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Transmission of Images over LoRa

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In this research paper, a proposal is presented for a MAC layer designed specifically for image transmission over LoRa. The proposed layer utilizes polite spectrum access to overcome the limitations imposed by the duty cycle constraint. By implementing channel sensing, transmitting nodes can ensure efficient utilization of the available spectrum. Moreover, a contention mechanism has been incorporated to effectively reduce collisions. The feasibility of this solution has been demonstrated through its implementation in a testbed, serving as a proof of concept. During the initial performance evaluation, it was observed that the transmission of JPEG images via LoRa, with a resolution of 640x480 pixels and an average size of 11.3 KB, requires an average of 7.9 seconds.

Keywords **– LoRa, multimedia communications, polite spectrum access, listen-before-talk, contention**

I. Introduction

According to a report by Internet of Things (IoT) Analytics, the number of IoT connections is projected to rise from 7 billion in 2018 to 22 billion by 2025 [1]. In 2019, Low Power Wide Area Networks (LPWANs) accounted for 231 million of these IoT connections [2]. LPWANs are wireless networks designed specifically for IoT, enabling the connection of numerous low-cost devices. They offer long-range communication capabilities while transmitting small amounts of traffic and consuming minimal energy.

Currently, there are four dominant LPWAN technologies available in the market: LoRaWAN, Sigfox, NB-IoT, and LTE-M. Among these, LoRaWAN stands out as a highly promising solution that meets the requirements for long-range and low-power communication. It supports bit rates ranging from 250 bps to 11 kbps within the non-licensed ISM band. LoRaWAN follows an open standard, defining the medium access control (MAC) layer and network topology. Moreover, it has been deployed in 157 countries worldwide and is supported by the LoRa Alliance, a non-profit association consisting of over 500 members [3]. LoRaWAN is intended for applications that send few messages per day, e.g., logistics, smart farming, environmental monitoring, smart cities, smart grids, etc.

The purpose of the developed MAC layer is to be able to use low-cost LoRa devices to transmit images without the need to include new wireless technology hardware. This will be useful in a multitude of use cases, such as visual verification of fire alarms in rural areas, visual aid to locate lost UAVs without coverage, or for agricultural monitoring.

There are several works about image transmission over LoRa. Chen [4] introduced a communication protocol called MPLR for transmitting images via LoRa, which employs bit-vector acknowledgments to reduce the number of ACKs. He also utilized a channel reservation protocol to reduce the collision probability. Ching-Chung [5] multiplexed the transmission of an image using, thanks to their orthogonality, different spreading factors, thus reducing the image transmission time. In [6], Jebril proposed to use the LoRa physical layer with a new encryption method for image transmission. Wei [7] tested different image encoding methods to analyze their impact on the transmitted file size and image transmission efficiency. To the best of our knowledge, these works did not consider contemption mechanisms nor other MAC layer modifications to overcome the duty cycle limitations in LoRa.

The rest of the paper is organized as follows. Section II makes a brief description of LoRa. Section III describes the modifications to the MAC layer proposed, while Section IV summarizes the proof of concept carried out. Section V concludes the paper.

II. LoRa Overview

LoRa [8] is a modulation technique developed by Cycleo in 2009 and later acquired by Semtech in 2012. It operates using chirp spread spectrum modulation. One of the advantages of LoRa modulation is its receiver design, which has low complexity due to the timing and frequency

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offsets between the transmitter and receiver being equivalent. In this modulation scheme, the data signal is modulated onto a chirp signal that varies its frequency over time. The spectral bandwidth (BW) of a LoRa signal is determined by the chirp rate, where a 125 kHz BW corresponds to a chip rate of 125,000 chips per second. The data rate, on the other hand, can vary based on the spreading factor (SF) employed, with SF ranging from 7 to 12. The spreading factor represents the number of raw bits carried per symbol. Consequently, the data rate (*Rb*) can be calculated using the following formula:

$$R_b = SF \times \left(\frac{BW}{2^{SF}}\right) \times \left(\frac{4}{4+CR}\right) \quad (1)$$

where the spreading factor (*SF*) is the first term in the equation, the symbol rate (*Rs*) is represented by the second term (symbols per second), and the third term is dependent on the coding rate (*CR*). LoRa modulation incorporates a FEC (Forward Error Correction) scheme to detect and correct erroneous bits by introducing redundancy in the code, thereby enhancing the robustness of the transmitted signal. The coding rate (*CR*) can vary between 1 and 4. Assuming a fixed bandwidth and coding rate, it is observed that as the spreading factor increases, the data rate decreases and thus, the Time over Air (*ToA*) becomes higher. Table 1 presents the data rate configuration for different bandwidths with a Coding Rate of 4/5 (*CR* = 1). The bit rate increases and the ToA decreases as the SF is decreased.

In the case of Europe, the band used for LoRa and LoRaWAN is ISM868. The use of this band forces us to use a duty cycle that depends on the specific subband, being the most restrictive of 0.1% among all the channels [9]. This means that, for example, if a transmitter takes 1 second to transmit, it would not be able to transmit again until 999 seconds later ($duty\ cycle = \frac{1}{999+1} = 0.001 = 0.1\%$). However, the regulations [10] also allow the use of *polite spectrum access*. In this case, the device senses the channel for at least the Clear Channel Assessment (CCA) interval to determine if it is free. The main parameters of CCA are included in Table II.

It shall be noted that the maximum allowed cumulative on time can be increased by changing the operating channel (*Adaptive Frequency Agility* or AFA).

The use of *polite spectrum access* will allow the transfer rate of LoRa and LoRaWAN devices to be significantly increased, since it will eliminate the need to comply with such a restrictive duty cycle. In the case of Europe, LoRa devices can generally use 8 channels of 125 kHz, i.e., a total of 1000 kHz, so it could transmit up to 500 seconds per hour (100 seconds/hour for each 200 kHz).

Table I. DATA RATE CONFIGURATION IN THE EU868 ISM BAND (24-BYTE FRAME, CODE RATE = 4/5, WITH CRC).

	Effective Data Rate (bps)			ToA (ms) for a 24B Packet		
BW→ SF ↓	125 kHz	250 kHz	500 kHz	125 kHz	250 kHz	500 kHz
12	293	586	1172	1319	659	330
11	537	1074	2148	741	371	185
10	977	1953	3906	371	185	93
9	1758	3516	7031	206	103	51
8	3125	6250	12500	113	57	28
7	5469	10937	21875	62	31	15
6	9375	18750	37500	34	17	9

Table II. CLEAR CHANNEL ASSESMENT PARAMETERS.

Parameter	Value	Notes
Min CCA interval	160 µs	Min CCA listening period
Min deferral period	CCA interval	Min value of the deferral interval
Dead Time	Declared by vendor, not exceeding 5 ms	Max time between the end of a listening interval and the start of a transmission
Max Tx duration (T_{on} *max*)	1 s	For a single transmission
Max Tx duration (T_{on} *max*)	4s	For a transmission dialogue or a polling sequence
Max T_{cum} *on* over 1 hour	100 s / 1 h per 200 kHz spectrum	Max allowed Cumulative On Time over a 200 kHz proportion of spectrum per hour
Min T_{off} *min* on the same operating frequency	100 ms	The min T-off time period where a specific transmitter shall remain off after a transmission on the same operating frequency
CCA radiated threshold limit (e.r.p < 100 mW)	-79 dBm	15 dB above Rx sensitivity level limit, value for devices with 200 kHz
CCA radiated threshold limit (e.r.p from 100 mW to 500 mW)	-84 dBm	11 dB above Rx sensitivity level limit, value for devices with 200 kHz

III. PROPOSED MAC LAYER

Based on the *polite spectrum access* regulations, we propose to employ a *listen-before-talk* approach to avoid the duty cycle limitations. This will allow us to transmit low resolution images via LoRa in a reasonable amount of time. Since multiple packets will be transmitted for one image, we included a negative block ACK mechanism to reduce signaling due to retransmissions.

The process for transmitting an image with our modified MAC layer is as follows:

- First, the transmitter sends a signaling message with the content "#IMAGE# <ImageSize>". This notifies the receiver that the transmitter is going to send an image of a certain size.
- Later, the transmitter splits the image into packets according to their maximum size, which will depend on the chosen spreading factor.
- The LoRa frames associated to an image have an application header that includes the source (4-bytes *src* field), the destination (4-bytes *dst* field), the transaction identifier (2-bytes *transID* field) and the sequence number within the transaction (4-bytes *seq* field). Each image is identified with a different transaction.
- Similar to IEEE 802.11, our MAC layer also employs a contention procedure to reduce the number of collisions.
- Once the packets are received, a BLOCKNACK message is sent that includes the chunks (consecutive frames) not received. If all packets have been received correctly, an empty BLOCKNACK is sent. This is done when the last packet of the image is received or when no packets have been received from this transaction during the *packetReceptionTimeout* parameter. The maximum number of retransmissions

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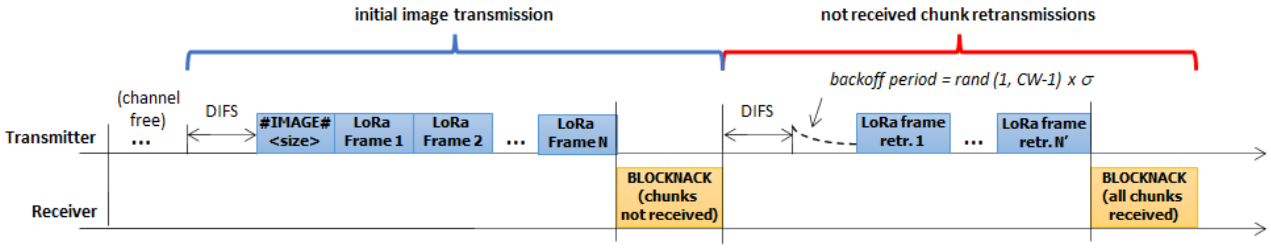


Fig. 1. Example of the transmission of one image using our modified MAC layer, including the contemption procedure.

of signaling messages is indicated by the maxNoRetx parameter.

- Once a BLOCKNACK is received, the packets corresponding to the indicated chunks are retransmitted.
- The process ends when all the image packets have been correctly received or when the maximum number of signaling message transmissions has been exceeded (assuming there are coverage problems).

The contention procedure employs the following parameters: DIFS (Data InterFrame Space), a slot time (σ), CW_{min} and CW_{max} (Contention Window minimum and maximum values). If the channel is free, the transmitter node senses the channel during a DIFS. For consecutive (re)transmissions, the transmitter will sense the channel for DIFS plus a *backoff* period, which is computed as a random number of slots between 0 and CW – 1. If the channel is busy, CW is doubled (up to its maximum value). If the channel is free, CW returns to its minimum value. Hence, in contrast to IEEE 802.11, the evolution of the contention window depends on whether the medium has been found to be busy or not, not on whether there have been collisions. This is easy to implement and avoids the need to receive ACKs and their corresponding delays.

To increase the cumulative transmission time by more than an hour, the transmitter uses the next channel for a new image to overcome the T_{cum} *on* limitation. In addition, the transmitter will have to wait T_{off} *min* if the transmission of an image takes longer than T_{on} *max*.

Fig. 1 shows an example of this procedure, considering that there has only been one retransmission.

IV. Proof-of-Concept

Our proof of concept uses Pycom Fipy modules as LoRa devices. One of the main advantages of the Fipy board is that it supports LoRaWAN class C, which will be useful to extend this work to LoRaWAN. As the maximum transmit power of these devices is 25 mW (14 dBm), the threshold to sense the channel would be -79 dBm according to Table I.

We connected a 2MP camera to the transmitter node. The camera includes an OV2640 sensor with a SPI (Serial Peripheral Interface) interface. The tests were carried out by taking photos with a resolution of 640x480 pixels, which generated JPG images.

To maximize the data rate in the tests, we chose SF7 with a bandwidth of 500 kHz, which allows a maximum LoRa frame of 222 bytes. Considering a 14-byte application header, this means that we can send 206 bytes of data per frame. Assuming a typical 10KB image, approx. 50 frames were sent per image.

The proposed MAC layer has been implemented using MicroPython in the FiPy motes, both for the transmitter and the receiver. The repository with our implementation will be made publicly available [11] once we have extended this work for a journal paper.

For our experimentation, the following values were used: DIFS = 5 ms, σ = 2 ms, CW_{min}=16, CW_{max}=1024. These values are similar to those of 802.11 but scaled by the difference in data rate.

Additionally, we developed a web site which receives the images (sent over Wi-Fi from the receiver node) and shows them in real-time. For that purpose, we utilized Ajax (to seamlessly update the browser) and PHP (to process and store the images).

Our testbed is shown in Fig. 2, where you can see the transmitter node with the camera and the receiver node. In addition, Fig. 3 shows an example of traces (including busy channel occurrences and BLOCKNACK sending) a nd the web server showing the photograph sent via LoRa.

As an initial performance evaluation of our solution, we conducted the transmission of 100 images. The transmitting node was moved during the experiment to ensure that the pictures were not always the same. The size of the images and their transmission time were measured, and the results are presented in Fig. 4. As observed, image size ranges from 9.3 KB (10th percentile) to 14.8 KB (90th percentile), with an average of 11.3 KB. This corresponds to transmission times varying from 5.7 s (10th percentile) to 9.8 s (90th percentile), with an average of 7.9 s.

V. Conclusions

This paper presents a proposal for a MAC layer for image transmission over LoRa. This layer is based on the use of polite spectrum access, which eliminates limitations due to the usage of a duty cycle. To achieve this, the transmitting nodes must sense the channel before transmitting. Additionally, a contention mechanism has been included to reduce the number of collisions. This solution has been implemented in a testbed as proof of concept. In an initial performance evaluation, it was



Fig. 2. Proof of concept.

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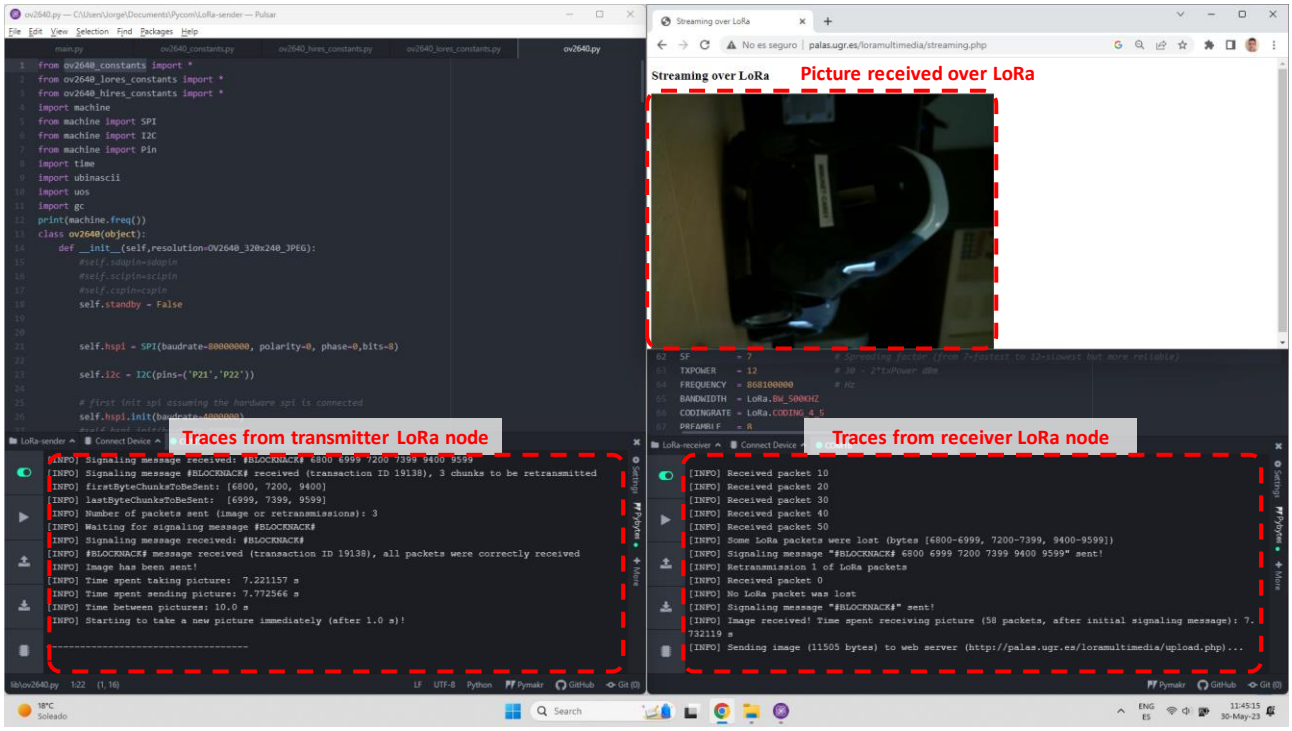


Fig. 3. Proof of concept: traces and image received.

observed that the LoRa transmission of JPEG images with a resolution of 640x480 pixels, with an average size of 11.3 KB, takes an average of 7.9 seconds.

As future work, the following aspects are included: 1) studying the impact of different parameter values (DIFS, slot time, CWmin, CWmax), 2) developing a mathematical model to estimate the transmission time of images and the collision probability of frames, 3) creating a simulator to verify the proper functioning of the mathematical model and 4) expanding the solution to transmit H.264 video frames (e.g., sent by UAVs).

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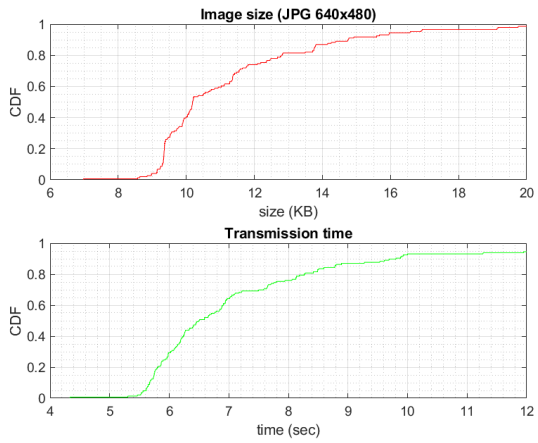


Fig. 4. CDFs of image size and transmission time.

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