle environmental data from a user's surroundings.

Goal of this research is the development of a mobile monitoring system ecosystem using LoRa and hardware devices for GWs and end-node. In contrast with the above mentioned systems, the proposed ecosystem can be used in SAR scenarios (monitor of vulnerable groups by their relatives). For ecosystem's needs, we have deployed a local server that is responsible for the data collection and storage in database as well as visualization of the data in both mobile application and web application. Following our previous study [5] on location algorithms, we continue this research through the implementation of this IoT Geolocation monitor system as a proof of concept. The above system could be used in any application that needs track objects or people. [6][7].

The rest of this work is organized as follows: Section II presents the most relevant IoT protocols for long distances coverage. Section III is focused on the architecture of our ecosystem. Section IV presents the performed experiments. Section V concludes our study and finalize with future work. Finally, section VI includes acknowledgements.

## II. LOW POWER WIDE AREA NETWORKS (LPWAN) PROTOCOLS

Low Power Wide Area Networks (LPWANs) come to meet the needs of applications that require long-distance coverage together with low data rate capability. These technologies fill the above gap as they also solve energy consumption issues (low-power applications) which are a key factor in an IoT ecosystem.

### A. Sigfox

SigFox network technology has been developed to equip a high-capacity network, scalable with very low energy consumption. Based on an Ultra Narrow Band (UNB) technology, SigFox radio link uses unlicensed Industrial, Scientific and Medical (ISM) radio bands. The exact frequencies can vary according to national regulations, but in Europe the 868MHz band is used; in the US the 915MHz band is used; and in Asia the 433MHz band is used. The density of the cells is varying from 30 to 50km in rural areas and about 3 to 10km in urban areas due to more obstructions and noise. However the distance coverage can be vary for outdoor nodes where SigFox messages could travel over 1000km.

SigFox operation is using very narrow bandwidths. The uplink channelization mask is 100 Hz or 600 Hz in case of USA where the baud rate is 100 baud or 600 baud in the USA. The modulation scheme used is Differential Binary Phase Shift Keying (DBPSK). The uplink transmission power is compliant with local regulation. Also the link budget is about 155 dB (or even better) and the central frequency accuracy has no significant frequency drift within an uplink packet. In Europe, the UNB uplink frequency band is limited from 868.0 to 868.6 MHz, with a maximum output power of 25 mW and a maximum mean transmission time of 1%.

From the other hand the downlink channelization mask is 1.5 kHz where the baud rate is calculated about 600 baud. The modulation scheme in case of downlink is Gaussian Frequency Shift Keying (GFSK) . The transmission power is 500 mW (4W in the USA) where the link budget is varying from 153 dB (or better). The frequency of downlink transmission set by the network according to the corresponding uplink transmission. In Europe, the UNB downlink frequency band is limited to 869.40 to 869.65 MHz, with a maximum output power of 500 mW with 10% duty cycle

Downlink connectivity is device driven based on the requirements of energy minimization. For this reason, the device transmits an uplink message with a request flag (ACK) that all base stations can detect in the area. Then the SigFox cloud pushes the uplink message to the customer which senses that the device is waiting for a downlink message. It is up to the platform or customer to send this message to the IoT device over SigFox and when this done the whole communication process is over [8].

### B. Long Range Protocols

LoRa is a low data rate, low power wireless platform technology for building an IoT network. It uses unlicensed radio spectrum in the ISM bands to enable communication between remote sensors and gateways connected to the Network Server and Application Server. As a technology is being introduced by Semtech. Semtech has formed the LoRa Alliance, which already develops global standards. Semtech builds LoRa Technology into its chipsets. These chipsets are used into products that created by IoT companies and partners and integrated into LPWANs from mobile network operators worldwide.

LoRa uses Direct Sequence Spread Spectrum (DSSS) is widely used in data communication applications. However, challenges exist for low-cost or power-constrained devices and networks. The Spreading Factors (SF) in the LoRa case varying from 7 to 12 to decide the trade-off between range and date rate at long range distances. LoRa use also a Frequency Modulated (FM) chirp based on a spread spectrum modulation with a Chirp Spread Spectrum (CSS) variation. It improves the receiver sensitivity and uses the whole channel bandwidth to transmit a signal. In general, it uses unlicensed spectrum (868 MHz in Europe and 915 MHz in US), bandwidths 125 and 250 kHz depending on SF which also vary from 7 to 12. Higher SF values delivers long range at an expense of lower data rates 22bps (BW = 7.8kHZ and SF=12) to 27kbps (BW=500kHz and SF=7). The ranges extend from a few kilometers in dense urban areas up to 15-30 kilometers in rural areas. LoRa efficient energy consumption allows power life to up to 10+ years. It is important to mention that the radio chipset cost is calculated about $2 or less and the radio subscription cost about $1 per device/ year.

LoRaWAN is a network specification proposed by LoRa Alliance that offers a MAC layer based on LoRa modulation. This layer is able to be used in large-scale area. It can use Adaptive Date Rate (ADR) mode controlling the SF, the bandwidth occupation and the RF output power of each node. The goal of LoRaWAN protocol is to extend the battery life and the network overall capacity by transmitting also with the highest rate. The specification defines three different clients categories Class A (bidirectional), Class B (scheduled received windows and beacons), Class C (end-device is always available for reception except time of transmission).

LoRaWAN can cover up to millions of devices depending on various factors such as message transaction rates number of LoRa channels and etc. but theoretically it can receive up to 2,700 messages per hour in ideal conditions [9].

## III. Outdoor Real-time Geolocation System using LoRaWAN

LoRaWAN architecture is being used worldwide to provide long-range connection among many IoT devices. Its architecture uses a star topology consisting of the end-node acting like a wearable device, GWs and an application and network server. The proposed solution is an ecosystem for an outdoor real-time application based on LoRaWAN. Fig. 1. shows the proposed architecture. This system allows us to receive, process and visualize data from IoT devices. The network used is mesh type and the system can improve the communication range. Except from the range the cell size of the network can be also improved. This made LoRaWAN a good candidate for a variety of applications that need high coverage and low-power protocols. A communication cycle starts with the end-node where sensor data are gathered through the module and sent to one or many GWs available to the LoRa area [10]. In our case, three development boards were used as

GWs and an end-node (Fipy models of Pycom[1]) as a wearable device. The role of GWs includes the following: receive, correlate and maximize the accuracy of location detection with the use of multilateration technique.

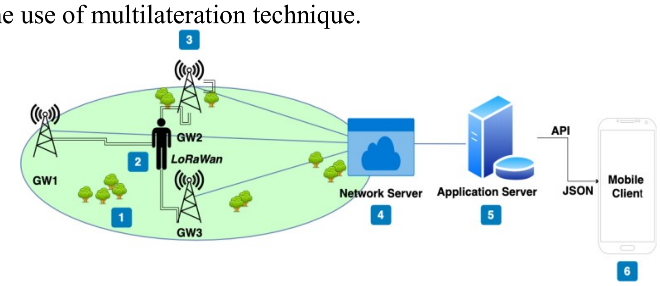


Fig. 1 The system architecture

The GWs' responsibility as we can see from Fig. 1 is to collect and forward the packets to the internet. The area where these GWs placed is not urban, but it was not just Line-of-sight (LoS), as buildings were in front, and objects that could make communication more difficult were exist. Depending on the use case, IoT wearable device together with sensors can transmit messages and receive acknowledgments or responses by listening to the network after sending on fixed intervals or in an always on mode to reduce latency.

In terms of tracking there are many techniques which can be used to estimate the position of the device, each one suitable for different cases and scenarios. In order to achieve better results in terms of accuracy it is highly important to select the one depending on the known information from the end-node. The three different ways used for performing location-tracking are triangulation, trilateration and multilateration. Triangulation uses angles of incidence of the signal received from the transmitter. Trilateration requires the distance between the transmitter and receiver which can be obtained by Time Of Arrival (TOA). In this case Time Difference of Arrival (TDoA) part of multilateration is used. In TDoA, the transmitters are synchronized to each other (only gateways). The intersection of the two hyperbolas gives the actual position. In Fig. 1 point 1 declares a LoRaWAN network in which the user (Point 2) with the IoT device (wearable) is located. Point 3 is referred to the LoRaWAN GW. The three GWs act as Nano-Gateways.

The wearable end-device communicates through LoRa with the central GW which forwards the wearable position related data to the Network Server and Application Server (Point 4 and Point 5). The above data can then be processed and visualized in mobile applications through an API or towards influxDB[2] and Grafana[3].The equipment used for the experiments includes 3 Fipy model of Pycom which are used for the Gateway implementation and one Fipy model of Pycom which is used for the end-node (wearable) implementation. Furthermore we used the shield Expansion Boards & PyTrack which have a built-in GNSS Glonass GPS as well as universal LoRa & Sigfox Antenna Kit working in the 868MHz LoRa bands. As for the power of the modules, for simplicity reasons we used LiPo Batteries.

[1] https://development.pycom.io/index.html
[2] https://www.influxdata.com/time-series-platform
[3] https://grafana.com/docs/grafana/latest/features/datasources/influxdb

### *A. LoRaWAN Nodes / End Points*

LoRaWAN end-node is any device which has sensors, can send data and be controlled remotely. In our case, the end-node is a PyCom development board that acts as a wearable device able to send data to the GW. The configuration of this device is presented in Table 1. In terms of energy requirements, we used a LiPo battery together with an Expansion Board so that our end-device has the required power to collect the measurements, communicate and successfully connect to the nearest Gateway and send the message packet.

*Table 1: Wearable and Gateway Configuration*

| **Type** | Pycom | Pycom |
|---|---|---|
| Ram | 4MB | 4MB |
| Voltage input | 3.3V to 5.5V | 3.3V to 5.5V |
| Node Range | Up to 40km | Up to 22km |
| Battery | LiPo | Up to 100 Nodes |

### *B. Gateway*

The LoRa GWs acts as a layer for transforming messages between end-nodes and a central network server on the backend. Data frames from IoT device can be sent to the GW and the communication will split to different channels and data rates. The data rate used in the LoRaWAN area was between 0.3 kbps and 50kbps using 868 MHz (Europe) frequency.

### *C. Network server*

In this step, these data are transferred to network server. Its functionality is to connect sensors, gateways and end-users applications as well as ensure the reliable and secure data routing along the LoRaWAN network. In order to access the data at any place and anytime we store the data in a cloud server.

### *D. Application server*

In the application server we have a created a timeseries database for the data storage. Influx DB is used for this purpose, and Grafana as a general plugin visualization dashboard. It can also be integrated in any web application as third party library for data optimization. As application server is the final destination of the data, most networks push data to this server in JSON format, or either an HTTP Post or at a MQTT topic. MQTT is a network (light) protocol that has been integrated in many IoT solutions. It is developed by IBM and it is implemented at the TCP/IP stack. It uses publishers and subscribers, where message topics are used as queue for this transformation. It has gained a lot of popularity because of its simplicity and low network resource usage. [11].

## IV. EVALUATIONS AND EXPERIMENTS

In order to make the visualization easier, a smartphone mobile application has also been deployed in order to visualize collected data and retrieve notification in real-time. In the current version, the application supports two basic features.

Firstly, a location tracking system in which the user can monitor the IoT position in real-time and secondly, the user (with the wearable) can send a notification event to the server, which in turn will notify the predefined contact for the current position of the user. The mobile application is written in Swift[4] for the iOS operation system and allows monitoring the current position of a LoRa wearable device. The choice for iOS was because it is widely used, offers stability and increase of security. The above application can be used by familiar people of the vulnerable person for SAR scenarios in order to track them.

### *A. Real Time Tracking*

In order to retrieve user's location and display on the map, MapKit[5] framework is used for the map creation and location visualization as we can see from Fig. 2. The location is determined through the already formed shield (PyTrack). The above sensor shield supports GNSS Glonass GPS with 3 axis and accelerometer of 12-bit. After the location is collected and processed the related package is prepared. The package instead of location includes also the time of data collection and the connected GW. This package is forwarded to the Network server and from there to our cloud server (running on Node JS) for further processing.

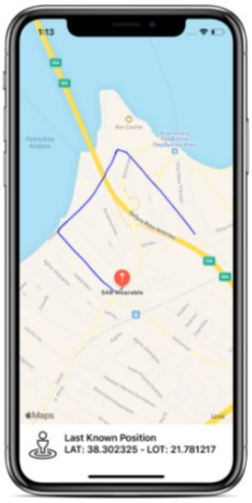


Fig. 2 Real-Time position

Each user's location includes the UUID identifier of the device and this match in every data we receive from GWs. So we can know from which GW the measurement came from. After that each measurement after correlated, is recorded and stored in a time series database (influxDB) for further process which can be exported by the API.

Using low cost devices with good performance is critical in order to ensure the Quality of Service (QoS) of IoT applications for LPWAN. With the battery of the device to be the most expensive component in a module, it is critical to ensure that this battery will last and meet the requirements of our system. For this case a LiPo battery has been used for each Pycom device through PyTrack in order to ensure that the module can connect to the Gateway and send its payload. To verify our experiments, the samples we took were every 30 seconds to see the resilience of the application. However, this leads to increased power consumption as the wearable device must record, collect and send data within seconds to the server. This could reduce the battery life of the device. For the above reason we increased this frequency to 1 measurement per minute in orders to ensure the battery life of the device and its extension [12]. Having created an REST client in swift application, we make also available an API able to request the data from the database and visualize them. The position as mentioned above is updated every few seconds giving us a clear and accurate user location. The above feature could be used in an SAR environment where users can track familiar people belonging to vulnerable groups to know each time where they are located.

### *B. Alert Notification*

Moreover the wearable device through LoRa connection can send also notification messages (through a button press on the wearable) to the application server as alert events. For the implementation of the notification service we used MQTT. The MQTT protocol make use of a publish-subscribe model where clients connect and publish messages to a broker for a notification event. This broker is responsible to dispatch the data to the subscribers and then acknowledge them. The alert events are published in a MQTT topic where a client running in iOS application is subscribed waiting for new messages. For better performance our system checks asynchronous for new messages and once new messages arrive the mechanism process them.

The above functionality is triggered through publish from LoRaWAN IoT devices to the Server by publishing the data to a preconfigured topic. MQTT delivers messages according to the QoS [13]. The delivery protocol used in our case is symmetric. The QoS level used to deliver a message outbound to the client could differ from that of the inbound message. The MQTT configuration is available at Table 2.

*Table 2: MQTT Configuration*

| | |
|---|---|
| Connection | host,port=1883,keepalive=6,serverURI=tcp://localhost,ConnectionTimeout=5,KeepAliveInterval=10 |
| QoS | quality of service;; default = 0 |
| Maximum messages | optional; default is 5000 |

After retrieving the data through the topic the mobile application uses UNMutableNotificationContent a framework from Swift language to optimize the information to UI and trigger notification events to the smartphone as we can see in Fig. 3.

[4] https://developer.apple.com/swift/resources

[5] https://developer.apple.com/documentation/mapkit

Fig. 3 Alert Notification

Knowing user's location in a SAR environment is especially important as people in vulnerable groups may need help. LoRa as technology has been developed in order to be used for outdoor and indoor communication as well based on its capability for long range communication.

In addition to being able to track an IoT wearable via LoRa in long-range distances, it is very important the user be able to press a button to send an alert to a familiar person to indicate his location. In this case, using an alert notification and the above application, a user wearing a wearable (IoT module) with LoRa connectivity could press a button to trigger a notification event so that it informs the familiar people through the mobile application.

### C. *Data Storage and Grafana Optimization*

In order to evaluate the collected data, we must store them in a database. As our data are time dependent we used a time-series database, InfluxDB.

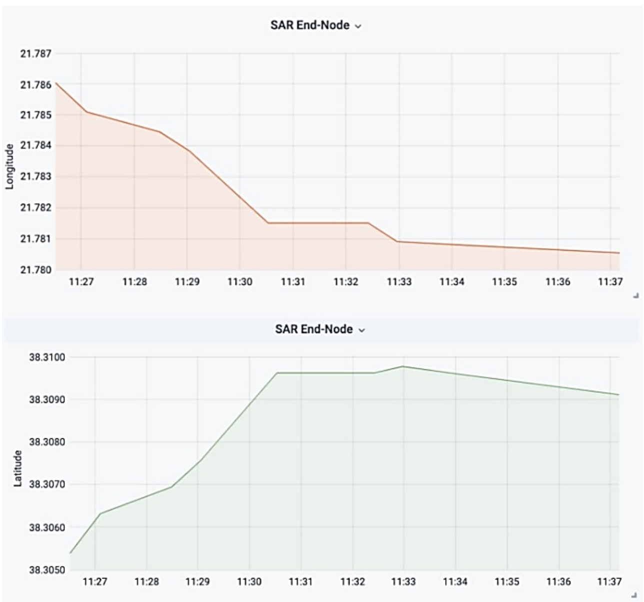


Fig. 4 Partial view of the Grafana dashboard showing user's position in latitude and longitude measurements.

This database is open source and makes it easy to save a large amount of data in real-time with their delivered timestamp. To store data to the InfluxDB database, a Node Server has been deployed exposing a simple API for the CRUD (Create, Read, Update, Delete) operations. Each time data is received the server sends the data to the database. When the data is imported it automatically produces a timestamp. For the visualization of the data we used Grafana, an open source tool for this purpose. It also offers operations to share and export data through graphs and embed codes together with its timestamp. Fig. 4 shows an example of user's position in relation to time including latitude and longitude.

### D. *Performance comparison on collected data*

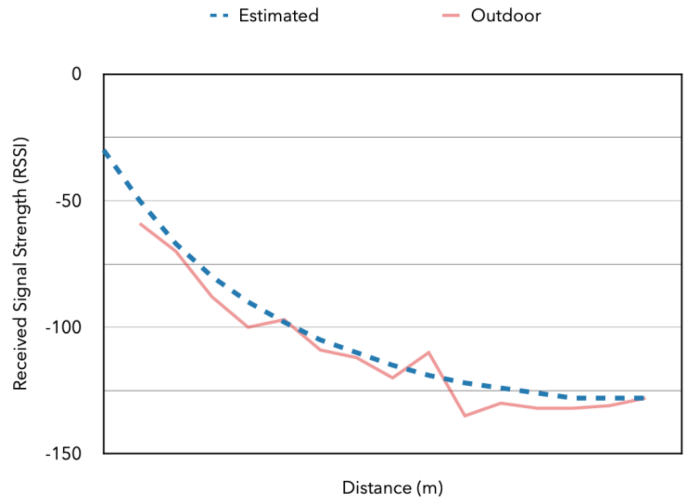


Fig. 5 Combined outdoor and estimated position RSSI.

The above figure shows the relationship between RSSI and distance between end-node and Gateway, which is inversely exponential. As we can see, from the RSSI curve, while the distance is increased the RSSI value gradually decreases. This may lead to poor localization performance for large distances between the Gateway and the end-node due to the path loss effect. For this reason, parameters such as SF, interferences and code rate can be modified for better performance.

### E. *Comparison with similar location-estimation methods*

Table 3 compares RSSI, AoA, ToA and TDoA, as potential methods for location-estimation. As we can extract only RSSI does not require extra special hardware and low in cost, however attenuation problem occurs. Moreover, AoA has high cost due to antenna array required in this technique and medium attenuation problem.

*Table 3: Comparison of Localization Methods*

| Method | Operation | Attenuation Problem | Cost |
|---|---|---|---|
| RSSI | Signal Strength | High | Low |

| | Measurement | | |
|---|---|---|---|
| AoA | Angle of Signal Arrival | Medium | High |
| ToA | Time of Arrival | Low | Medium |
| TDoA | Time Diff of Arrival at different points | Low | Medium |

Compared to RSSI and AoA, ToA and TDoA techniques have medium cost (modules and gateways must be purchased) in contrast to RSSI with low attenuation problem. However ToA and TDoA seem according to our experiment to have better accuracy because of the fact that LoRa modules support sensors for better accuracy. This lead to the conclusion that we must careful select the suitable localization method based on the hardware we have, the distance of the gateways and nodes as well as well as the application that we would like to develop.

## V. CONCLUSIONS AND FUTURE WORK

LoRa is already a proven technology deployed in millions of sensors. In this paper we discussed about the development and deployment of a monitor system using LoRa and IoT real hardware. The location of the end-node in our case was predicted accurately using the multilateration and study of various location algorithms. In terms of power consumption, while the received data are raw, it will also be important to perform aggregation of data. The aggregation of the data and time of collection could save also the battery of the wearable device. The major anticipated outcomes of the proposed platform are the improvement of the monitor of vulnerable persons. Familiar people will be able to track their people with access in real-time information. They are also able to receive notifications in case of emergency. This will improve early detection and tracking experience of people in need. Our future works includes the introduction of security features in proposed system. Our goal is the introduction of cryptography as security approach by using a unique 128-bit network session key shared between the end-device and network server and by using a unique 128-bit application session key (AppSKey) shared end-to-end at the application level.

## VI. ACKNOWLEDGMENTS

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