2021 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE) | 978-1-6654-1878-2/20/$31.00 ©2021 IEEE | DOI: 10.1109/ATEE52255.2021.9425330

Wireless Communications for IoT: Energy Efficiency Survey

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Abstract **Internet of Things concept has brought us many sensors application possibilities that aim to make our lives better. The IoT concept entail the use of low-power, low-cost, long-range sensors that can collect data from the environment and send it to the user application using wireless link, for maximum mobility. In this paper we evaluate and compare a couple of the market available LPWAN solutions, trough the energy efficiency perspective. Although LPWAN implies low-power devices, some of the modules used in the experimental setup need a high current burst, making them inefficient if the power supply is not properly sized. Thus, the main contribution of this paper is the energy efficiency analysis of the main existing IoT technologies like LoRa or SigFox. From the obtained results one may conclude that some modules can transmit using high current peaks for short period of time while others can transmit low current peaks for long period of time, being useful only for specific monitoring applications.**

Keywords: **energy efficiency, IoT, SigFox, LoRaWAN, wireless communication**

I. INTRODUCTION

Internet of Things (IoT) market has gained a huge notoriety in the past years promising low power, low cost, and long-range solutions for multiple sensor applications. The fulfillment of these promises revolves around the multiple LPWAN (Low-Power Wide-Area Networks) technologies emerged in the past decade, the current market leaders being LoRa (Long-Range), SigFox and NB-IoT (NarrowBand-IoT).

These types of technologies can cover large geographical areas in urban propagation conditions and can be easily scaled up to the application's demands having the possibility of integrating thousands of nodes [1], [2]. The fact that the exchanged data packets are limited in size does not represent a problem since most of the applications involve sending one or two parameters with small data payload like temperature, humidity, or GPS (Global Positioning System) location. Data packets broadcasted by the end nodes are received by the Gateways (GW) or the Base Stations (BS) and forwarded to the user application via the internet protocol [3].

The following sections present a short presentation of the LoRa and SigFox communication protocols, as well as an evaluation of the energy efficiency for the LPWAN solutions currently available.

II. OVERVIEW OF THE LPWAN SOLUTIONS

Most of the LPWAN technologies operate in the sub-GHz part of the ISM (Industrial, Scientific, and Medical) and SRD (Short Range Devices) frequency bands (LoRa 868 MHz Europe/915 MHz North America, SigFox 868-878,6 MHz RC1/ 902.1375-904.6625 MHz RC2), excepting the NB-IoT which operates in the 4G LTE (4^{th} generation Long-Term Evolution) frequency band [4].

LoRa technology firstly appeared as a start-up project under the name of Cycleo in Grenoble, France being purchased only three years later by the Semtech company in USA and standardized in 2015 by the LoRa-Alliance. It uses a CSS (Chirp Spread Spectrum) modulation, the frequency bands being split into multiple uplink and downlink channels, depending on the deployment area. Besides the CSS modulation, LoRa also uses the FSK (Frequency Shift Keying) modulation (in Europe frequency plan) for uplink and the second receive window Rx2, which is used as a last resort solution in case if the communication channels are overcrowded.

LoRaWAN is a protocol for media access control (MAC) designed for IoT applications and wide area networks that uses LoRa modulation. The LoRaWAN devices are spread into three classes: class A (the most power efficient, which can initiate uplinks at random moments decided by the end devices and has two receive slots after each uplink), class B (it can open scheduled receive slots besides the ones mentioned in the A class devices) and class C (the receive slot is closed only during the uplink, being the most power-hungry class of all three mentioned above). The network topology is a star one, each end device transmitting the message to the user application using the Gateways connected to the Internet [5], [6].

Meanwhile, SigFox is an ultra-narrow band LPWAN solution also developed in a start-up with the same name, in Toulouse, France 2010. Apart from being a company, SigFox is also a LPWAN network operator. For the communication architecture, SigFox uses the same star topology as in the LoRaWAN systems. Each end device will transmit using a redundancy mechanism, so the same message is transmitted for three time on different channels (to ensure frequency

ISBN: 978-1-6654-1878-2/21/$31.00 ©2021 IEEE

diversity) at different time intervals (to ensure time diversity). This redundancy mechanism makes communication more robust to interferences and is the main important advantage of this technology comparing with other LPWAN technologies mentioned above.

The ultra-narrow label attached to SigFox technology comes from the fact that the bandwidth of a communication channel is only of 100 Hz. The modulation used in SigFox technology is D-BPSK (Differential Binary Phase-Shift Keying), and the messages have a maximum of 12 bytes or 8 bytes, a device being allowed to send a maximum of 140 messages a day in the uplink mode and only 4 messages a day in the downlink mode.

Considering the SigFox method of sending the data and the limited data packet size we can say that this technology ensures high redundancy, being the most promising technology for using in the IoT devices worldwide [7].

III. ENERGY EFFICIENCY ANALYSIS OF LPWAN TECHNOLOGIES

In this section we evaluate the current consumption of the LPWAN technologies we selected several devices currently found on the market and measure the current draw during the transmission of a data packet: RFM95W, SX1276, RA-02 Lopy4 and EU-SIGFOX GEVB. The chosen modules can be seen in Figure 1.

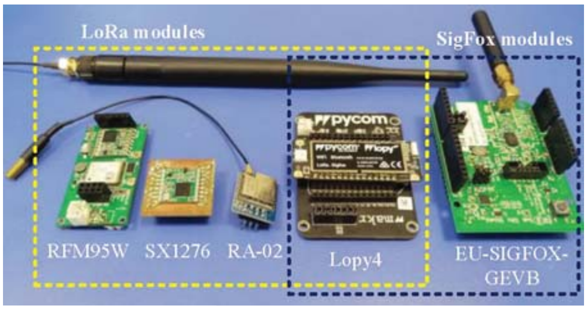

Fig. 1. LoRa and SigFox transceivers used in the experimental setup.

The measurements were performed using a high-resolution current sensor (INA219) and a data acquisition development board [8]. The experimental setup can be seen in Figure 2.

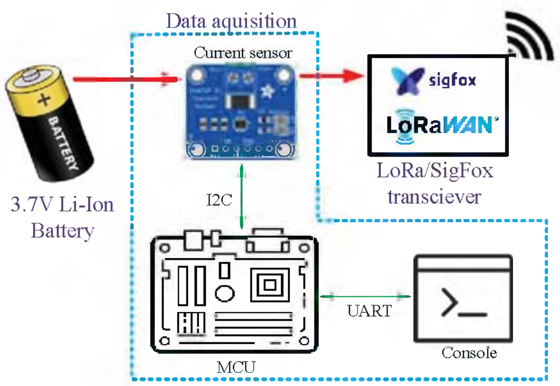

Fig. 2. Experimental setup for current consumption evaluation.

The first tested module is the LoRa transceiver from HopeRF, named RFM95W [9]. Some characteristics regarding the frequency range and other RF parameters of this module can be found in Table 1.

TABLE I
RFM95W PARAMETERS

Frequency range	868 / 915 MHz
Sensitivity in receive mode	-111 to -148 dBm
RF input level	+10 dBm
Current consumption in Tx	87-120 mA
Current consumption in Rx	10-12 mA

The product datasheet states that the device draws 87-120 mA in transmit mode and 10-12 mA in receive mode. From the graph shown in Figure 3 we can see that the current consumption is within the datasheet limits. Also, the graph presents the LoRaWAN protocol as is related in [10]. In the first part of the graph, we have the Tx transmitting window with a current peak of 94 mA. The width of the transmitting time, also known as the airtime, depends on the spreading factor we use, the coding rate and the size of the data packet we want to send. In the conducted test from this paper, we used the spreading factor SF7, a coding rate CR of 4/5, and a message with a payload of 12 bytes, resulting an airtime of 61.7 ms. The message is received using TheThingsNetwork [11] IoT Cloud platform and the airtime is the same as the calculated value using the LoRaWAN airtime calculator from the same IoT Cloud platform [12]. Some additional tests were performed using the other remaining spreading factors (8 to 12) and the only modification is recorded to airtime of the communication. The middle and the final part of the graph shows the two RX slots opened by the LoRaWAN node, as the studied device is a class A need. We can observe that the transceiver draws 10 to 12 mA in receive mode as stated in the datasheet. The true value of the device idle current cannot be measured with this current sensor from the test setup as it is in the µA domain.

The second module tested is SX1276 from Semtech [13]. According with the datasheet specifications, the SX1276 Semtech LoRa transceiver has the same characteristics as the previous mentioned transceiver from HopeRF. The difference is the frequency range, that can cover a wide radio spectrum, being used in any region from the globe, according with the spectrum frequency allocation. If we take the values from the measurements, this transceiver draws a slightly lower current in Tx mode in comparison with the HopeRF counterpart. The difference between them is about 15 mA, but for low power applications it can make a big difference on the long term. In receive mode the SX1276 draws 10-12 mA, which is the same as the RFM95W transceiver.

Pycom offers an integrated solution for LoRaWAN, SigFox, Wi-Fi and Bluetooth communications, embedded into one single development board, named Lopy4. For the LPWAN communication, the same SX1276 transceiver is used [14].

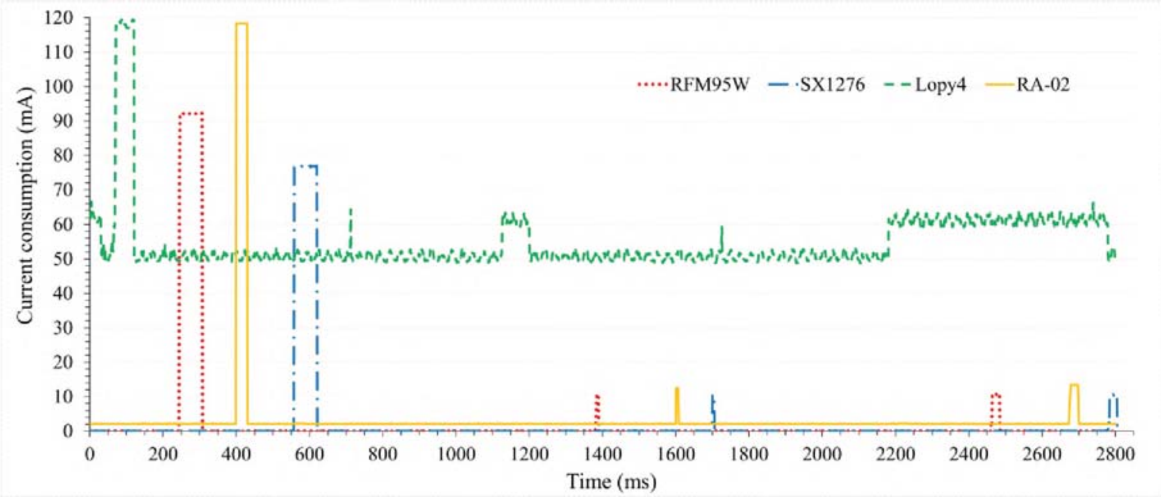

Fig. 3. LoRa modules current measurements.

As it can be seen from Figure 3, the current consumption has an offset of about 50 mA in comparison to the other tested modules. This offset comes from the fact that the measured current is for the Lopy4 board entirely (LoRa transceiver and ESP32 microcontroller). If we subtract the 50 mA offset from the Tx and Rx current consumption, we can see that the values are close to the SX1276 transceiver. In comparison to the previous tested modules the Lopy4 has a wider Rx window.

Another tested module is the RA-02 module from the Ai-Thinker [15]. This module has embedded the SX1278 transceiver from Semtech. Some characteristics of this module can be seen in Table 2.

TABLE II
SX1278 PARAMETERS

Frequency range	410 - 525 MHz
Sensitivity in receive mode	-111 to -148 dBm
RF input level	+18 dBm
Current consumption in Tx	87-120 mA
Current consumption in Rx	10-12 mA

From the performed measurements this module showed the highest current draw of all the LoRa transceivers, with 118 mA during uplink, and the same 12 mA in the receive mode. Although other tested modules shown a small idle current (in the µA domain), this time the idle current is about 2 mA, being approximately the same value as the one depicted in the RA-02 datasheet.

Since there are not too many SigFox solutions available on the market we only tested two modules: EU-SIGFOX-GEVB from ON Semiconductors [16] and the Pycom Lopy4 that has integrated and the SigFox communication technology. Here in both cases the transceiver could not be separated from the microcontroller, so the obtained measured current has both the transmission current and the microcontroller current, respectively. Still, to compare the Tx values we can consider the current between the transmissions as microcontroller idle current and subtract it from the obtained results. In SigFox technology a message is sent three times at three different time stamps, on three different frequency bands, to achieve maximum redundancy. This can be clearly seen in the Figure 4 where the data packets can be clearly distinguished. One of the main differences from the LoRaWAN is the larger airtime for a single data packet. In LoRaWAN the airtime varies with the spreading factor and is at the most 2800 ms for the worst-case scenario (51 bytes at SF12), while in SigFox technology we have three times 2000 ms of airtime just to send one data packet.

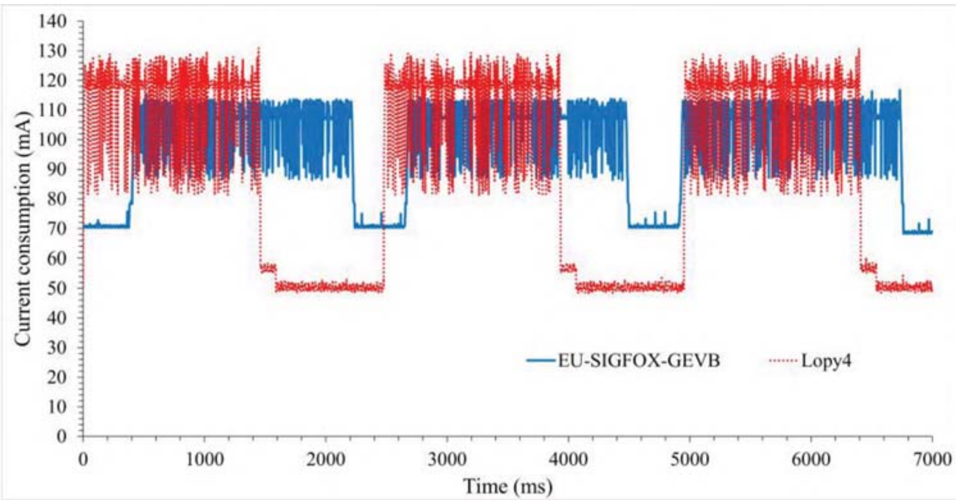

Fig. 4. SigFox modules current measurements.

If we analyze the values presented in Figure 4, we can see that the EU-SIGFOX-GEVB module from ON Semiconductors showed better performances than the Lopy4 development board, with only 45 mA drawn during transmission (subtracting the idle current) with smaller timeslots between the transmissions. The Lopy4 SigFox device drew about 75 mA (subtracting from the measurement the idle current) during each uplink with longer pauses between the transmissions. For both modules were chosen the standard testing examples.

IV. Results and conclusions

To evaluate each solution overall we calculated the energy required for a data packet transmission. Thus, we took into consideration the time gap between the initialization of the data packet transmission and the end of the transmission according to each technology (for LoRaWAN the two RX windows were taken into consideration). Also, the idle current was ignored for the scenarios where we could not separate the transceiver from the microcontroller as we propose to evaluate the transceiver performance.

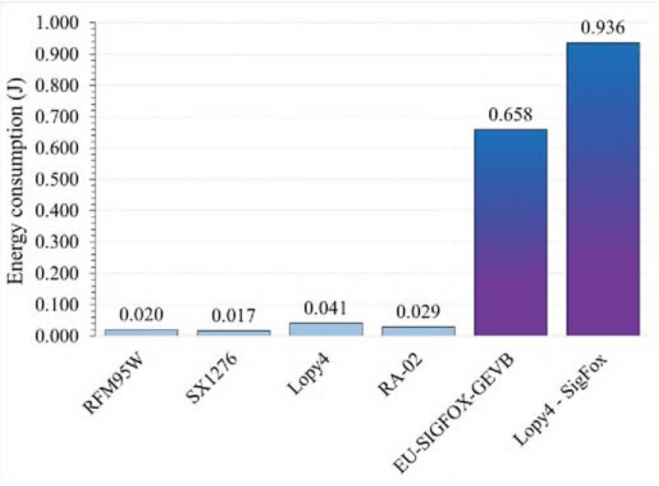

Fig. 5. Energy required to send a data packet.

From the results shown in Figure 5 we can see that the LoRa transceivers has a much lower energy consumption than SigFox, this mainly being since the airtime of one SigFox data packet is about 6 seconds and cannot be changed while the LoRaWAN packet we sent had an airtime of approximately 61.7 ms when SF7 is used.

In this paper an estimation of energy efficiency is made from the perspective of the main existing IoT technologies, LoRa and SigFox, respectively. According with the obtained results some modules can transmit using high current peaks for short period of time (LoRa modules) while other can transmit low current peaks for long period of time (SigFox modules). Both technologies can be used for sensor data acquisition with the minimum power consumption. Thus, a battery can last several years if the communication is performed at long period of times.

Acknowledgment

This paper was made using the infrastructure from the project "Integrated Center for research, development and innovation in Advanced Materials, Nanotechnologies, and Distributed Systems for fabrication and control (MANSiD)", Contract No. 671/09.04.2015, Sectoral Operational Program for Increase of the Economic Competitiveness co-funded from the European Regional Development Fund and was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, project number PN-III-P2-2.1-PTE-2019-0642, within PNCDI III.

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