IoT Geolocation Performance Using LoRaWAN

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Abstract. Low Power Wide Area Network (LPWAN) technologies aiming to provide power-efficient solutions to the world of IoT. This paper describes a solution based on the Long Range Wide Area Network (LoRaWAN) technology to geolocalise IoT modules such as wearables used from vulnerable groups. Through estimation of the behavior of a LoRaWAN channel and using trilateration and RSSI information, the localization of an IoT wearable can be obtained within a small range. Routing people in need is one of the use cases the above mechanism could be integrated so as to be able to be tracked by familiar people.

1 Introduction

The world of Internet of Things (IoT) refers to the interconnection of data among smart devices and sensors. Nowadays an explosion of IoT applications can be seen in many industries, many of which focusing on long-range communication, low data rate and low power consumption. These requirements give rise to the emergence of a number of new wireless communication technologies and application development using low power protocols.

Low Power Wide Area Network (LPWAN) technologies have attracted a lot of research attention since their emergence. In [1] a comparative study of three LPWAN technologies that compete for large-scale IoT deployment SigFox, LoRa and NB-IoT is being studied. As the results of the evaluation show, SigFox and LoRa have advantage in terms of battery lifetime, capacity and cost, while NB-IoT offers benefits in terms of QoS. Another interesting perspective in [2] investigate how could LoRaWAN with the 5G could be integrated in Universities for applications development. In [3] object of the paper is centralized to IoT network development and more specific the authors specialize on the selection of Ultra Narrow Band (UNB) and Spread Spectrum (SS) by examining some of the most critical factors (interference, capacity, link budget and coexistence) responsible for the performance of LPWAN technologies. Through experiments they present their results. In [4], authors present a rescue monitoring study of two wireless technologies used for data transmission from IoT devices: the already known WiFi and the upcoming LoRa technology.

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Geolocation is the identification of the geographic position of an object, an IoT device or a person. In its basic implementation, Geolocation involves the generation of a set of geographic coordinates and is closely related to the use of positioning systems [5]. Many researches have been already done using the traditional Global Positioning System (GPS) in terms of Global Navigation Satellite System (GNSS) receivers. Note that GPS systems use a similar approach but need to be more accurate by: estimating the distance between a GPS end-client and at least three GPS satellites. This can also be done by measuring the time delay that a signal takes to be sent from the satellite to the GPS end-node, and converting this time delay into a distance. GNSS systems have the possibility to provide high accuracy in a few meters but require more complex, energetically demanding and costly devices [6]. In [7] researchers propose a system to locate a mobile device in case of emergency rescue need within the GSM network using a method that involves the known positions of three base stations and the power of the received signal. In comparison with our study we are trying to locate a person in need (wearing an IoT device) with LoRa connectivity and the known positions of already existed LoRaWan gateways. Another approach compared to our study is the one described in [8]. In this paper, authors exploit trilateration in order to locate a robot from its distances, or range measurements from three known base stations. The mathematical model uses geometric arguments, coordinate-free formulas in order to find the position of the robot inside an area. Having this in mind, we start by examining a scenario for Search And Rescue (SAR) systems using trilateration in LoRaWan networks by using existed gateways, network server and the IoT device (wearable).

A Geolocation application service built-in using LoRaWAN can be useful for area-based location positioning, with the advantage of requiring fewer and low cost devices with long-lasting batteries. Such devices could be wearable devices worn by people in need of help. In this case, because we do not know the actual time of location detection, the battery life as well as the cost of the device are considered important factors and should be taken into account when designing such a system.

Some use cases that above devices could be used are positioning monitor systems for a vulnerable group of people. In this use case the goal is to locate people in need such as track them as they move or by creating geo-fences, for example, sending an alert if the person in need moves outside a defined area, like a child in a neighborhood.

In this paper we describe our approach based on IoT devices and on the deployment of various LoRaWAN gateways. Through the estimation of the behavior of a LoRaWAN channel and using trilateration, the localization of an IoT wearable device can be obtained within a small range (about 40–60 m). It's a low cost solution, and with a good possibility to operate even though in indoors cases such as shopping malls or playgrounds.

The rest of this work is organized as follows: The next section introduces the LoRaWAN technology whereas Sect. 3 refers to the proposed architecture. Section 4 contains the Geolocation algorithm where Sect. 5 the performance experiments and general analysis. Section 6 includes the conclusions as well as discusses the future work and remarks on the implemented system.

2 LoRaWan Overview

LoRaWAN is one of the first LPWAN technologies presented in IoT market. The above technology designed particularly for IoT devices and applications since they typically need both low frequencies and small sizes of data transfer. This technology can be used for monitoring vulnerable groups of people from their familiar. The LoRaWAN standard defines MAC and network management protocols for devices using the LoRa modulation. The network topology is a star-of-stars, formed by three kinds of devices:

- End Device (ED): a peripheral node, typically a sensor or actuator that communicates only through the LoRa PHY;
- Network Server (NS): a centralized entity that controls the network parameters, forwards messages to applications and sends replies to the EDs through the gateway(s);
- Gateway (GW): an intermediate node that relays messages between EDs and NS.

EDs and GWs communicate using the LoRa modulation, while the connection between GWs and NS is realized using legacy IP technologies [9]. Typically, the GWs are equipped with LoRa chipset that allow for the parallel reception of multiple signals. The LoRa physical layer operates usually in the 433 MHz, 868 MHz or 915 MHz frequency bands. In Europe, only the 868 MHz and 433 MHz bands can be used. In the 868-MHz band, there are three 125-kHz channels that are mandatory to be implemented in every ED. There are another five 125-kHz channels that can be optionally used for LoRa communication. By using Ultra-Narrow Band (UNB), LoRaWAN utilizes bandwidth efficiently and experiences very low noise levels, resulting in high receiver sensitivity, ultra-low power consumption, and inexpensive antenna design. For this reason, LoRaWAN has been selected as one of the most suitable candidates for IoT network application development [10].

3 Proposed Architecture

The solution proposed in this paper is based on the use of the multiple associations that a LoRaWAN node establishes with surrounding GWs. All established GWs in our area receiving a packet from a LoRaWAN IoT device and forward it to the network server. This leads the network server to have multiple copies of the same package. The next step is to filter the duplicate copies and send a unique copy to the application service. The above data can be extracted through the application service by developing a simple API. In this scenario Message Queuing Telemetry Transport (MQTT) used to obtain the above information. It is a lightweight messaging protocol being used for small sensors and IoT modules, optimized for high-latency or unreliable networks improving the data communication [11]. The basic concept is the deployment of a broker, publishers/subscribers and topic creation. A JSON file containing all the data and various details about the data channels and GWs is being created.

The critical condition in our approach is that in any position inside an area the client has connectivity with a minimum of three GWs so that we can benefit of trilateration. The locations of the GWs are to be installed and the total number of required GWs is strongly dependent on the context in which the localization process has to take place. The setup of the LoRaWan GWs has to be done into consideration of factors like the size of the area that we want to cover, the number of devices that can be tracked and any buildings that may be inside (Fig. 1).

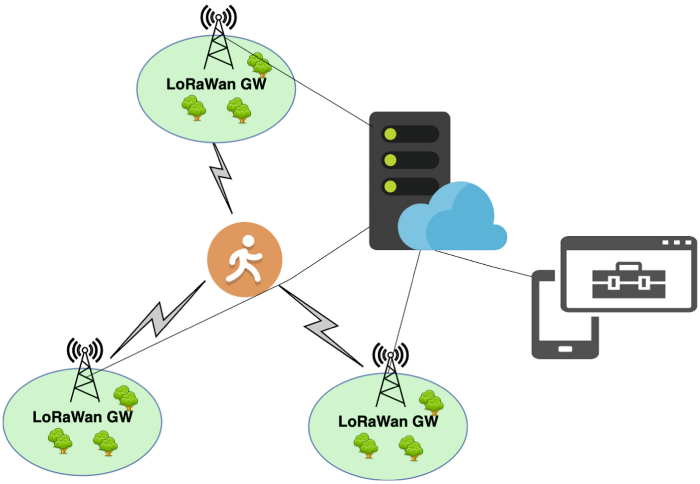

Fig. 1. The architecture of the proposed system.

The network server provides the data in form of *JSON* file with various details of the data channels and the GWs where the packet got through.

Example of the metadata format in JSON


```
{
  “modulation”: LoRa,
  “coding_rate”: “4/5”,
  “data_rate”: “SF7BW125”,
  “frequency”: 868.1,
  “gateways”: [
   {
   “channel”: 1,
   “id”: eui-fipy1,
   “latitude”: 38.306520
   “longitude”: 21.778365,
   “rssi”: -95,
   “snr”: 10
   “time”: “2019-11-05T14:00:30”
   },…
}
```

Our approach includes devices which act as end-devices (for example wearable IoT devices) and GWs. The end-points are associated with whatever the vulnerable people are required to be located. The main advantages of these devices are small size; and low energy consumption. The roles of these devices are the periodically broadcast of the selected data. Frequency of this functionality varies according to network availability as well as power consumption in the specific time. This also is vary through the degree of the mobility of the user wearing the IoT device, for example slowly moving ones can send every 4–8 min, rapidly moving ones can each 10–20 s. Duty cycle is one of the major factors of LoRaWAN standard, and so much be considered. For this reason, the purchase and use of low cost modules is required. In this project Pycom[1] modules (by Pycom LTD) is used including: FiPy modules together with PySense sensor shield, track PyTrack sensors shield and SiPy modules. The GWs in our case (FiPy modules) can be single-channel devices that do not require extra special software besides the basic standard forwarding software to the cloud servers. All GWs must head to the central network server and must be configures to be part of the same "application". The code running on both GWs and end-devices is Micropython.

4 Geolocation Algorithm

In this phase, the Geolocation algorithm is being proposed. The basic characteristic of the algorithm is that it uses the generated JSON file as proposed above. The LoRaWAN architecture provides complete information about the GWs that received the packet sent by the wearable device and the strength of the signal (RSSI) with which it was received. Using the above information after that we can apply the algorithm. As already proposed the algorithm is based on trilateration [12]. The same logic is used by the already known GPS. With three LoRaWan GWs, the true location can be provided as the central point where all three circles intersect. In our case, the GWs that receive the broadcasted message from the wearable device act like the satellite on the GPS use case, and the RSSI value for each GW perceived by the client is used to determine an estimate of the distance [13, 14]. The received RSSI values from the three GWs are the starting point for the estimation of the distance. This process is already known in the literature through various models [15, 16]. So it can simply be defined as:

$$P_r(d) = \frac{P_t}{d^n}, \tag{1}$$

where n is the called distance-power gradient. In the ideal case, $n = 2$; Interval of value n is [2, 6].

$$d = 10^{\frac{RSSI}{10*n}}, \tag{2}$$

[1] https://docs.pycom.io/products/

Supposing the use of the RSSI value from three different LoRaWan GWs, g_1, g_2, g_3 that are located at coordinates of type (*x, y*). If we indicate the computed distances as d_1, d_2, d_3, we have the following equations:

$$\begin{aligned}(x - x_{g1})^2 + (y - y_{g1})^2 &= d_1^2 \\ (x - x_{g2})^2 + (y - y_{g2})^2 &= d_2^2 \,, \\ (x - x_{g3})^2 + (y - y_{g3})^2 &= d_3^2\end{aligned} \tag{3}$$

After expanding the squares and subtracting the equations:

$$\begin{aligned}Ax + By &= C \\ Dx + Ey &= F\end{aligned}\,, \tag{4}$$

which finally give us:

$$\begin{aligned}x &= \frac{CE-FB}{E-BD} \\ y &= \frac{CD-AE}{BD-AE}\end{aligned}\,, \tag{5}$$

where $A = (-2x_{g1} + 2x_{g2})$, $B = (-2y_{g1} + 2y_{g2})$, $C = d_1^2 - d_2^2 - x_{g1}^2 + x_{g2}^2 - y_{g1}^2 + y_{g2}^2$, $D = (-2x_{g2} + 2x_{g3})$, $E = (-2y_{g2} + 2y_{g3})$, and $F = d_2^2 - d_3^2 - x_{g2}^2 + x_{g3}^2 - y_{g2}^2 + y_{g3}^2$. This is clearly a 2D plane (Fig. 2).

Python Algorithm Implementation

```
#Trilateration formulas to return intersection point of three circles

def trackIoTWearable(x1,y1,r1,x2,y2,r2,x3,y3,r3):
 A = 2*x2 - 2*x1
 B = 2*y2 - 2*y1
 C = r1**2 - r2**2 - x1**2 + x2**2 - y1**2 + y2**2
 D = 2*x3 - 2*x2
 E = 2*y3 - 2*y2
 F = r2**2 - r3**2 - x2**2 + x3**2 - y2**2 + y3**2
 x = (C*E - F*B) / (E*A - B*D)
 y = (C*D - A*F) / (B*D - A*E)
 return x,y

#Generate and represent data to be used by the trilateration algorithm

 x1 = randint(-150,-80)
 y1 = randint(-150,150)
 x2 = randint(80,150)
 y2 = randint(20,150)
 x3 = randint(80,150)
 y3 = randint(-150,-20)
 x = randint(-60,60)
 y = randint(-60,60)
```

```
r1 = ((x-x1)**2 + (y-y1)**2)**0.5
r2 = ((x-x2)**2 + (y-y2)**2)**0.5
r3 = ((x-x3)**2 + (y-y3)**2)**0.5

x,y = trackIoTWearable(x1,y1,r1,x2,y2,r2,x3,y3,r3)

#Output IoT location - coordinates
print(x,y)
```

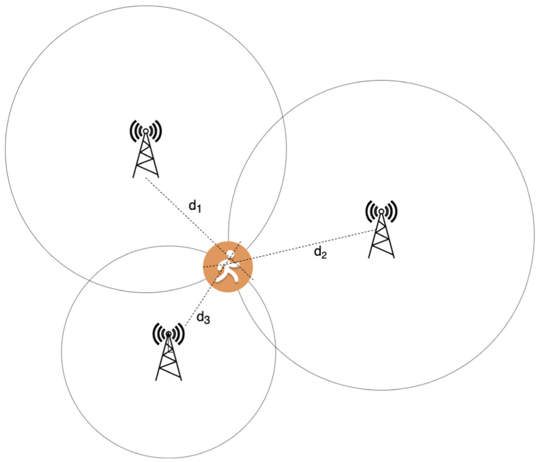

Fig. 2. Graphical representation of the trilateration algorithm

5 Results

This section includes the results as extracted from out experiments. We run our experiments in area of Rion of Patras (Greece). The GWs were distributed around the area in distance about 100–200 m. The hardware used for the experiments were 3 FiPy modules acting as GWs and 2 SiPy modules acting like clients. The networks servers were provided through The Things Network (TTN) for simplicity reasons.

Our goal in this study is the calculation of the distance as extracted from the RSSI information. The Spreading Factor (SF) indicates number of chips used to represent a symbol. The higher the spreading factor, the higher the coding gain. A low SF requires more power to accomplish a satisfactory Bit Error Rate (BER) that makes the implementation not suitable. Since in our scenario the end-node acting like a wearable device at vulnerable people only needs to broadcast the latitude, longitude as well as their id. BER is not a factor that is major.

On about 200 m, the maximum distance that we could reach, with SF12 the packet loss rate was about 0, with SF 10 the packet loss was about 25% higher and on SF7 packet loss rate was higher than 47% of initial value [17]. This can also be viewed from the figures below (Figs. 3 and 4):

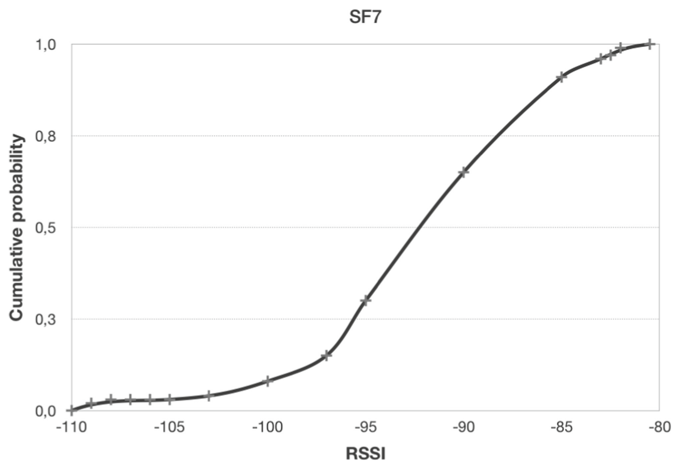

Fig. 3. Cumulative distribution of the RSSI for SF7 at 150 m

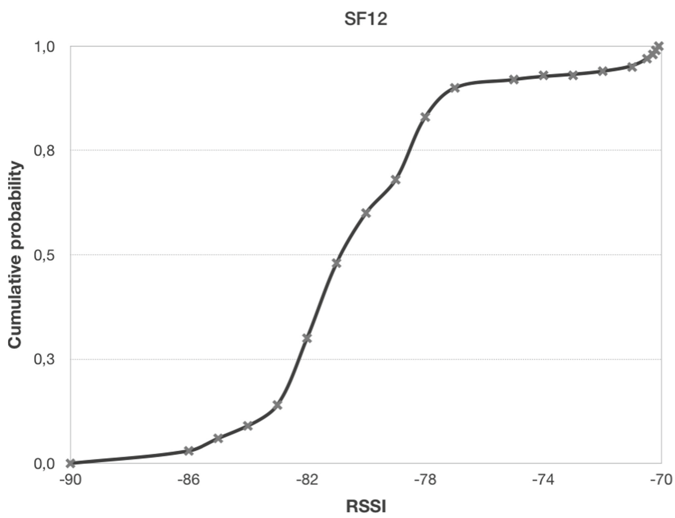

Fig. 4. Cumulative distribution of the RSSI for SF12 at 150 m

The cumulative distribution as metric describes the chance that a given variable will fall between or within a specific range. Using Eq. 2, we have $n = \frac{|RSSI|}{10 * \log_{10}(d)}$ with n = 3.9, d = 150 m and |RSSI| = 82. This value may be different in other cases where the topology is different and RSSI signal is vary. Values of n at interval [4, 6] seem to be ideal in our scenario using 3 GWs for trilateration.

Figure 5 shows the distribution on the obtained position estimation; we could place the IoT module in a circle where the distances from the LoRa GWs are in the middle of a circle. Using Geometric dilution of precision (GDOP), we can describe the error caused by the relative position of the devices; Basically, the more signals a LoRaWAN receiver can “see” (spread apart versus close together), the more precise it can be. From an other point of view if the GWs are spread apart in the locations, then we could have a better GDOP.

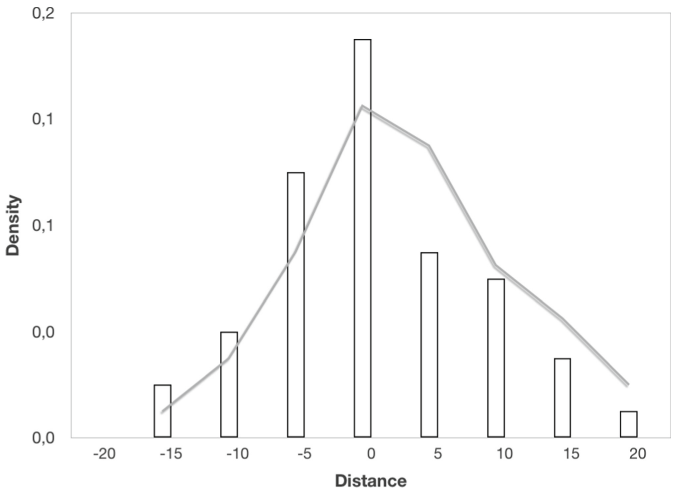

Fig. 5. Variation of the precision of the localization

6 Conclusions and Future Work

This section concludes our study on LoRaWAN distance estimation through trilateration algorithm. We described a solution which is based on IoT devices and the deployment of various LoRaWAN GWs to provide localization of vulnerable people use cases. Some improvements must be implemented in order to make this system work as a real-time tracking system. Through estimation of the LoRaWAN channel and using trilateration, the localization of the person can be obtained within 40–60 m range. The main advantage of this current solution is that it is low cost as the modules cost a few dollars and as a mechanism can give better results even indoors.

Our approach is based on the usage of the RSSI by various GWs. In this study we focus on the RSSI meaning value, together with the SF selection for the distance estimation. We consider that the above solution could be a research study for indoors areas such as Shopping malls, Universities Campus or even Playgrounds where we could locate people wearing just a wearable device.

Future work in this study could be the improvement of the above hypotheses and experiments through GW factors modification, or ED’s factors such as power of data transmission and etc. These modifications could be made in order to work as a real-time tracking system. Technologies like Machine Learning, Decision Tree, Naive Bayes or Support Vector Machine could be applied to RSSI different datasets of measurements improving accuracy of positioning.

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