Low Cost LoRaWAN Image Acquisition System for Low Rate Internet of Things Applications

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***Abstract*—This paper proposes a low cost LoRaWAN image acquisition and transmission prototype for low rate and unconstrained delay IoT applications. Real scenario tests were performed and images, at distances up to 2.5 km from node to gateway in urban environment, were transmitted and correctly decoded. The obtained results show the effectiveness of a low-power wide-area (LPWAN) technology prototype for long distance image transmission in applications without delay constraints and where other wireless technologies are not available.**

***Index Terms*—LoRaWAN, low rate image transmission, IoT visual sensor node, smart agriculture.**

I. Introduction

The Internet of Things (IoT) is an innovative paradigm with an increasing and fast development, allowing for massive data applications with a direct impact on the daily activities and lives of people and communities, influencing human behavior and the way we relate in society. The IoT is characterized by the connection of several devices without human intervention, allowing an almost infinite capacity of data and information collection that will increasingly transform consumption habits and interaction in societies.

In this context, IoT will increasingly allow data collection in activities such as agriculture, domestic environments and devices, remote health systems, industrial activities, transport and mobility systems. Considering agricultural, industrial or city monitoring activities, IoT architectures are characterized by a large number of sensor nodes, typically measuring values such as temperature, humidity, air quality or car parks' occupancy, where information to be transmitted by each node is relatively contained. On the other hand, multimedia applications, such as video surveillance, image and video-based smart cities monitoring systems, or smart visual agriculture applications require the transmission of large amounts of information supported by high-speed short-range networks.

Massive data applications and the associated transmission to the cloud systems, produces challenges related with latency, bandwidth and network resources, data transmission costs, long transmission times leading to higher power consumption of IoT devices, service availability, as well as security and privacy issues. To cope with these problems, edge computing architectures are a promising strategy. To overcome these challenges, they bring data processing and storage close to end users and IoT devices, in order to use intelligent algorithms capable of better understanding reality and thus optimizing the processes.

In particular, in regard to the image-based systems, such as object classification and intelligent video surveillance applications, local intelligent processing can be performed, sending the extracted information to data analytic systems and consequently, reducing the transmitted information of each node. However, this approach is not always possible, since the computational cost may not be compatible with the processing capacity and power consumption constraints of the sensor nodes. In these applications, visual information must be transmitted to the network edges in order to perform more demanding processing algorithms.

On the other hand, in order to democratize the possibility for small communities to organize themselves and to collect data from activities they want to develop, there are open platforms that provide all the necessary infrastructure to receive and process information where applications can be developed with reduced costs. This is the case of The Things Network[1] (TTN), based on LoRaWAN technology. This approach is very interesting urban environments but also in rural small cities or villages, where local authorities or other organisations can provide the basic the LoRaWAN network backbone, in order to feed IoT applications with sensor nodes located in remote areas.

Taking into account the described IoT ecosystem, this paper proposes a low cost LPWAN based image acquisition and transmission prototype for low rate unconstrained delay image based applications, where a low number of images must be sent at sparse time intervals and, at the same time, access to other higher rate wireless technologies (mobile or Wi-Fi) are limited or not available. This prototype can be used in smart agriculture applications [1] [2], where sporadic image data can be transmitted to feed automatic classification algorithms in order to detect specific insects pests [3], to assess plant growth

This work has been funded by national funds through FCT - Fundacao para a Ciencia e a Tecnologia, I.P., under the Projects UIDB/05567/2020 and UIDP/05567/2020

[1] https://www.thethingsnetwork.org/

[4], or simply for image surveillance in remote areas in order to inspect animal vandalism [5]. Based on TTN infrastructure, and taking into account its available throughput limitations [6] as well as the available daily data throughput for each node, the proposed prototype is able to successfully perform image acquisition and transmission.

The Figure 1 presents the application scenario of the proposed image acquisition and transmission system. Several image acquisition nodes communicate with a LoRaWAN gateway, in this case, a TTN gateway. Each node has the ability to control the image quality according to the available bandwidth. The application layer is feed by the image data available at network server. For that, an image reconstruction service is provided, controlling the received packets from the nodes.

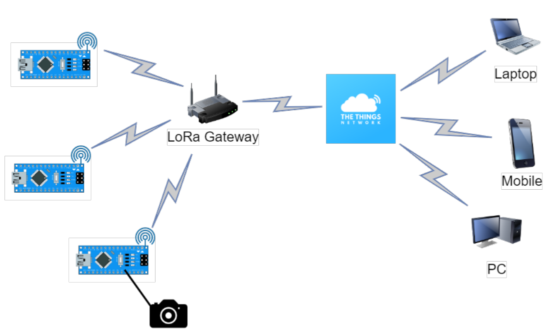

Fig. 1. Demonstration of image acquisition, as described in the above-mentioned scenario.

II. Related Work

Several works have been proposed in order to transmit visual information via LoRaWAN, taking into account the coding efficiency and transmission effectiveness in terms of packet loss and throughput. In [7], a comparison of LoRa image transmission efficiency based on different encoding methods has been proposed, namely JPEG and Webp + Base64 encoding. A point to point transmission link has been tested across a 1.5km distance. In [8], an image compression scheme, based on H.264 video encoding approach, is proposed in order to reduce the data rate to be transmitted, where image transmission is based on Wireless LAN technology. In [9], a communication framework for image transmission through LPWAN technology is proposed, jointly combining image processing techniques (classification, compressive sensing (CS), and reconstruction) and LoRa modulation parameters using a Software-Defined Radio (SDR) environment. Regarding reliable image transmission using LoRa, in [10], an efficient retransmission scheme is presented in order to reduce the overall throughput of the image transmission scheme.

III. System Architecture

The high-level architecture of the proposed solution is illustrated in Figure 2. The image acquisition node is composed by two modules: the ESP32-CAM[2] for image acquisition, and the LoRa board Arduino MKR WAN 1310[3] for communication with the public TTN LoraWAN gateway. The LoRaWAN gateway in use is the WiFx LORIX One[4], which forwards the RF packets received by the concentrator to the TTN network server through an IP/UDP connection (uplinks), and also is able to transmit RF packets that are sent by the server (downlinks).

The ESP32-CAM is based on an ESP32 micro-controller connected to a video camera and a MicroSD memory card. The communication between both modules is done using UART serial link. Each image is taken by the ESP32-CAM and sent to the LoRaWAN module MKR WAN 1310, that is connected to the TTN through the LoRaWAN gateway. The network uses an ALOHA based protocol [11], where each node can send messages using different gateways in range. In such cases, duplicated ones are later discarded by the network server. The image grabbed by the ESP32-CAM is JPEG encoded, where resolution and quality are set in order to cope with the bandwidth constraints of the wireless link. Image decoding is done at the application level, using the several packets received from the network server, through the MQTT protocol (provided as part of the TTN). The application is implemented using Node-RED.

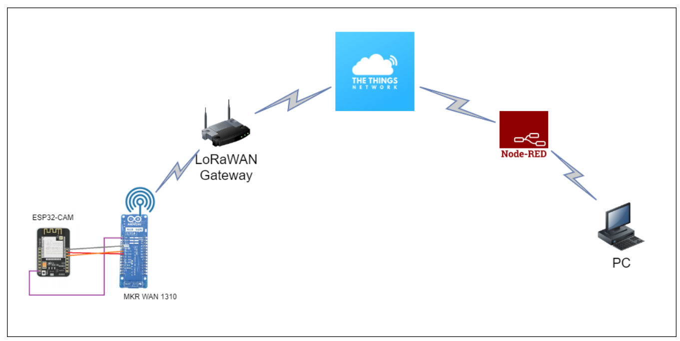

Fig. 2. System architecture.

IV. Sensor Node

A. Hardware

Figure 3 shows the image acquisition node components. The image acquisition is done using the low cost ESP32-CAM. The ESP32-CAM is based on ESP32-S micro-controller, with an integrated OV2640 camera and a microSD memory card slot. Images can be stored on the SD card in several image resolutions from QVGA (320x240 pixels) up to UXGA (1600 x 1200 pixels), and coding formats, namely RGB and JPEG. Using JPEG, is possible to set the image quality and corresponding rate. This camera has an angular lens with a 160° angle of view, and allows image captures with a resolution of up to 1600 x 1200 pixels, with a maximum refresh rate of 15 frames per second.

[2]https://randomnerdtutorials.com/esp32-cam-ai-thinker-pinout/

[3]https://docs.arduino.cc/hardware/mkr-wan-1310

[4]https://iot.wifx.net/en/products/lorix-one/

Since the ESP32-CAM has no LoRaWAN transmission capabilities, the Arduino LoRa MKR WAN 1310 module was used.

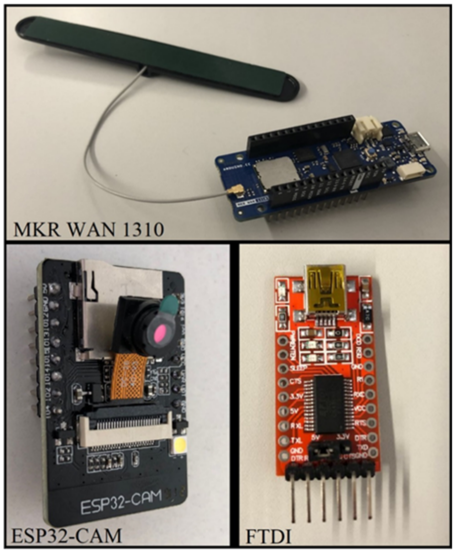

Fig. 3. Sensor node components.

Figure 4 shows the resulting PCB integration of the proposed sensor node.

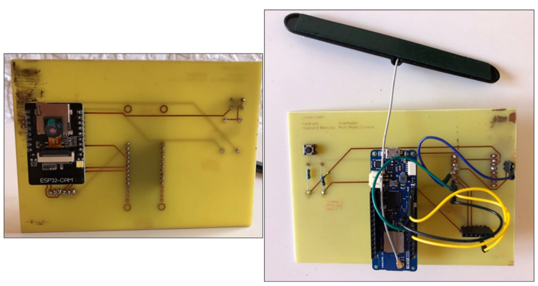

Fig. 4. Sensor node PCB integration.

B. Software

The software of the sensor node is composed by two modules:

1) The ESP32-CAM algorithm, which is responsible for image acquisition, packet definition and serial transmission for the Arduino MKR WAN 1310. A stop and wait protocol ARQ is implemented in order control the packet re-transmission when some packet transmission fails;
2) The MKR algorithm, which receives the packets from the ESP32-CAM and sends it to the LoRaWAN gateway. Additionally, the algorithm requests the ESP32-CAM for packets re-transmission when sending LoRa transmission fails.

Each of these two algorithms is further detailed in the following sections.

1) ESP32-CAM algorithm: The flowchart of the ESP32-CAM algorithm describing the process of image capture and transmission to the LoRa module is presented in Figure 5. The image is captured with a defined resolution and quality, and then divided into packets. The packet size is defined taking into account the distance between sensor node and the gateway. After setting the packet size, the ESP32-CAM knows the number of packets to be transmitted for each image. Note that packet size is agnostic related to the JPEG syntax.

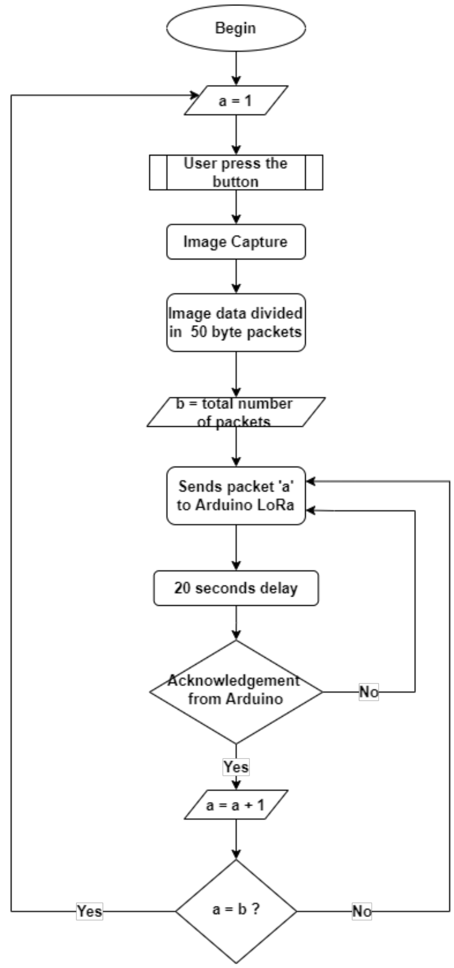

Fig. 5. ESP32-CAM algorithm flowchart.

In order to improve the packet transmission resilience of the sensor node, the ESP32-CAM waits a for certain interval to receive a confirmation from the LoRa Module about the successful transmission. When a packet fails, the ESP32-CAM sends it again.

The transmission time is packet-size dependent. The smaller the packet, the faster is the sending and, consequently, the time slot between packets. Initially, this time slot was defined as 15 seconds. However, in order to improve system performance, the size of each packet was increased (from 25 bytes to 50 bytes),as well as the sending interval to 20 seconds.

2) MKR algorithm: The Arduino MKR WAN 1310 was used in this project in order to communicate via LoRaWAN to the TTN Network Server. This device is serial connected with the ESP32-CAM via UART communication (TX and RX pins). The image data generated by the ESP32-CAM is sent in packets to the Arduino LoRa device, and these packets are then forwarded directly to the network server by the gateway.

In order to cope with packet transmission errors at the LoRa module, a packet sending control method was implemented, increasing the confidence that each packet is received by the server. Thus, the next packet is transferred only after a successful sent confirmation of the previous one.

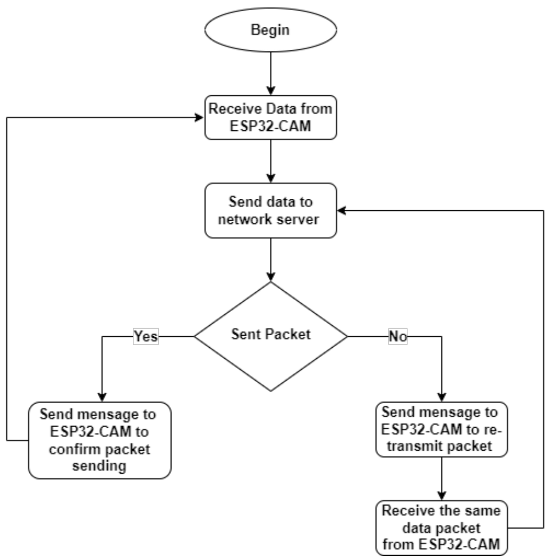

Fig. 6. MKR algorithm flowchart.

V. Image Receiver

Figure 7 shows the Node-RED MQTT client-server link for the image receiver. This node is capable of receiving data from the TTN LoRaWAN network server, allowing the application layer to save information in image format. When the LoRa device sends an image divided into packets, this transmission occurs in time slots of 20 seconds. In this process, the commands in Node-RED consist in the following steps:

- Data received from the network server;
- The image data is parsed from received MQTT messages payload (orange block 'Locate');
- Conversion from base64 to bytes (yellow block);
- Each received packet has information about its number, so it is necessary to remove it, filtering the bytes related to the image;
- Buffer receives the array of bytes;
- Image data is stored in the image format.

VI. Tests and Results

Performance tests for the sensor node prototype were firstly carried out in the Laboratory of the Polytechnic Institute of Tomar, Tomar campus, transmitting to the nearby TTN LoRaWAN gateway at the campus. After this initial batch of tests, it was possible to increase the distance from the sensor node to gateway up to a maximum distance of approximately 2500 meters. The map below (Figure 8) shows the points where images were captured in the test. The blue one represents the gateway location, while the red points are the locations at which the tests were carried out in the city of Tomar, Portugal. The lines measure the distances from the gateway to the test sites, with the green one being at distance of 260 meters, the orange line measuring 600 meters, and finally the yellow line showing the furthest point, at a distance of 2500 meters from the gateway. The LoRa parameters were set with 125 kHz bandwidth using Adaptive Data Rate (ADR) with spreading factors (SF) rages between SF=7 and SF=12. In order to make practical experimental tests, the image resolution was set to QVGA (320×240) pixels, JPEG encoded with low quality, resulting in image sizes between 2.6 and 8.4 kbyte. Higher image quality setup could be chosen, increasing the transmission time.

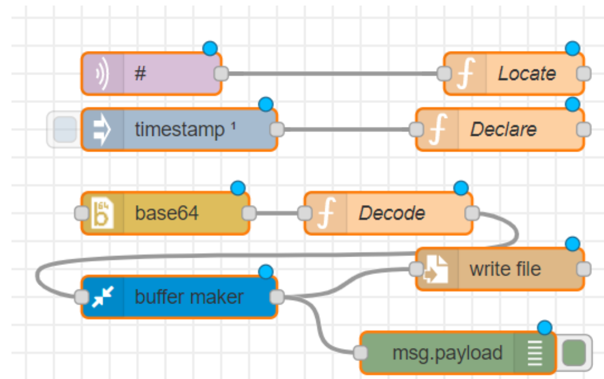

Fig. 7. Node Red MQTT client-server link.

Fig. 8. LoRaWAN gateway (blue) and sensor node test sites (red) locations.

Several experimental tests were conducted in an error free environment, with the sensor node placed close to the gateway. Based on these, the minimum interval for sending each packet has been increased from 15 to 20 seconds. Additionally, in order reduce the transmission time, the size of each packet was doubled from 25 bytes to 50 bytes. As a result of these changes, the image capture was performed by sending one packet of 50 bytes every 20 seconds. When the transmission of a packet fails, the packet is re-sent before continuing to the next one.

Figure 9 represents an image sent by the sensor node, close to the gateway (without packet re-transmission) with a total of

157 packets, with 15 seconds delay and 25-byte packet size.

Fig. 9. Image sent close to the gateway (2.6 kbyte).

Figure 10 shows an image transmitted using 180 packets, over a distance of approximately 260 meters from the gateway, with 15 seconds delay and 25-byte packet size.

Fig. 10. Image sent at 250 meters away from the gateway (3.0 kbyte).

Increasing the distance from the sensor node to the gateway to approximately 600 meters still resulted in a 100% successfully transmission, with all image data packets effectively received and stored, due to implemented packet re-transmission algorithm. The new image, shown in 11 was sent with of 205 packets with 20 seconds delay and 50-byte packet size.

Fig. 11. Image sent at 600 meters from the gateway (8.4 kbyte).

Other tests were performed at a distance of 2500 meters, in an urban environment. To find the line of sight between sensor node and gateway, a high point in the city was chosen, with the sensor node located in the Convent of Christ. In this case, the conditions were very difficult due to both urban environment and distance. Image transmission has been performed, even if the circumstances are totally unfavorable, with high re-transmissions rate. The receive image is shown in Figure 12 with 3.3 kbyte and 81 packets with 20 seconds delay and 50-byte packet size.

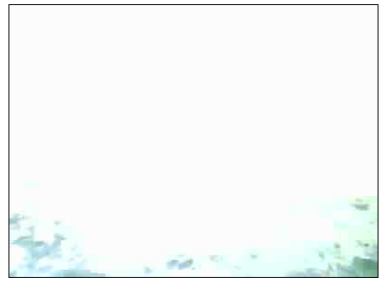

Fig. 12. Image sent at 2500 meters from the gateway (3.3 kbyte)

Additional image transmission tests with several images were performed. In these, images were transmitted at 50 and 600 meters from node to the gateway, using between 72 and 79 packets per image, corresponding to sizes between 2.9 kbyte and 3.2 kbyte respectively. Table I further details the results. As said before, transmission close to gateway is done without packet re-transmissions. With higher distances, re-transmissions have been performed and all images have been received. The transmission time (duration) was between 24 and 26 minutes.

TABLE I
PERFORMANCE TESTS AT DIFFERENT SENSOR NODE TO GATEWAY RANGES.

Test Num.	Gateway dist.(m)	Sent packets	Received packets	Image decoded	Packet re-trans.	Sending time
1	50	75	75	Yes	0	00:24:38
2	50	73	73	Yes	0	00:24:00
3	50	79	79	Yes	0	00:26:00
4	50	79	79	Yes	0	00:26:00
5	50	72	72	Yes	0	00:23:40
6	600	76	76	Yes	0	00:24:57
7	600	73	73	Yes	0	00:24:00
8	600	73	73	Yes	0	00:24:00
9	600	73	73	Yes	1	00:24:25
10	600	73	73	Yes	1	00:24:25

The next paragraphs provide a brief critical analysis on the lessons learned about the proposal of a LoRaWAN image sensor node.

Regarding the transmission distance, our tests demonstrated the feasibility of the proposed system for smaller distances (hundreds of meters), where a low number of packet retransmissions was observed. For longer distances, the existence of line of sight between the image sensor and LoRaWAN gateway was extremely important for successful transmissions. This is supported by our field tests where images were successfully transmitted using ADR with low SF values, even for distances around 1.5 kilometers, as long as line of sight existed. To mitigate this problem, a redundant network of gateways should be deployed, in order to obtain uniform coverage of the site.

As for the long time taken to transmit an image, as well as the time interval between packets, these are purposely high due to the technology used, in order to guarantee the effective communication of each packet. Thus, such system is a possible solution for problems where the transmission of an image is not time depend, e.g., gathering a daily picture from remote locations in agricultural fields. In the future, we aim to study the trade-off between image quality and transmission rate, since there are several variables that come into play, i.e., airtime, image size, compression, among others.

Nonetheless, this specific solution serves as a proof-of-concept, demonstrating that LoRaWAN and similar low-power, high range communication technologies are not limited to the typical IoT scenarios, transmitting few bytes of textual information. Nowadays high-speed mobile internet coverage is frequently available, with many real-life scenarios requiring its use. Still, for specific problems, as is the case of very large agricultural fields, it might be desirable to have an extensive mesh of image sensors to assess crop development, with nowadays provide environment information, and as demonstrated could provide images as well. Such sensors transmit to a central LoRaWAN gateway, delivering a more advanced and still low-cost solution to the problem.

VII. Future Work

Taking into account the developed prototype some future approaches can be considered. In order to improve rate-distortion performance, since the target applications use very low frequency refresh rate between images, residual coding techniques should be explored. Additionally, coding approaches that use regions of interest (ROI) can be applied. On the other hand, new rate distortion metrics taking into account the machine to machine processing must be considered for very low rate transmission environments.

Taking into account transmission efficiency, node diversity schemes can also be proposed in order to overcome the LoRaWAN limitations in terms of available bandwidth, duty cycle and bit-rate.

VIII. Conclusions

This paper proposes a low cost LoRaWAN image acquisition sensor node prototype for IoT applications, using the community TTN infrastructure. The tests were performed in real environment in urban area, and proved that the proposed low cost sensor node is a valid solution in applications scenarios where the image data that must be sent does not have rigid delay constraints, namely, when only a single image per day needs to be transmitted.

Overall, the real-life tests, performed in urban environment, showed that the proposed solution can be effectively used in visual unconstrained delay applications, where high demanding image processing tasks at the nodes are not possible, and higher rate wireless technologies are not available.

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