An Outdoor Localization System based on SigFox

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***Abstract*— Localization and tracking applications are bringing new challenges to the Internet of Things (IoT) scenarios, especially when it comes to applying this concept in areas of high coverage. The emerging Low Power Wide Area Network (LPWAN) protocols offer, in their own way, solutions for this type of applications. This paper presents the design and implementation of a localization and tracking solution based on the Sigfox protocol that uses only one base station and so, a GPS device to supply the coordinates to be transmitted. An Information Centric Network (ICN) concept applied IoT network application model as a propose of a new information-driven service architecture. High level Application Program Interfaces are the main connection between services and information. The proposal is evaluated, demonstrated and validated in a real scenario and it is ready for use.**

***Index Terms*— Internet of Things; Low Power Wide Area Networks; Sigfox; Information Centric Networks; Location services.**

I. Introduction

The technologies and protocols for IoT applications cover long distances, however, they are immature, innovative, and sometimes not so standardized. The variations of the business models are also many. In this scenario, the optional Narrow Band - IoT (NB-IoT) technologies offered on industrial, scientific, and medical radio (ISM) bands stands out in terms of their innovations and as an option to the NB-IoT offered by mobile operators [1]. Open protocols such as LoRaWAN (Long Range Wide Area Network), systems with proprietary protocols, such as Sigfox and proprietary protocols, such as Ingenu, are the most prominent examples in the current available solutions [2].

NB-IoT systems offered by mobile operators are increasingly gaining a focus on the study of Machine-to-Machine (M2M) communication given its large coverage and flexible data rates. The scenarios defined by the 3rd Generation Partnership Project standardization body, 3GPP, appear as the most promising solutions to enable the wireless infrastructure of M2M communications [3].

Following this model of a telecommunications system operator, the developer, manufacturer and operator of French origin, named Sigfox, is increasing the capillarity of its network, investing in the current demand of communication systems for IoT that meet this demand immediately. Developed especially for IoT solutions and differently from the mobile network which is an IP address based communication architecture, the Sigfox solution, using a message-based architecture, presents some advantages such as low power consumption, low device cost, low cost of connectivity , long range and ease connectivity, operator coverage availability, among others [4].

This paper proposes, demonstrates, and validates a practical application of outdoor location using the Sigfox network to transmit the coordinates of a Global Positioning System (GPS) device, pointing out the characteristics of the system used, to contextualize the experiments and the results. The purpose of the paper is to present a new solution based of this technology, its operation and characteristics when used to track mobile objects with the objective to give inputs to interpret and evaluate the Sigfox reception quality when tracking mobile elements. The presented results were obtained through an user application model on a real environment scenario.

The rest of the paper is organized as follows. Section II presents some IoT protocols for long distances explaining their main characteristics in order to compose a comparative scenario for applications that demand communications in long distances through LPWANs. Section III addresses the proposal of an outdoor location IoT application construction and implementation using the Sigfox protocol and its network architecture. Evaluation, demonstration and validation of the proposed system is considered in Section IV. Section V concludes the paper highlighting the main points addressed and brings the future work that may emerge from this study.

II. Link Layer Protocols for Application on IoT LPWAN Networks

LPWAN networks arise from the need to obtain data transmitted by devices that are at a distance that only technologies such as mobile cellular networks could achieve. However, this service will depend on the coverage availability of a mobile operator and where energy savings is not a strong point in the technologies of mobile terminals [5]. Currently, some technologies emerges, offering an option to the use of mobile networks, always within some context considering frequency of operation, data rate, effective final reach, energy saving, among others. Some of these protocols are set out below.

A. LoRaWAN protocol

LoRaWan is a Low Power Wide Area Network (LPWAN) technology developed by the LoRa Alliance to contribute to

978-1-5386-6355-4/18/$31.00

the advancement of IoT, M2M communications, and intelligent environments. It uses ISM spectrum and operates in the bands of 868MHz and 433MHz in the European Union, while in the United States of America it operates at 915M Hz and 433MHz [6]. The coverage range is from 2 to 5 kilometers in urban areas and can reach up to 15 kilometers in suburban or rural areas. In addition, the data rate of LoRaWan ranges from 0.3 kbps to 50kbps and uses star network topology to simplify the operation [7] [8].

The protocol allows the realization of uplink communication, which is sending the information from the terminal to the gateway, and downlink, which is the reverse operation. Whereby, an end device may communicate with one or more gateways.

B. Ingenu

Ingenu is a protocol developed for IoT with coverage in 52 countries that works with a carrier agreements business model. It operates on the 2.4 GHz ISM frequency that does not present any type of cost, so it is possible to use the same device in different countries, as there are no changes in spectrum specifications. The protocol utilizes Random Phase Multiple Access (RPMA) technology, which enables high-power messages to be sent in the short time period, which significantly reduces power consumption and extends battery life for 10 years or more [9] [10].

Ingenu technology has an average range of 15km per base station, making it a major competitor of the Sigfox and LoRa protocols. In addition, Ingenu still offers a diferente behaviour profile offering diferent characteristics when compared with the LPWAN competitors, for example, broadcast capability, acknowledgement of data transactions, flexible packet sizes, and authentication process [11].

C. Sigfox

Sigfox is an Internet protocol developed by a French company with the same name, especially for applications in IoT, founded in 2010 by Ludovic Le Moan and Christophe Fourtet. The company is based in Labège, near Toulouse, the French "IoT Valley". The company's business model functions as a mobile operator, which provides antennas installed at strategic points to receive data from the application terminals. The Sigfox network is in the process of expansion, operating in 17 countries with full coverage and in others, it operates with partial or punctual coverage [12]. The technologies characteristics are summarized in Table I.

Table I: Main Sigfox technology characteristics.

Characterisitics	Regions		
	FCC	ETSI	ARIB
Channel Bandwidth	600 Hz	100 Hz	
Operation Frequencies - ISM - Sub-GHz	902-928 MHz	863-870 MHz	
Data Rate	600 bps	100 bps	
Terminal Maximum Transmission Power	22 dBm	14 dBm	
Base Station Maximum Transmission Power	30 dBm	26 dBm	
Base Station Sensitivity	- 136 dBm	- 142 dBm	
Modulation	D-BPSK to uplink, GFSK for downlink		
Medium Access Technique	RFTDMA		

Sigfox protocol uses a D-BPSK modulation for three main reasons: *i*) it is easy to deploy, *ii*) a low bit rate allows the use of low cost components, and *iii*) the base station receiver is highly sensitive since can demodulate signals even with low Signal to Noise Ratio (SNR). Working with the UNB technique, its physical layer employs a frame-repetition pattern in time and frequency that reduces the influence of interference. This standard called RFTDMA (Random Frequency and Time Division Multiple Access), is, basically, an Aloha-based protocol without preliminary channel occupancy detection, which means that nodes access the wireless medium in both time and frequency domains randomly and without any containment method. The carrier frequencies are chosen in a continuous range rather than a predefined discrete set. Some benefits are no power consumption for detection in the middle, no need for network time synchronization, no beacon packets and, therefore, no restrictions on oscillator accuracy and low power consumption. The main disadvantage is access to the medium without any control that leads to packet interference or collisions between active users. So the devices can randomly access the physical resource at any time, according to FCC and ETSI rules activating itself for the next uplink transmission, transmit the message, and return to stand-by mode. This mechanism offers high network capacity, high network scalability and power save [13].

A strong point of the RFTDMA is the strong noise robustness and spectrum interference because it offers *i*) frequency diversity when repeating uplink transmission at three different random frequencies; *ii*) time diversity when repeating each uplink message of different frequencies at different times; and *iii*) spatial diversity when these three uplink messages can be received by more than one base station. Its disadvantages remain on the fact that the transmission repetition of each device can impose some scalability constraint at a certain moment [14].

At the Medium Access Control (MAC) layer there is no signaling technique between the base station and the device to control the messages flow. A third layer, called a Frame Layer, gets the payload provided by the application layer, segments it, and generates the frame of transmission to the radio interface on which a sequence number is added to guide the reception.

High resiliency is achieved due to the transmission power of the Sigfox signal be concentrated on a narrow bandwidth, providing a high robustness against interference, allowing the signal of the terminal transmissions to be easily demodulated, even though more powerful interference signals are received which will be more scattered.

For uplink communication with a 12-byte data payload, a Sigfox frame will use a maximum of 26 bytes in total in the transmission, which yields a good performance when compared to an IP stack that uses a 40-byte header even with data 12 bytes to carry. This way, Sigfox can resort to the time diversity transmission technique, repeating the same message three times, with a 500 ms interval between each transmission. As a downlink communication control mechanism a connectivity service device-driven is used to minimize the power consumption, after an uplink message transmission process, a receive window of 50 s duration is opened by the device to receive the downlink message.

Sigfox base stations detect, demodulate, and send the messages to the Sigfox cloud, which is a client-server platform, also called backend, which can be accessed by an end user or through Application Program Interfaces (APIs) that are programmed to handle specific data from the Sigfox cloud data server.

The characterization of an information centric network (ICN) occurs at point where an event or a reporting need triggers the sending of an uplink message to the Sigfox network. Another aspect that characterizes the Sigfox network as an ICN is the fact that the business perspective revolves around charging for messaging plans, that is, charged for the amount of information demanded. This policy makes it clear that the focus of the business and therefore the network's purpose to treat information by putting information as the focus of the goal. Radio choices made by SigFox brings specific benefits: long battery life, low device cost, low connectivity rate, high network capacity, and long range.

III. Proposal of an Outdoor Location System using SigFox - OLUS

The proposal is based on an outdoor localization application designed with Sigfox solution with the utilization of a GPS device to supply the geographical coordinates. Although it is possible to design an outdoor location application using the triangulation of received signals, it would be necessary to use at least two bases receiving the same signal to obtain a satisfactory result. This real case study has the purpose of using only one base station receiving the coordinates data sent by mobile devices and evaluate the performance of the Sigfox protocol in an application that demands communication through long distances, monitoring objects in movement, in urban environments with high and low density of civil construction, even where the coverage of the Sigfox network still present limitations.

The used terminals include a GPS device model U-Blox-6M connected to a STMicroelectronic STEVAL-FKI915V1 kit composed of a Nucleo-L152RE card, which is a low power MCU (Micro Controller Unit) that controls a radio interface card S2-LP. This kit also includes the ST-LINK/V2-1 debugger used for debug programming of the kit, which is built inside the core board. For the kit activation, the S2-LP software tool Sigfox Demo GUI v.1.0.0 was used which besides the registration, also allows making experiments of transmission with the transceiver separately. Integrated Development Environment (IDE) Keil μVision 5 for ARM processors was then used to develop and implement the kit programming code. Figure 1 shows the developed kit.

A Sigfox base station, SBS-T902, was provided by the company WND, a representative of Sigfox in Brazil, which is installed on the terrace of the university's campus highest building, with its antenna operating at an altitude of 885 meters. After GPS integration into the terminal, it was programmed to send the location coordinates messages for experimental academic purposes. The messages transmission will allow the analysis of the system quality upon the reception of messages that are transmitted during a process of spatial displacement due to sudden variations in speed and/or altitude.

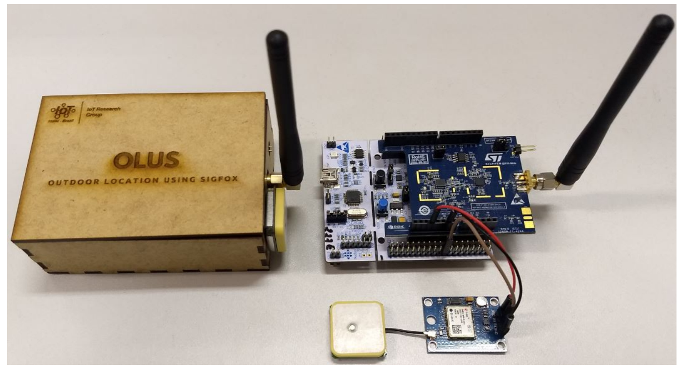

Figure 1: STMicroeletronics STEVAL-FKI915V1 kit.

The messages that are received by the Sigfox network are then made available through the Sigfox backend, which is a Web platform available online, where the user, besides consulting the messages sent by his terminals, can also configure the backend to send these messages, traps, and informations to midlewares, information management platforms, or for customer or partner service platform. Using a developed API, the application was integrated with a Google Earth API enabling plotting of coordinates in an overlay of maps and images.

In order to enrich the data analysis, a GPS device model U-Blox-6M connected to a laptop computer running the U-Blox U-Center application was used in parallel, which surveys the altitude profile as well as the speed variation profile in the test drive path. The experiments were performed in the city of Santa Rita do Sapucaí, MG, Brazil.

IV. Evaluation, Demonstration, and Validation

With this set of tools and equipment, two types of experiments were performed. One ran in an outdoor environment on the highway and the other on urban densely populated area. The first part of the experiment was done on a route that leaves the urban center and continues on the BR459 highway for 40km towards SE, which has the best coverage path of the Sigfox network in the region, according to information from the local operator [13]. Figure 2 shows the coverage map indicated by the local operator and 3 illustrates the outdoor highway drive test experiments results.

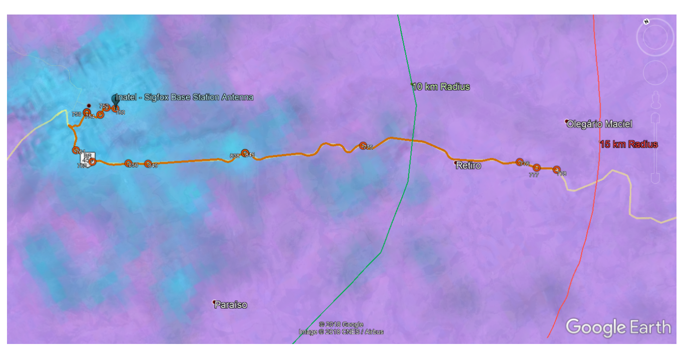

Figure 2: Sigfox coverage and highway test drive map.

On Figure 2 map, the blue color indicates strong signal intensity and the pink color indicates total absence of signal, the

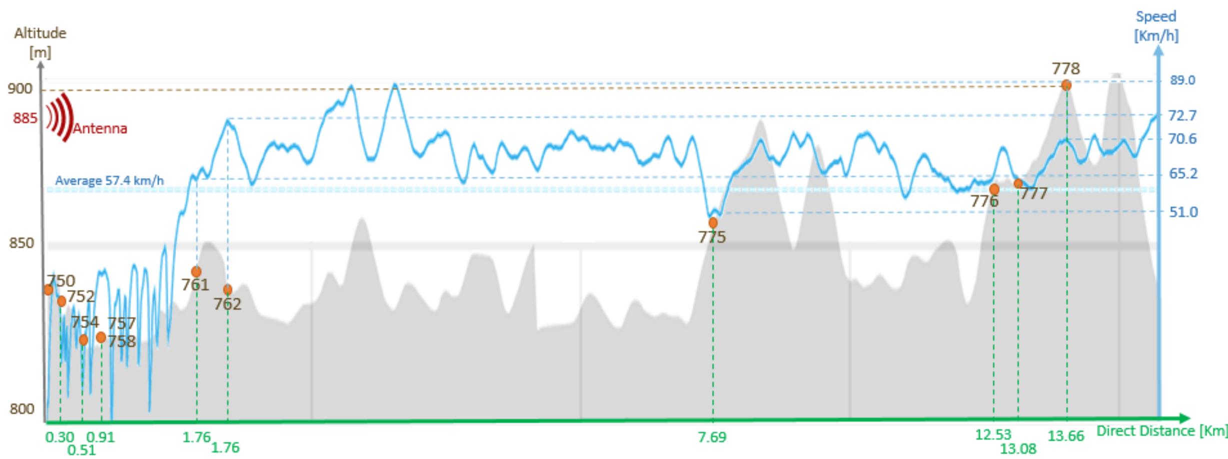

Figure 3: Outdoor highway experiments results.

orange line represents the path traveled during the experiments and the orange points represent the points of the coordinates received by the Sigfox network. Overlapped on the coverage map, there is the path where the test drive was done and the points indicating the coordinates sent to the backend of the Sigfox network.

With the test drive in this scenario, the Sigfox network received the transmission of the points indicated on the map during the trajectories traversed. During the beginning of route, in an urban area, the collection of coordinates had a greater index of success because at this region the relief was favorable. These data are exposed in Figure 3 where the altitude parameters can be compared in the main vertical axis, the altitude profile highlighted in the image background with the gray shadows and the speed profile presented by the blue line with its measurements in the secondary vertical axis. The orange dots represent the coordinates received at the backend of the Sigfox platform, the background on the gray shadows in the figure represents the altitude of the point at the time of transmission and its value can be read on the main vertical axis.

The last received point, number 778 was received at an altitude of approximately 900 m when its value is read on the main vertical axis. Reflecting this point in the blue curve, is possible to read that the object was, at the time of transmission, moving at a speed of approximately 70.6 km/h. On the horizontal axis, is possible to notice that this reading was transmitted at a distance of 13.66 km from the base station reception antenna. The enumeration of the points received displayed on the graphics, follows the enumeration standard according to its identification in the backend of the Sigfox network, being the reference to be used for a future search of this data on Sigfox backend.

According to the results shown in Figure 3, it is possible to perceive that, although relative, the high speed was not such a significant obstacle since it was possible to perceive the reception of a valid sequence between points 775 and 778. The absence of readings in the interval between points 762 and 775 was impacted by the shadow area because this part of the route is located behind a hill whose altitude exceeds in approximately 20 meters the hight of the system antenna. In these experiments, altitude and lack of coverage had a greater impact in the absence of readings, more than the mobility characteristics. Performing an urban test drive through the route displayed on Figure 4, it was possible to acquire a greater number of points within the same time interval. The results of the urban test drive are shown in Figure 5.

Figure 4: Sigfox coverage and urban test drive map.

In the urban test drive, the performance of the system was slightly better, presenting an absence of packets received between packets number 850 and 859, which corresponds to the coverage shadow area previously mentioned. Within the city, despite the attenuation due to the constructions and a strong variation of the relief, behaved as expected, with the transmissions occurring and being received within the estimated time intervals. Table II brings the comparison statistics of the GPS reading points that were received in the Sigfox network backend during the urban test drive. Failure to receive the points between 859 and 859 can be perceived due to the coverage shadow area on this part of the route where there is a hill obstructing of the signal.

When analyzing the performance of the system regarding to the number of lost messages, 68% of the messages transmitted in the highway did not reach the Sigfox backend due to lack of signal coverage by the transmission system and, comparing with the urban test drive, losses were about 56.86% of the transmitted messages.

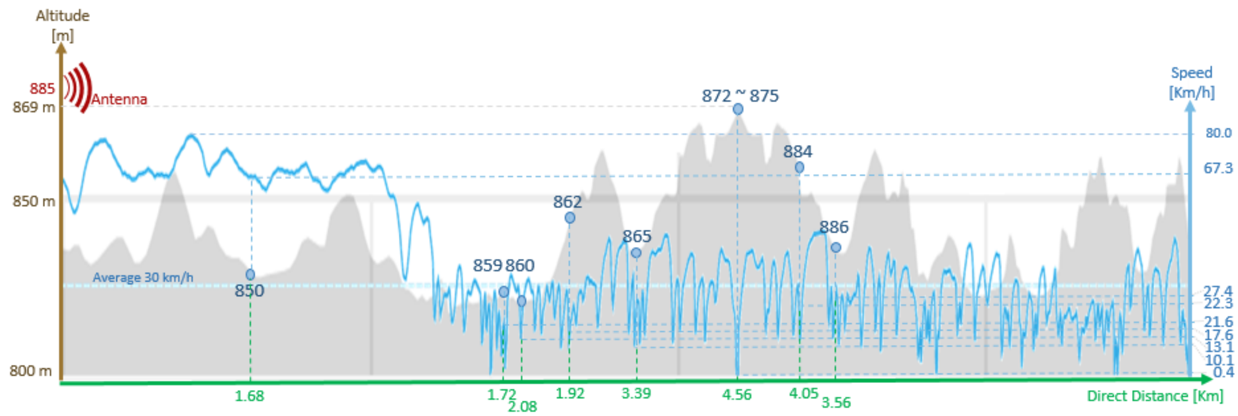

Figure 5: Outdoor urban test drive results.

Table II: Messages Statistics.

Messages Transmitted	Highway		Urban		Total	
Description	QTY	%	QTY	%	QTY	%
Max sequence number	850		901		901	
Min Sequence Number	750		850		750	
Total by sequence number	100		51		151	
Not received on backend	68	68.00	29	56.86	97	64.24
Total received by backend	32	32.00	22	43.14	54	35.76

V. Conclusion and Future Work

It was expected that the displacement of an object would be a very impacting factor in the performance of receiving messages from Sigfox systems. It comes from the fact that the obstruction of the signal is a factor as or more shocking than the displacement of an object itself. This study demonstrates that, within its limitations, Sigfox technology has a performance that can satisfy most of the applications that do not require the transfer of a large data stream and, mainly, for transmission of messages with few bytes.

Mobility and coverage shadow areas are a detrimental combination to the performance of the Sigfox system when analyzed the ratio between the amount of messages transmitted and the number of messages received in the Sigfox network backend. The availability of the Sigfox network and the low cost of implementation are very strong points in this technology that is continually expanding its coverage. The growing number of handset manufacturers also counts as an advantage.

A considerable energy consumption in the terminal was detected, even when it was not in transmission mode. This was due to the fact that GPS is configured to provide the coordinates at a rate of 9600 bps with all messages standardized by the systems of geo-positioning. This consumption can be reduced by filtering only the geo-positioning messages required for this application and reduce the delivery rate of these data. This procedure can both reduce power consumption and help prevent the loss of synchronism between reading the coordinates in the terminal registers and transmitting them.

Acknowledgments

This work has been supported by National Funding from the FCT - Fundação para a Ciência e a Tecnologia through the UID/EEA/500008/2013 Project; by Brazilian National Council for Research and Development (CNPq) via Grant No. 309335/2017 – 5; by Finatel through the Inatel Smart Campus project; and by Finep, with resources from Funttel, grant no. 01.14.0231.00, under the *Centro de Referência em Radiocomunicações* — CRR project of the National Institute of Telecommunications (Inatel), Brazil.

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