Ana I. Pereira · Florbela P. Fernandes ·
João P. Coelho · João P. Teixeira ·
Maria F. Pacheco · Paulo Alves ·
Rui P. Lopes (Eds.)

Communications in Computer and Information Science 1488

Optimization, Learning Algorithms and Applications

First International Conference, OL2A 2021
Bragança, Portugal, July 19–21, 2021
Revised Selected Papers

Springer

OL2A INTERNATIONAL CONFERENCE 2021

Communications in Computer and Information Science 1488

Ana I. Pereira · Florbela P. Fernandes ·
João P. Coelho · João P. Teixeira ·
Maria F. Pacheco · Paulo Alves ·
Rui P. Lopes (Eds.)

Optimization, Learning Algorithms and Applications

First International Conference, OL2A 2021
Bragança, Portugal, July 19–21, 2021
Revised Selected Papers

Springer

Editors
Ana I. Pereira
Instituto Politécnico de Bragança
Bragança, Portugal

João P. Coelho
Instituto Politécnico de Bragança
Bragança, Portugal

Maria F. Pacheco
Instituto Politécnico de Bragança
Bragança, Portugal

Rui P. Lopes
Instituto Politécnico de Bragança
Bragança, Portugal

Florbela P. Fernandes
Instituto Politécnico de Bragança
Bragança, Portugal

João P. Teixeira
Instituto Politécnico de Bragança
Bragança, Portugal

Paulo Alves
Instituto Politécnico de Bragança
Bragança, Portugal

ISSN 1865-0929 ISSN 1865-0937 (electronic)
Communications in Computer and Information Science
ISBN 978-3-030-91884-2 ISBN 978-3-030-91885-9 (eBook)
https://doi.org/10.1007/978-3-030-91885-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The volume CCIS 1488 contains the refereed proceedings of the International Conference on Optimization, Learning Algorithms and Applications (OL2A 2021), an event that, due to the COVID-19 pandemic, was held online.

OL2A 2021 provided a space for the research community on optimization and learning to get together and share the latest developments, trends, and techniques as well as develop new paths and collaborations. OL2A 2021 had more than 400 participants in an online environment throughout the three days of the conference (July 19–21, 2021), discussing topics associated to areas such as optimization and learning and state-of-the-art applications related to multi-objective optimization, optimization for machine learning, robotics, health informatics, data analysis, optimization and learning under uncertainty, and the Fourth Industrial Revolution.

Four special sessions were organized under the following topics: Trends in Engineering Education, Optimization in Control Systems Design, Data Visualization and Virtual Reality, and Measurements with the Internet of Things. The event had 52 accepted papers, among which 39 were full papers. All papers were carefully reviewed and selected from 134 submissions. All the reviews were carefully carried out by a Scientific Committee of 61 PhD researchers from 18 countries.

July 2021 Ana I. Pereira

Organization

General Chair

Ana Isabel Pereira	Polytechnic Institute of Bragança, Portugal

Organizing Committee Chairs

Florbela P. Fernandes	Polytechnic Institute of Bragança, Portugal
João Paulo Coelho	Polytechnic Institute of Bragança, Portugal
João Paulo Teixeira	Polytechnic Institute of Bragança, Portugal
M. Fátima Pacheco	Polytechnic Institute of Bragança, Portugal
Paulo Alves	Polytechnic Institute of Bragança, Portugal
Rui Pedro Lopes	Polytechnic Institute of Bragança, Portugal

Scientific Committee

Ana Maria A. C. Rocha	University of Minho, Portugal
Ana Paula Teixeira	University of Trás-os-Montes and Alto Douro, Portugal
André Pinz Borges	Federal University of Technology – Paraná, Brazil
Andrej Košir	University of Ljubljana, Slovenia
Arnaldo Cândido Júnior	Federal University of Technology – Paraná, Brazil
Bruno Bispo	Federal University of Santa Catarina, Brazil
Carmen Galé	University of Zaragoza, Spain
B. Rajesh Kanna	Vellore Institute of Technology, India
C. Sweetlin Hemalatha	Vellore Institute of Technology, India
Damir Vrančić	Jozef Stefan Institute, Slovenia
Daiva Petkeviciute	Kaunas University of Technology, Lithuania
Diamantino Silva Freitas	University of Porto, Portugal
Esteban Clua	Federal Fluminense University, Brazil
Eric Rogers	University of Southampton, UK
Felipe Nascimento Martins	Hanze University of Applied Sciences, The Netherlands
Gaukhar Muratova	Dulaty University, Kazakhstan
Gediminas Daukšys	Kauno Technikos Kolegija, Lithuania
Glaucia Maria Bressan	Federal University of Technology – Paraná, Brazil
Humberto Rocha	University of Coimbra, Portugal
José Boaventura-Cunha	University of Trás-os-Montes and Alto Douro, Portugal
José Lima	Polytechnic Institute of Bragança, Portugal
Joseane Pontes	Federal University of Technology – Ponta Grossa, Brazil
Juani Lopéz Redondo	University of Almeria, Spain

Jorge Ribeiro	Polytechnic Institute of Viana do Castelo, Portugal
José Ramos	NOVA University Lisbon, Portugal
Kristina Sutiene	Kaunas University of Technology, Lithuania
Lidia Sánchez	University of León, Spain
Lino Costa	University of Minho, Portugal
Luís Coelho	Polytecnhic Institute of Porto, Portugal
Luca Spalazzi	Marche Polytechnic University, Italy
Manuel Castejón Limas	University of León, Spain
Marc Jungers	Université de Lorraine, France
Maria do Rosário de Pinho	University of Porto, Portugal
Marco Aurélio Wehrmeister	Federal University of Technology – Paraná, Brazil
Mikulas Huba	Slovak University of Technology in Bratislava, Slovakia
Michał Podpora	Opole University of Technology, Poland
Miguel Ángel Prada	University of León, Spain
Nicolae Cleju	Technical University of Iasi, Romania
Paulo Lopes dos Santos	University of Porto, Portugal
Paulo Moura Oliveira	University of Trás-os-Montes and Alto Douro, Portugal
Pavel Pakshin	Nizhny Novgorod State Technical University, Russia
Pedro Luiz de Paula Filho	Federal University of Technology – Paraná, Brazil
Pedro Miguel Rodrigues	Catholic University of Portugal, Portugal
Pedro Morais	Polytechnic Institute of Cávado e Ave, Portugal
Pedro Pinto	Polytechnic Institute of Viana do Castelo, Portugal
Rudolf Rabenstein	Friedrich-Alexander-University of Erlangen-Nürnberg, Germany
Sani Rutz da Silva	Federal University of Technology – Paraná, Brazil
Sara Paiva	Polytechnic Institute of Viana do Castelo, Portugal
Sofia Rodrigues	Polytechnic Institute of Viana do Castelo, Portugal
Sławomir Stępień	Poznan University of Technology, Poland
Teresa Paula Perdicoulis	University of Trás-os-Montes and Alto Douro, Portugal
Toma Roncevic	University of Split, Croatia
Vitor Duarte dos Santos	NOVA University Lisbon, Portugal
Wojciech Paszke	University of Zielona Gora, Poland
Wojciech Giernacki	Poznan University of Technology, Poland

Contents

Optimizing Data Transmission in a Wireless Sensor Network Based on LoRaWAN Protocol

Thadeu Brito[1,2,3], Matheus Zorawski[1], João Mendes[1(✉)], Beatriz Flamia Azevedo[1,4], Ana I. Pereira[1,4], José Lima[1,3], and Paulo Costa[2,3]

[1] Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal
{brito,matheuszorawski,joao.cmendes,beatrizflamia,apereira,jllima}@ipb.pt
[2] Faculty of Engineering of University of Porto, Porto, Portugal
[3] INESC TEC - INESC Technology and Science, Porto, Portugal
[4] Algoritmi Research Centre, University of Minho, Campus de Gualtar, Braga, Portugal

Abstract. Internet of Things, IoT, is a promising methodology that has been increasing over the last years. It can be used to allow the connection and exchange data with other devices and systems over the Internet. One of the IoT connection protocols is the LoRaWAN, which has several advantages but has a low bandwidth and limited data transfer. There is a necessity of optimising the data transfer between devices. Some sensors have a 10 or 12 bits resolution, while LoRaWAN owns 8 bits or multiples slots of transmission remaining unused bits. This paper addresses a communication optimisation for wireless sensors resorting to encoding and decoding procedures. This approach is applied and validated on the real scenario of a wildfire detection system.

Keywords: Internet of Things · LoRaWAN · Wireless sensor network · Fire detection · Transmission optimisation

1 Introduction

The project "SAFe: Forest Monitoring and Alert System" proposes an intelligent system for monitoring situations of potential forest risk. This system combines sensor nodes that will collect various parameters, namely temperature, humidity and data related to infrared sensors that identify the presence of flame. This collection of information, combined with a system based on artificial intelligence and other collected data (such as weather forecasting), will allow an efficient and intelligent data analysis, allowing the creation of alerts of dangerous situations to alert the different actors (for example, firefighters, civil protection or city

A. I. Pereira et al. (Eds.): OL2A 2021, CCIS 1488, pp. 281–293, 2021.
https://doi.org/10.1007/978-3-030-91885-9_20

council). These alerts will be parameterized and presented in a personalised way and tailored to each actor. Thus, it is intended to minimise the occurrence of ignitions, monitor fauna and flora, and contribute to the environmental development of the region of Trás-os-Montes, particularly in the district of Bragança. In addition to the capacity for early detection of forest fires, the accurate estimation of the fire hazard, using fire risk indices in real-time, on a sub-daily and local scale, in meteorological data, in the availability of fuels and moisture content vegetation is of utmost importance.

The SAFe's implementation is localised to the Serra da Nogueira area, belonging to the Natura 2000 Network, with unique characteristics in the Bragança region and with an extension of approximately 13 km. Considering the region's size to be monitored, data transmission is carried out by LoRaWAN, it is based on low power wide area network, which will guarantee full coverage of the area in question [1–4]. This type of communication is increasingly used, and it is estimated that by 2024, the IoT industry will generate revenue of 4.3 trillion dollars [5]. LoRaWAN networks are composed of end devices, gateway and network server in the midst of a rising state. The data is acquired from the modules (end devices) that send the data to the gateway, which in turn relays the messages to the servers through non-LoRaWAN networks, such as Ethernet or IP over cellular [6].

The LoRaWAN communication itself uses the Chirp Spread Spectrum (CSS) modulation, where chirp pulses modulate the signal. It uses an unlicensed sub-gigahertz ISM band that varies in width depending on the region of application, and for Europe, it is 863 MHz to 870 MHz [7]. Within the communication settings, three parameters allow a network adjustment between bit rate and robustness of the transmission: Bandwidth (BW), Spreading Factor (SF), and Coding Rate (CR) [8]. The format of the Long Range (LoRa) message is subdivided into several layers, the physical layer, which is composed of five fields, the preamble, the physical header (PHDR), the physical header Cyclic Redundancy check (PHDR0_CRC), the physical payload (PHY Payload) and an error detection tail (CRC). The Medium Access Control (MAC) layer, in turn, is a subdivision of the PHY Payload field and consists of three fields, the MAC Header (MHDR), MAC Payload and the Massage Integrity Code (MIC). Within the MAC Payload is the message itself, which consists of three fields, the Frame header (FHDR), the port and the frame payload (FRM Payload) [9].

At this stage of the SAFe project, while the testing period is still underway in an urban environment, the configuration being used is a 125 kHz Bandwidth, an SF7 and a Coding Rate of 4/5, which allows transmission of about 242 Bytes. However, taking into account that when the project passes the test phase in a rural environment, it will be necessary to cover a larger area. It is probably required to use a larger SF to improve the communication range, thus reducing transmission capacity. Using an SF12 and maintaining the BW and CR, the LoRaWAN communication will allow transmission of about 51 Bytes. Therefore, there is a necessity to optimise the use of all bits' packages as much as possible and not lose data essential for the project's realisation. But some sensors have a 10 or 12 bits resolution while LoRaWAN owns 8 bits, which means, in some cases, multiples slots of transmission remaining unused bits. In this way, this paper addresses a communication optimisation for Wireless Sensors Network (WSN) resorting to encoding and decoding procedures.

The rest of paper is organized as follows. After the introduction, Sect. 2 presents the related work. In Sect. 3, the system architecture is addressed where the focus of this paper is highlighted. Section 4 presents the algorithm used to optimise the data sent though the network and Sect. 5 stresses the results of the proposed encoding/decoding. Last section, concludes the paper and points future work.

2 Related Work

Real-time data collection and analysis had new possibilities with the emergence of the Internet of Things (IoT). Typically, IoT devices are manufactured to use in short-range protocols, such as Bluetooth, WiFi, and ZigBee, among others, which may have limitations, such as the maximum number of devices connected to the gateway and high power consumption. On the other hand, mobile technologies that have an extensive range (LTE, 3G and 4G) are expensive, consume a lot of power and have a continuing cost [10]. The gap that these technologies have been filled in part by Low Power Wide Area Network (LPWAN) technologies, which cannot cover the critical applications (e.g. remote health monitoring), but fit very well for the requirements of IoT applications. Although low data rates limit LPWAN systems, there are reasons for their use, especially after the emergence of technologies such as SigFox, NB-IoT, and LoRa [10,11].

LoRa network is highly used in applications requiring low power consumption and long-range, in which LoRa Alliance proposed the LoRaWAN, defining the network protocol in the MAC and network layers [10,12]. Different scenarios of typical LoRa networks applications are pointed out in [12], besides providing documentation of LoRa networks design and implementation, searching for a better cost-benefit for LPWAN applications. Also, Baiji [13] showed in 2019 an application using LoRaWAN in an IoT monitoring system aimed to minimise the non-productive time for Oil and Gas companies through the detection of a leak.

Researches are being carried out seeking improvements to the LoRaWAN system, in which numerous of these are being carried out to seek optimisation of data rate, airtime, and energy consumption through an Adaptive Data Rate (ADR), as in [14], where a review of research on ADR algorithms for LoRaWAN technology is presented. Also, in [15] a method for the use of ADR is implemented, seeking to provides an optimal throughput with multiple devices connected to LoRaWAN. Furthermore, a study was carried out looking for maximising the battery lifetime through different LoRaWAN nodes and scenarios in [16], demonstrating relationships between different payload sizes with the power consumption and air time using various SF and CR, indicating an increase in power consumed per bit of payload used.

As cited by [11], all the advantages of the LoRa network of achieving a long transmission range, low power and enabling low-cost IoT applications to exist with the downside of low data throughput rate. The LoRaWAN data transfer must respect a protocol, and it is possible to send the Payload in several forms, as long as it is within the limit of the number of Bytes. Considering the article [9], the LoRa message format is composed of several fields that have specific or limited sizes. Therefore, it is necessary to optimise the use of bytes in Payload as much as possible. Some techniques have been used over the years, such as selecting the best packet size by adjusting the bit rate to achieve maximum throughput as demonstrated by the authors of the article [17], to optimise the payload sizes in voice and video applications. Still, within this dynamic, the authors of the article [18] used throughput as the optimisation metric and based their study on wireless ATM networks to maximise the efficiency of transfer by adapting the packet size with the variation of the channel conditions. Also, Eytan Modiano in [19] presented a system to dynamically optimise the packet size based on the estimates of the channel's bit error rate, being particularly useful for wireless and satellite channels.

The importance of packet size optimisation in WSN are debated in the article [20], presenting several packet size optimisation techniques and concluding that there is no agreement on whether the packet should be fixed or dynamic. The packet size optimisation technique to be used for WSN is defended in article [21], proposing an energy efficiency factor evaluation metric, being a fixed packet size for the case studied. Furthermore, the authors of the article [22] present a variation of the packet size depending on the network conditions to increase the network throughput and efficiency. The method of payload recommended by The Things Network (TTN) when using LoRaWAN has described in [23] only the specifications of how to send each type of data. Suppose the user needs to use the minimum Bytes possible for a shorter transmission time and being within the limit of 51 Bytes. One way to implement data encoding for the LPWAN network as LoRaWAN is through Cayenne Low Power Payload (LPP), which allows sending the payload dynamically, according to the LoRa frequency and data rate used [24]. Nevertheless, besides the various optimisations that have been mentioned above, it remains crucial to find the form to optimise the data that will be transferred for better use of the LoRa network.

3 System Architecture

The presented system has the main ideology of monitoring a determined area with a reduced application cost. In this way, it is expected to obtain constant surveillance to identify any ignition that may exist. This surveillance will be achieved using the various sensors present in the modules (end devices). Each module consists of six sensors, with three distinct values types: five flame sensors and a sensor that provides data on relative humidity and air temperature. The entire operation of the safe project combines the collection of data from the modules present in the forest; this data collection mustn't fail. Consequently, the proper functioning of data transmission is guaranteed because if the data does not reach the competent entities, they will be of no use. This transmission will be handle using LoRaWAN technology, which allows us to connect several modules to different gateways. Thus, guaranteeing low-cost and efficient coverage of the area. Figure 1 exemplifies the whole system architecture of the SAFe project.

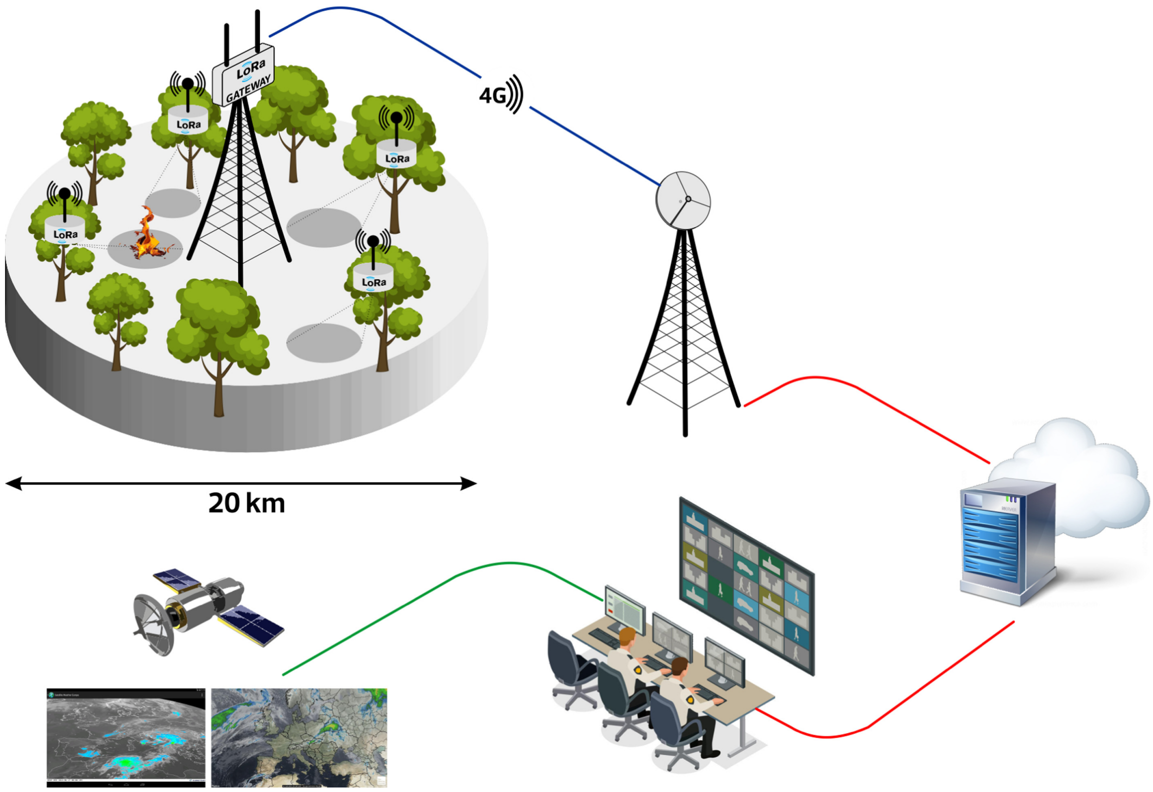

Fig. 1. System architecture of SAFe project [2].

Due to the specificity that each of these elements is defined and developed (Fig. 1), this work is concentrated only on the LoRaWAN's Transmission and the proposed arrangement bits protocol. Other SAFe's approaches can be seen in [1–4]. In this way, considering the high number of modules (end devices) used in this project, there is a requirement to ensure no collisions between their messages; the whole modules' description is explained in [2,4]. Thereupon, it is necessary to optimise the size of the data package sent, thus guaranteeing the minimum necessary occupation of bytes to reduce the chances of these collisions and consequent data losses. The normal sending process (recommended by TTN service) will be exemplified below to explain the process, for this information will be used related to the six sensors present in the modules as well as the battery information, resulting in:

– **Flame sensors:** as mentioned before, each node has five flame sensors. These sensors make 10 bits reading, which means they will generate values between 0 to 1023. To send just one value from one of them is demanded to use 2-Bytes (16 bits), consequently, to send all of them is required a total of 10-Bytes.
– **Relative humidity sensor:** this sensor produces a reading between 0 to 99, but 2-Bytes are required to transmit the message.
– **Temperature sensor:** gives a reading between 0 to 50 °C, which results in the use of 2-Bytes to transmit.
– **Battery level:** the battery level is converted from a 10 bits ADC and a total of 2-Bytes will be required to transmit.

Analysing the sending process recommended by TTN service, it is possible to observe that the total package has 16-Bytes per interval of sending data (Fig. 2). However, the messages resulting from all sensors have unused bits because 16-Bytes has 128 bits and the data produced by all sensors in each module has a total of 73 bits. Thus, this work aims to optimise the use of these unfilled bits. Using the example of flame sensors, it is possible to notice that the 2-Bytes sent correspond to a message with 16-bits, and only 10-bits are used to transmit the value with a range of 0 to 1023. In this case, 6-bits are left to optimise with the data from another sensor's value. This example can be seen looking for $B0$ and $B1$ in the following Fig. 2.

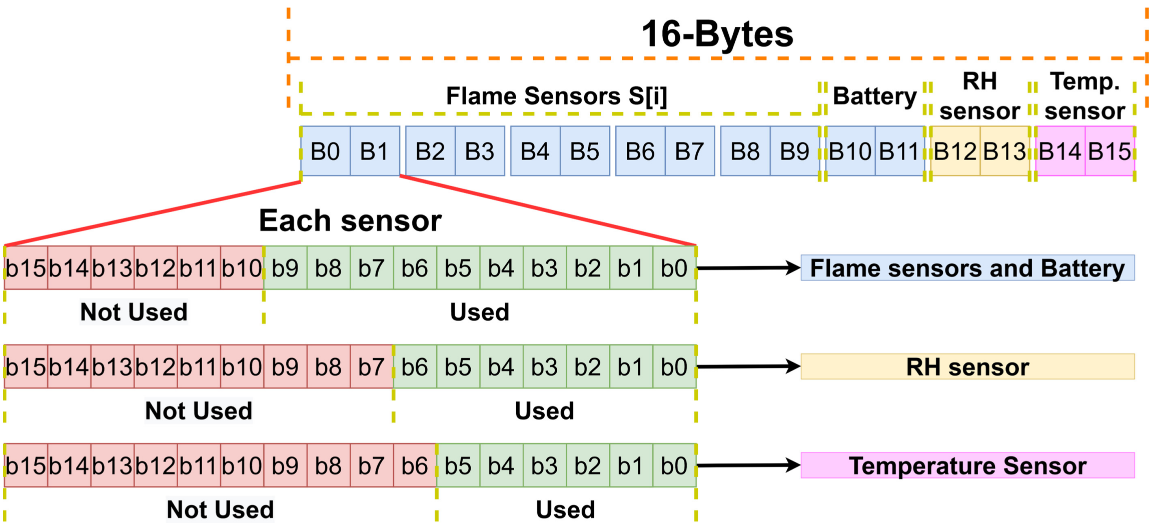

Fig. 2. 16-Bytes (B) of data necessary to send. The unused bits (b) are red coloured. Where $i \in \mathbf{R} | 0 \leq i \leq 4$.

This methodology of taking advantage of the unused bits will be explained in the following section in more detail.

4 Algorithm

From the previous section, it is possible to notice that for each flame sensor data ($S[i]$), there are some unused bits (x) available to receive data to be carried. In this way, the humidity sensor (RH) and the temperature sensor (T) will be stored on a Byte type and the battery (B) level will be stored in 10 bits resolution. Table 1 presents the transmission package without optimise the encoding procedure (using the recommendation in [23]).

Table 1. Transmission without optimise encoding. S[i] are the flame sensors, H, T and B are the Humidity, Temperature and Battery Voltage sensors, respectively. The 'x' are the unused bits.

S[0]									
x	x	x	x	x	x	s9[0]	s8[0]	...	s0[0]

S[1]									
x	x	x	x	x	x	s9[1]	s8[1]	...	s0[1]

S[2]									
x	x	x	x	x	x	s9[2]	s8[2]	...	s0[2]

S[3]									
x	x	x	x	x	x	s9[3]	s8[3]	...	s0[3]

S[4]									
x	x	x	x	x	x	s9[4]	s8[4]	...	s0[4]

RH									
x	x	x	x	x	x	x	RH7	...	RH0

T									
x	x	x	x	x	x	x	T7	...	T0

B									
x	x	x	x	x	x	B9	B8	...	B0

Legend	
	Used by 10 bits sensors
	Used by Relative Humidity
	Used by Temperature

This approach intends to sort the bits using a less value as possible in bytes protocol used to transmit the data by LoRaWAN. The main idea is distribute each bit from each sensor during the encoding process, in a manner that is necessary use the minimum Bytes. In order to optimise these *Not Used* bits (b15, b14, b13, b12, b11 and b10, see Fig. 2) for each sensor $S[i]$ (where $i \in \mathbf{R}|0 \leq i \leq 4$), the word (2-Bytes) of Humidity (RH), Temperature (T) and Battery (B) will be separated and combined with the unused bits at the encoding procedure. A bit manipulation operation is required to use the previous unused bits. Table 2 presents the previous "x" assuming bits from other sensors. Moreover, even including the H, T and B values, there are 4 bits that remains unused. They will be appropriated to hold four auxiliary bits (AUX) for future applications.

Table 2. Proposed encoding map.

S[0]									
T5	T4	T3	T2	T1	T0	s9[0]	s8[0]	...	s0[0]

S[1]									
RH3	RH2	RH1	RH0	T7	T6	s9[1]	s8[1]	...	s0[1]

S[2]									
B1	B0	RH7	RH6	RH5	RH4	s9[2]	s8[2]	...	s0[2]

S[3]									
B7	B6	B5	B4	B3	B2	s9[3]	s8[3]	...	s0[3]

S[4]									
AUX4	AUX2	AUX1	AUX0	B9	B8	s9[4]	s8[4]	...	s0[4]

RH									
x	x	x	x	x	x	x	x	...	x

T									
x	x	x	x	x	x	x	x	...	x

B									
x	x	x	x	x	x	x	x	...	x

Legend	
	Used by 10 bits sensors
	Used by Relative Humidity
	Used by Temperature
	Used by AUX

This encoding operation is carried by an embedded system that is programmed on C language. For the encoding, the proposed C code is detailed on Listing 1.1. The message will go through the network and will be decoded by Listing 1.2.

Listing 1.1. Data encoder

```
S[0] = S[0] + (T & 0X3F) << 10;
S[1] = S[1] + (T & 0XC0) << 10 + (H & 0X0F) << 12;
S[2] = S[2] + (H & 0XF0) << 10 + (B & 0X003) << 14;
S[3] = S[3] + (B & 0X0FC) << 10;
S[4] = S[4] + (B & 0X300) << 10 + (AUX & 0X0F) << 12;
//TRANSMIT array S
```

An opposite operation of decoding will allow to extract the Flame values, Humidity, Temperature and Battery voltage from the message. The C code of decoding procedure can be found on Listing 1.2.

Listing 1.2. Data decoder

```
//RECEIVE array S
T = (S[0] & 0XFC00) >> 10 + (S[1] & 0X0C0) >> 4;
H = (S[1] & 0XF000) >> 12 + (S[2] & 0X3C00) >> 6;
B = (S[2] & 0XC000) >> 14 + (S[3] & 0XFC00) >> 10
  + (S[4] & 0X0C00) >> 2;
AUX = (S[4] & 0XF000) >> 12;

S[0] = S[0] & 0X03FF;
S[1] = S[1] & 0X03FF;
S[2] = S[2] & 0X03FF;
S[3] = S[3] & 0X03FF;
S[4] = S[4] & 0X03FF;
```

This optimised message can be sent to the LoRaWAN network and at the destination, a decoder procedure will construct the original message. Figure 3 presents the encoding, transmission and decoding procedures. As it can be seen, the packet to be sent keeps the size of produced by the flame sensors $S[i]$ (where $i \in \mathbf{R} | 0 \leq i \leq 4$):

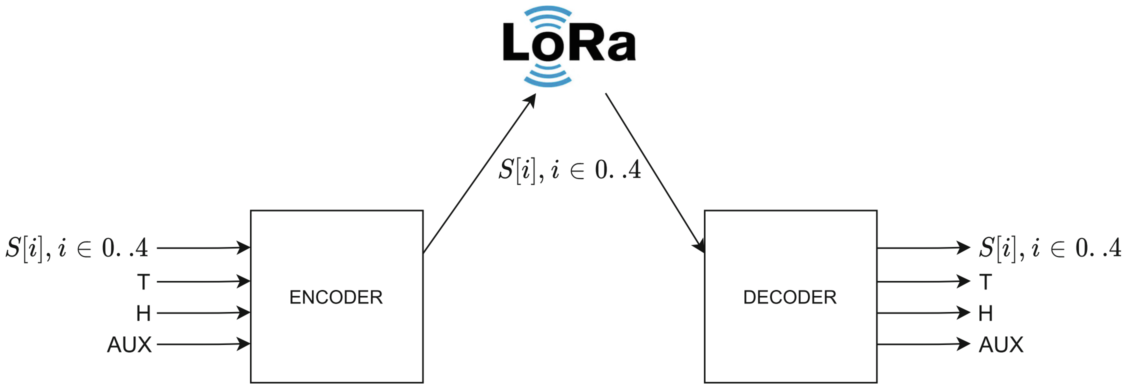

Fig. 3. Encoding and decoding procedures. Size of $S[i]$ is 16 bits whereas T and H are 8 bits. AUX is an auxiliary variable that was created with the 4 bits that remain free.

By this way, a reduction of transmission from 8 words (16-Bytes) to 5 words (10-Bytes) is obtained. The following section demonstrates the difference between the procedure of recommendation by TTN and this approach.

5 Results

To demonstrate the difference during transmission using the LoRaWAN network with the algorithm proposed in this work, a comparison test is performed with the method recommended by TTN. Therefore, five sensor modules are configured for each transmission method: five nodes with the TTN transmission technique and another five nodes with the algorithm shown in the previous section. Figure 4a shows the ten modules distributed on the laboratory bench. They are configured according to the mentioned algorithms and simulate a small WSN. All of these modules are configured to transmit at a specific frequency within the range that LoRaWAN works. In this way, it is possible to probe the behaviour of the duty cycle in the settings of the gateway used. The gateway used is RAK 7249, which is attached to the laboratory's roof shown in Fig. 4b.

(a) Five modules configured for each algorithm.

(b) LoRaWAN gateway used for the test.

Fig. 4. Structure used for the comparison between the two algorithms.

The five modules responsible for transmitting the data from the sensors with the TTN's recommendations were configured to send using the frequency 864.9 MHz, 865.5 MHz and 863 MHz (this frequency is exclusive for FSK). The other five modules, those configured with the algorithm proposed in this work, carried out transmissions on 863.5 MHz , 863.9 MHz and 860.1 MHz (this frequency is exclusive for FSK use). To ensure that no other frequencies were used, the RAK 7249 was still configured to only work on these six frequencies mentioned. In addition, it was also chosen to enable a modulation concentrator for each frequency range used.

All ten modules have the same sending values; that is, all of them must send the five values of the flame sensors, the battery level, humidity and relative air temperature. They have also been configured to communicate in an interval of 60 s. Therefore, after all the necessary configurations for the test, the modules were deposited under the laboratory bench. Where they are under the same climatic circumstances, it is also possible to guarantee that they will send corresponding temperature and humidity values. Also, note that all batteries are fully charged.

After 24 h, the generated duty cycle graph was verified in the gateway system, and a screenshot is shown in Fig. 5. Through this graph, it is possible to notice the difference between the two algorithms based on the lines generated when the gateway performs transmissions at a specific frequency. In this sense, it is observed that the primary frequencies are the most used (864.9 MHz and

863.5 MHz), as the firmware will always choose them as the first attempt to send. However, when analysing the secondary frequencies (865.5 MHz and 863.9 MHz), a difference is noted between the amount of duty cycle occupation. This graphical difference demonstrates the optimisation of bytes during data transmission through the LoRaWAN network. Thus, using the algorithm proposed in this work, it is possible to insert more modules under the same facilities.

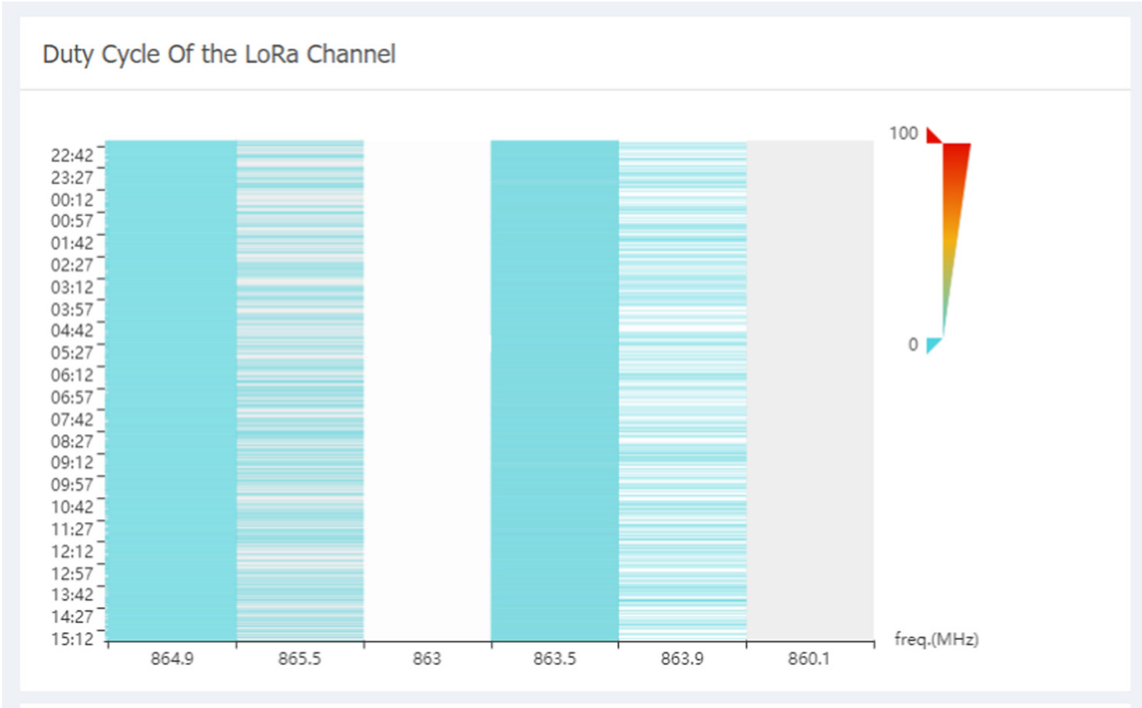

Fig. 5. A screenshot is obtained from the RAK 7249 gateway system after 24 h of use.

6 Conclusion and Future Works

The limited resources of the LoRaWAN requires a reduction of the transmission data. In this paper, an optimised transmission is proposed availing the unused bits of the 16 bits values. It is a lossless bit manipulation that will fit the temperature, humidity and battery level data bits in the unused bits of the sensors data where each sensor occupies 10 bits. The remaining 6 bits are used to perform this procedure. Also, 4 free bits will allow to use an auxiliary value from 0 to 0xF that can help on synchronisation and packet sequence verification. The results showed that the reduction of the duty cycle of the LoRaWAN while maintaining the data integrity allow to verify that the proposed methodology is able to be installed on the wireless sensor network, as future work.

Acknowledgements. This work has been supported by Fundação La Caixa and FCT—Fundação para a Ciência e Tecnologia within the Project Scope: UIDB/5757/2020.

References

1. Brito, T., Pereira, A.I., Lima, J., Castro, J.P., Valente, A.: Optimal sensors positioning to detect forest fire ignitions. In: Proceedings of the 9th International Conference on Operations Research and Enterprise Systems, pp. 411–418 (2020)
2. Brito, T., Pereira, A.I., Lima, J., Valente, A.: Wireless sensor network for ignitions detection: an IoT approach. Electronics **9**(6), 893 (2020)
3. Azevedo, B.F., Brito, T., Lima, J., Pereira, A.I.: Optimum sensors allocation for a forest fires monitoring system. Forests **12**(4), 453 (2021)
4. Brito, T., Azevedo, B.F., Valente, A., Pereira, A.I., Lima, J., Costa, P.: Environment monitoring modules with fire detection capability based on IoT methodology. In: Paiva, S., Lopes, S.I., Zitouni, R., Gupta, N., Lopes, S.F., Yonezawa, T. (eds.) SmartCity360° 2020. LNICST, vol. 372, pp. 211–227. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-76063-2_16
5. Seye, M.R., Ngom, B., Gueye, B., Diallo, M.: A study of LoRa coverage: range evaluation and channel attenuation model. In: 2018 1st International Conference on Smart Cities and Communities (SCCIC), pp. 1–4 (2018). https://doi.org/10.1109/SCCIC.2018.8584548
6. Phung, K.H., Tran, H., Nguyen, Q., Huong, T.T., Nguyen, T.L.: Analysis and assessment of LoRaWAN. In: 2018 2nd International Conference on Recent Advances in Signal Processing, Telecommunications Computing (SigTelCom), pp. 241–246 (2018). https://doi.org/10.1109/SIGTELCOM.2018.8325799
7. Kufakunesu, R., Hancke, G.P., Abu-Mahfouz, A.M.: A survey on adaptive data rate optimization in LoRaWAN: recent solutions and major challenges. Sensors **20**(18), 5044 (2020). https://doi.org/10.3390/s20185044. https://www.mdpi.com/1424-8220/20/18/5044
8. Jovalekic, N., Drndarevic, V., Pietrosemoli, E., Darby, I., Zennaro, M.: Experimental study of lora transmission over seawater. Sensors **18**(9), 2853 (2018). https://doi.org/10.3390/s18092853. https://www.mdpi.com/1424-8220/18/9/2853
9. Casals, L., Mir, B., Vidal, R., Gomez, C.: Modeling the energy performance of LoRaWAN. Sensors **17**(10) (2017). https://doi.org/10.3390/s17102364. https://www.mdpi.com/1424-8220/17/10/2364
10. Tsakos, K., Petrakis, E.G.M.: Service oriented architecture for interconnecting LoRa devices with the cloud. In: Barolli, L., Takizawa, M., Xhafa, F., Enokido, T. (eds.) AINA 2019. AISC, vol. 926, pp. 1082–1093. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-15032-7_91
11. Raza, U., Kulkarni, P., Sooriyabandara, M.: Low power wide area networks: an overview. IEEE Commun. Surv. Tutor. **19**(2), 855–873 (2017). https://doi.org/10.1109/COMST.2017.2652320
12. Zhou, Q., Zheng, K., Hou, L., Xing, J., Xu, R.: Design and implementation of open LoRa for IoT. IEEE Access **7**, 100649–100657 (2019)
13. Baiji, Y., Sundaravadivel, P.: iloleak-detect: an IoT-based LoRaWAN-enabled oil leak detection system for smart cities. In: 2019 IEEE International Symposium on Smart Electronic Systems (iSES) (Formerly iNiS), pp. 262–267. IEEE (2019)
14. Kufakunesu, R., Hancke, G.P., Abu-Mahfouz, A.M.: A survey on adaptive data rate optimization in LoRaWAN: recent solutions and major challenges. Sensors **20**(18), 5044 (2020)
15. Kim, S., Yoo, Y.: Contention-aware adaptive data rate for throughput optimization in LoRaWAN. Sensors **18**(6), 1716 (2018)

16. Bouguera, T., Diouris, J.F., Chaillout, J.J., Jaouadi, R., Andrieux, G.: Energy consumption model for sensor nodes based on LoRa and LoRaWAN. Sensors **18**(7), 2104 (2018)
17. Choudhury, S., Gibson, J.D.: Payload length and rate adaptation for multimedia communications in wireless LANs. IEEE J. Sel. Areas Commun. **25**(4), 796–807 (2007). https://doi.org/10.1109/JSAC.2007.070515
18. Akyildiz, I., Joe, I.: A new ARQ protocol for wireless ATM networks. In: ICC 1998. 1998 IEEE International Conference on Communications. Conference Record. Affiliated with SUPERCOMM 1998 (Cat. No.98CH36220), vol. 2, pp. 1109–1113 (1998). https://doi.org/10.1109/ICC.1998.685182
19. Modiano, E.: An adaptive algorithm for optimizing packet size used in wireless ARQ protocols. Wirel. Netw. **5**, 279–286 (2000). https://doi.org/10.1023/A:1019111430288
20. Leghari, M., Abbasi, S., Dhomeja, L.D.: Survey on packet size optimization techniques in wireless sensor networks. In: Proceedings of the International Conference on Wireless Sensor Networks (WSN4DC) (2013)
21. Sankarasubramaniam, Y., Akyildiz, I.F., McLaughlin, S.: Energy efficiency based packet size optimization in wireless sensor networks. In: Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications, pp. 1–8. IEEE (2003)
22. Dong, W., et al.: DPLC: dynamic packet length control in wireless sensor networks. In: 2010 Proceedings IEEE INFOCOM, pp. 1–9. IEEE (2010)
23. Working with bytes. https://www.thethingsnetwork.org/docs/devices/bytes/. Accessed 15 May 2021
24. Cayenne low power payload. https://developers.mydevices.com/cayenne/docs/lora/#lora-cayenne-low-power-payload. Accessed 15 May 2021