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Battery Lifetime Estimation for LoRaWAN Communications

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Abstract: *Smart Cities concept increased the number of end devices (ED) which allow the acquisition of parameters for further analysis and processing. The actual technologies based on Internet of Things (IoT) enable sensors connectivity to Internet. This feature allows real time acquisition of several physical data important for smart cities monitoring. In order to minimize the power consumption, Low Power Wide Area Networks (LPWAN) assumes an important role on the evolution and growing of wireless network sensors. In this particular type of network, LoRaWAN has taken the lead, among other technologies. Typically most end devices need to be powered with batteries, since they are in remote zones. Therefore one important issue to consider is the global power consumption of the end device building blocks: LoRa transceiver, microcontroller unit and sensor unit. This paper presents the study and simulation results supported on LoRa modulation parameters, in order to estimate the battery lifetime, which is useful for IoT remote sensing units. The achieved results denote it is possible to configure LoRa transceiver with similar parameters and different payloads, reaching the same battery lifetime.*

Keywords *: LoRaWAN, battery lifetime, spreading factor, bandwidth, duty-cycle.*

I. INTRODUCTION

Internet of Things (IoT) concept has grown over the last few years due to the development and optimization of Low Power Wide Area Networks (LPWAN). This technology enabled the growth of Smart Cities requirements in several and different applications such as smart buildings, smart metering, traffic control, and remote sensing [1]. The main objective of IoT, through the use of LPWAN, consists on the ability to connect a specific end device (ED) to Internet through a gateway, with low cost, limited infrastructure equipment and a very long battery lifetime. In this paper we assume that an ED is composed by one or more sensors, a microcontroller and a radio transceiver, operating in Industrial, Scientific and Medical (ISM) frequency band. From the several LPWAN standards [2,3], LoRaWAN, defined by LoRa Alliance [4] is spreading faster than others LPWAN [5], since is an open protocol that allows the creation of a private network with no data traffic limitation, packet size and no subscription fee need to be paid [5]. LoRa wireless communication is based on Chirp Spread-Spectrum (CSS) and Frequency Shift Keying (FSK) modulation schemes, operating in several bands. In Europe, the 868 MHz is the frequency band allocated for IoT applications [5]. Most relevant studies of LPWAN, based on LoRaWAN technology, focus on three mainstreams: power consumption [1,3], network coverage range and scalability [6,7,8]. However the mentioned works do not establish a relation between LoRaWAN CSS modulation parameters and power consumption, concerning a specific ED communicating with a gateway. Thus, the main contribution of this work is to propose a method for battery lifetime optimization supported on LoRaWAN CSS parameters, number of transmissions per hour and the electrical specifications of microcontroller and sensors that compose the end device. The obtained results are based on several simulation scenarios, supported by the manufacturer electrical specification of sensors and LoRaWAN transceiver.

This paper is organized as follows. Section II presents the LoRaWAN wireless network sensor parameters, where is described its physical parameterization, packet structure and channel access policy. The ED configuration for battery lifetime optimizations is presented in Section III. The conclusions of this work and future work are drawn in section IV.

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II. LoRaWAN COMMUNICATION PARAMETERS

In this section the following LoRaWAN parameters are presented: modulation scheme, medium access policy, data structure and power consumption.

A. Chirp Spread-Spectrum Modulation

LoRaWAN physical layer modulates base-band signals in sub-GHZ ISM band, using a proprietary technique [1,4], based on CSS modulation scheme. The modulated signal is given by signal s(t),

$$s(t) = \exp^{j\left(2\pi f_c t + 2\pi \frac{\beta}{2} t^2\right)}, \quad (1)$$

where f_c and β corresponds to the carrier frequency and slope, respectively [4].

CSS modulation used in LoRaWAN physical is based on linear frequency variation within a specific bandwidth (*BW*) during symbol duration (T_{symb}).

This value is given by (2)

$$T_{symb} = \frac{2^{SF}}{BW}, \tag{2}$$

where *SF* corresponds to the spreading factor [1,4,9].

Table I presents LoRa CSS modulation parameters for ISM frequency band of 868 MHz (Europe standard), namely 868.1 MHz, 868.3 MHz and 868.5 MHz. These channels must be supported by all end devices and network, since they are used for the join-procedure [1,4,9]. LoRa CSS modulation parameters are represented in Table I [1,4,9].

Table- I: LoRa CSS modulation parameters [1,4,9]

Carrier Frequency (f_c)	868 MHz
Spreading Factor (*SF*)	7 to 12
Channel Bandwidth (*BW*)	{125; 250;500} kHz

Fig. 1 represents a spectrogram of three LoRa CSS symbols for a *SF* of 7 to 9. This variation implies three different T_{symb}. According to expression (2), for the same channel bandwidth, when *SF* increases by one, T_{symb} value duplicates.

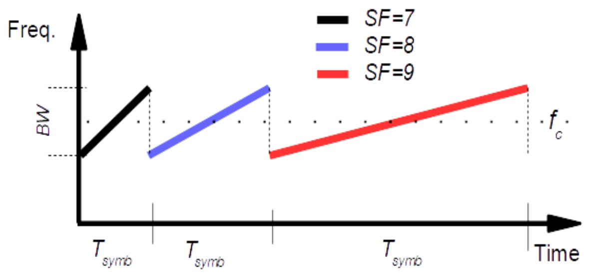

Fig. 1.Spectrogram representation for *SF* = 7, 8 and 9

According to LoRa standard, for longer distances, higher *SF* value is needed, however this will lead, for each symbol, a higher time for RF transceiver is enabled. This is a very import trade-off to take into account for power consumption optimization. Regarding power consumption all end devices may operate in three different classes named A, B and C [4,9]. In this work, for sake of simplicity only Class A is considered.

B. Packet Data Structure

LoRaWAN packet is composed by the following fields: preamble, used for synchronization, header, payload and the respective payload Cyclic Redundancy Check (CRC). All these fields as represented in Fig. 2 [4]. LoRaWAN packet duration is given by expression (3). Preamble duration, is obtained according to expression (4)[4].

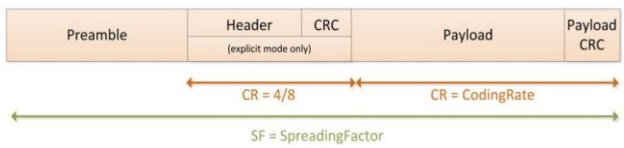

Fig. 2.LoRa ED uplink packet structure

$$T_{packet} = T_{preamble} + T_{payload}. \tag{3}$$

$$T_{preamble} = \left(n_{preamble} + 4{,}25\right) \cdot T_{symb}, \tag{4}$$

where the fixed value of 4,25 denotes that, per each preamble symbol, the length is increased 4 and ¼ symbol duration.

The payload time ($T_{payload}$), described in equation (4) is given by expression (6) [4]

$$T_{payload} = n_{payload} \cdot T_{symb}. \tag{5}$$

Expression (7) shows how to obtain the payload dimension used in (6). The variable *PL* corresponds to the message length, *IH* is implicit header, both expressed in bytes, and *DE* is flag for low data rate transmission [4].

$$n_{payload} = 8 + \max\left[\left\lceil\frac{(8PL - 4SF + 28 + 16CRC - 20IH)}{4(SF - 2DE)}\right\rceil \cdot (CR + 4), 0\right] \tag{6}$$

Variable *CR*, which corresponds to LoRa code rate, may change between 1 and 4 [4].

The T_{packet} can also be expressed by Time Over The Air (*ToA*), whose structure is presented in Fig. 2. [4].

In Fig.3 is presented the *ToA* evolution under *SF* variation, for *PL* of 16, 32 and 64 byte. As depicted, for the same payload amount, increasing *SF*, *ToA* presents and exponential variation, according to the symbol time dependency presented in expression (2).

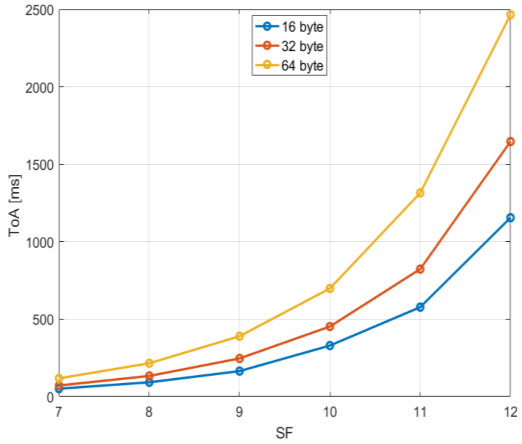

Fig. 3.*ToA* evolution for different *PL* amount

C. Channel Access Policy

LoRaWAN standard does not specify a channel access policy for the radio link between an ED and the gateway. However, European Telecommunications Standards Institute (ETSI) imposes either duty cycle or Listen Before Talk (LBT) access policy. However, according to LoRaWAN standard, only 1% duty cycle is used [4]. This feature represents the percentage of time that a specific ED allocates the radio channel according to the specifications showed in Table I. After the ED transmission, the waiting time can be obtained by equation (7) [4].

$$T_{off} = \frac{ToA}{Duty\ Cycle} - ToA. \tag{7}$$

Taking into account the 1% duty cycle access policy, and considering no packet collisions between ED, no retransmission is needed. Under this consideration, it is possible to estimate the maximum number of ED connected to a gateway during T_{off}, assuming a fixed PL. During this time slot it is possible to other ED connect to the gateway. This simulation can be performed for each parameter presented in Table I assuming that all ED are all synchronized.

In Fig. 4, it is presented the maximum ED that can be connected with a LoRa gateway depending of payload amount, SF and number of transmissions per hour (Tx/h).

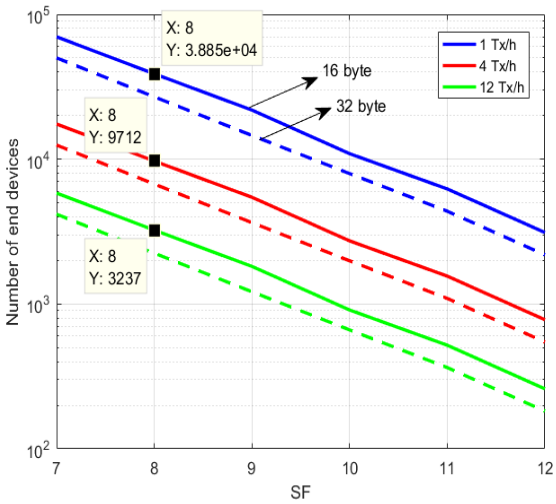

Fig. 4.Number of ED connected to LoRa gateway

As depicted in Fig. 4, for the same payload amount, increasing SF, the number of ED connected to LoRa gateway decreases. For the same SF value, the number of ED decreases due to the number of Tx/h.

III. END DEVICE CONFIGURATION FOR BATTERY LIFETIME OPTIMIZATION

Several works presents power consumption studies only with the LoRaWAN transceiver [10]. However, in remote sensing it is mandatory to take into account the power consumptions of the all ED building blocks: radio transceiver, microcontroller and sensors, as depicted in Fig. 5, for a supply voltage of 3.6 V.

In the following subsections it is presented all building electrical features and the correspondent battery lifetime optimization.

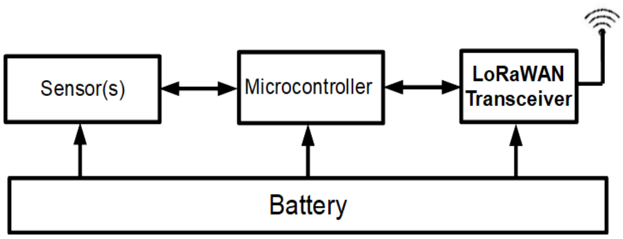

Fig. 5.IoT-LoRaWAN remote sensing unit

A. LoRaWAN Radio Transceiver Parameters

LoRa radio transceiver Printed Circuit Board (PCB) is presented in Fig. 6. This PCB allows the control of LoRaWAN SX1276 transceiver parameterization with an external microcontroller. Therefore it is possible to change the carrier frequency, spreading factor and transmission bandwidth.

Fig. 7 presents SX1276 power up process where all functional states are shown for transmit and receive modes [10].

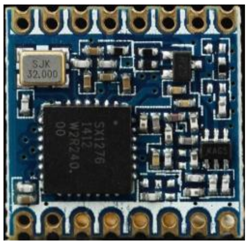

Fig. 6.SX1276 board [10]

In Table II it is presented the wakeup time for the oscillator, synthesizer, transmitter and receiver. Transceiver functional timing states are represented as A to E corresponding to each wakeup time acronyms described in Table II and current consumption presented in Table III.

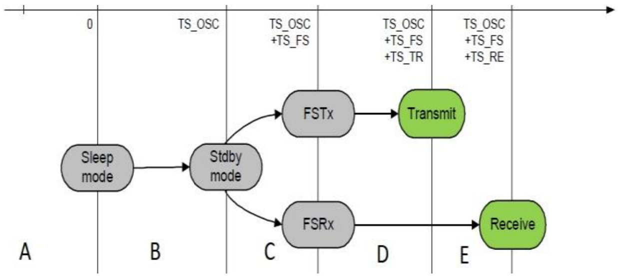

Fig. 7.SX1276 powerup process [10]

Table- II: Wakeup time and acronyms [10]

		µs
TS_OSC	Crystal oscillator wake-up time	250
TS_FS	Frequency synthesizer	60
TS_TR	Transmitter wake up time	120
TS_RE	Receiver startup time	71

Table- III: Current consumption for each state [10]

	Functional State	mA
IDDSL (A)	Sleep mode	0.0002
IDDST (B)	Standby mode	1.6
IDDFS (C)	Synthesizer mode	5.8
IDDT (D)	Transmit mode	120
		87
IDDR (E)	Receive mode	10.8

As depicted in Fig. 7, the first three functional states presented in Table III, despite if SX1276 is in transmit or receive mode, are always enabled. All these features are taken into account for the overall power consumption estimation. All current consumption for each state presented in Table III is cumulative. As described in LoRaWAN standard, the most frequent communication occurs from ED to the gateway [9]. Typically, the gateways send only the information to the ED of the SF and frequency channel during the negotiation period. Therefore, in this work, for battery the optimization proposed method it is only taken into account the uplink flow, e.g. messages send from the ED to gateway.

B. LoRaWAN Transceiver Current Consumption

Despite LoRaWAN transceivers may operate in three different classes, in this work it is assumed that SX1276 is operating in Class A [9].

This configuration provides bidirectional communications, although the transceiver receives messages from the gateway only shortly after each uplink transmission [9].

In Table III it is presented the instantaneous current for each SX1276 functional state. However, to obtain the current consumption for each transmission it is necessary to take into account values given by expression (2) and (6). With these values and the wake up time for each state, shown in Table II, it is possible to estimate the overall current consumption. These values depend not on only transceiver electrical characteristics, but also depend on the LoRaWAN CSS modulation parameters. The obtained results are presented in Fig. 8. These simulations results are obtained for a *BW* = 125 kHz. As depicted, for the same SF, increasing the payload amount from 16 byte to 64 byte, the current consumption increases. These values are obtained when the ED preforms four transmissions per hour.

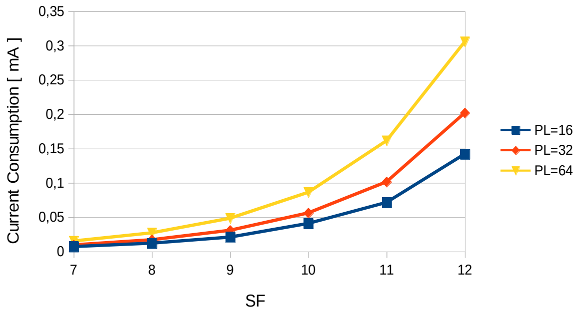

Fig. 8.SX 1276 power consumption for 4 Tx/h

As presented in works [1,3], increasing *SF* leads to higher LoRaWAN transmission distance. However, these works do not take into account the power consumption for different *SF* and *BW*. If the ED is located in a remote place, with no power supply, the overall system needs a battery for the power supply and battery charging. The power consumption variation increases with the number of transmissions per hour, denoted in expression (5). Therefore, it is important to know previously the amount of information and its periodicity, in order to estimate battery lifetime.

C. Battery Lifetime Estimation and Optimization

The microcontroller and sensor unit are presented in Fig. 9: Arduino Pro-Mini 3.3 V / 8 MHz [11] and a DHT22 temperature and humidity digital sensor [12]. The battery used as reference for this work is a 3.6 V rechargeable lithium-thionyl chloride (Li-SOCl2) battery with a capacity of 11000 mAh [13].

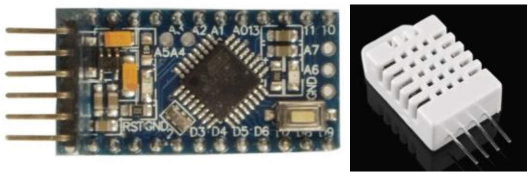

Fig. 9.Arduino Pro-Mini and Sensor

Arduino Pro-Mini microcontroller consumes 4.47 mA while in active state. DHT22 sensor current consumption is 1.5 mA during data collecting period of two seconds. In idle state, the microcontroller and sensor consumes 54µA and 40µA respectively [11][12].

In Fig. 10 it is represented the current percentage of ED building blocks for the same SX1276 spreading factor (SF=7). Fig. 10 (a) and (b) corresponds to a payload of 16byte and 64 bytes, respectively. These results present the overall ED current consumption. As depicted, the microcontroller and sensor current consumption is greater than the LoRa transceiver. With this information it is possible to infer, by simulation, battery lifetime and possible optimizations for its durability.

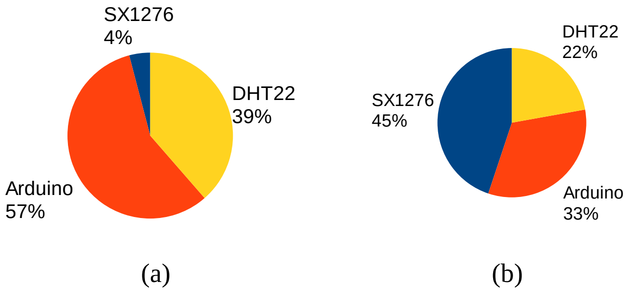

Fig. 10. ED current percentage (PL=16 byte)

Battery lifetime estimation can be obtained by (8)

$$time[\text{hours}] = \frac{\text{Battery Capacity } [\text{mAh}]}{\text{ED current } [\text{mA}]}, \quad (8)$$

where the ED current takes into account the current consumption in standby, power up and fully functional state for all building blocks.

In Fig. 11 it is presented the battery lifetime estimation obtained by expression (8), converted in years, for different LoRaWAN parameters. As depicted it is possible to achieve the same battery performance for different payloads and bandwidth. This is an important system characteristic, because it is possible to transmit, for the same SF, four times more information, doubling the bandwidth.

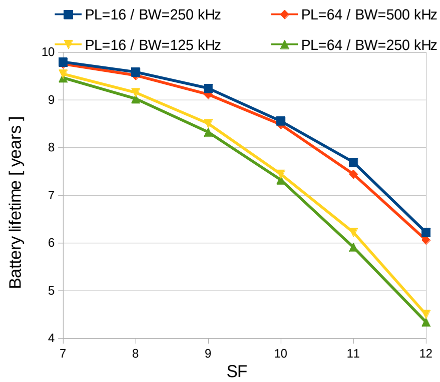

Fig. 11. End device battery lifetime estimation

Assuming 250 kHz bandwidth and increasing payload from 16 byte to 64 byte, battery life time, for the same SF=9, decreases in one year. Contrary to what might be expected, it is possible to transmit four times more information (16 byte to 64 byte), by doubling the BW. For all SF values, the battery life time is identical.

IV. CONCLUSIONS AND FUTURE WORK

This work presented the battery lifetime estimation and optimization for LoRaWAN communications. For this work it was used the transceiver parameterization, but also the microcontroller and sensor electrical characteristics, in order to obtain more reliable results and consequently estimate and propose changes in LoRA transceiver parameters to optimize battery lifetime. Based on the 1% duty cycle medium access policy, it was possible to estimate the maximum number of ED per gateway. However, due to possible LoRaWAN frame collisions that may occur, data retransmission maybe needed, which implies more power consumption and less battery lifetime. The obtained results allow us to infer that for the same *SF* it is possible to increase the *PL* in four times only doubling *BW* value. Under these conditions it is possible to increase battery lifetime in two years. Therefore, during the project of an IoT network based on LoRaWAN technology, it is advisable to optimize the number of transmitted messages with the *SF* and bandwidth.

For future work it is proposed the inclusion of a solar panel in order to extend battery lifetime.

REFERENCES

1. U. Raza, P. Kulkarni, and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview", IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 855-873, Second Quarter 2017.
2. Y. Miao, W. Li, D. Tian, M. S. Hossain, and M. F. Alhamid, "Narrowband Internet of Things: Simulation and Modeling", IEEE Internet Of Things Journal, vol. 5, no. 4, pp. 2304-2314 August 2018.
3. É. Morin, M. Maman, R. Guizzetti, And A. Duda," Comparison of the Device Lifetime in Wireless Networks for the Internet of Things", IEEE Access, vol. 5, pp. 7097 – 7114, 2017.
4. "LoRa Technology." [Online]. Available: https://www.lora-alliance.org/.
5. L. Angrisani, et al. "LoRa Protocol Performance Assessment in Critical Noise Conditions", in Proc. of RTSI 2017–IEEE 3rd International Forum on Research and Technologies for Society and Industry, Modena, Italy, Sep. 2017.
6. H. Mroue1, A. Nasser, S. Hamrioui, B. Parrein, E. Motta-Cruz and G. Rouyer, "MAC layer-based evaluation of IoT technologies:LoRa, SigFox and NB-IoT", IEEE Middle East and North Africa Communications Conference (MENACOMM), April 2018
7. Huang-Chen Lee, and Kai-Hsiang Ke, "Monitoring of Large-Area IoT Sensors Using a LoRa Wireless Mesh Network System: Design and Evaluation" , IEEE Transactions On Instrumentation And Measurement, vol. 67, no. 9, pp. 2177-2187, September 2018
8. J. Haxhibeqiri, A. Karaagac, F. Abeele, W. Joseph, I. Moerman, J. Hoebeke, "LoRa Indoor Coverage and Performance in an Industrial Environment: Case Study", 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), pp. 1-8, September 2017
9. LoRa™ Modulation Basics, AN1200.22 [Online] Available: https://www.semtech.com/uploads/documents/an1200.22.pdf
10. https://www.semtech.com/products/wireless-rf/lora-transceivers/sx1276 (datasheet)
11. www.microchip.com/wwwproducts/en/ATmega328p
12. https://datasheetspdf.com/pdf/792211/Aosong/DHT22/1
13. https://telit.co.rs

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