International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-12 Issue-12, November 2023

# Image Transmission Analysis using CSS Modulation Scheme

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***Abstract*****: *Image transmission through low-speed communication systems has been a challenge to overcome in the last few years. Actual IoT technologies are supported by LPWAN, where power consumption is a primary issue to consider. The image transmission study presented in this paper is based on Chirp Spread Spectrum (CSS) modulation scheme used by LoRa. A simulation model for image transmission is presented, where the communication channel is based on additive white Gaussian noise (AWGN), with a configurable signal-to-noise ratio (SNR). This model allows the modification of several LoRa CSS parameters such as: spreading factor (SF) bandwidth (BW) and code rate (CR). The adopted metrics for the evaluation of the proposed methodology are symbol error rate (SER), bit error rate (BER) and peak signal-to-noise ratio (PSNR). The first two figures of merit allow the study of the transmission quality and with the last one is possible to infer the received image quality. For a SF=8 and SNR=-10 dB the obtained values of SER and BER are 0.001 1e-4, respectively. These values will lead to a PSNR = 21 dB.***

***Keywords*****: *CSS, LoRaWAN, Image transmission, SER, SNR and PSNR***

## I. INTRODUCTION

Chirp Spread Spectrum is a modulation technique used in Low Power Area Network (LPWAN) more specifically in LoRaWAN. This protocol allows low data rate transmission through to achieve longer distances, typically in scenarios such as smart cities, agricultural monitoring and telemetry [1][8]. With the emergence of IoT, there have been several applications in image transmission, such as monitoring agricultural fields and monitoring forest fires. However, currently available in low-cost technologies, such as SigFox and LoRa, these technologies do not allow communication with a bit rate greater than 50 kbit/s [2]. Many of the mentioned scenarios use low data rate for telemetry purposes, where the transmitted data packet corresponds to tens or hundreds of bytes [2][11].

Image transmission requires several constrainements, such as image resolution and type of information: complete image transmission or transmission of differences between two different images. All these constraints must be considered when it is used CSS - LoRa modulation scheme to perform the base-band signal modulation.

**Manuscript received on 30 October 2023 | Revised Manuscript received on 03 November 2023 | Manuscript Accepted on 15 November 2023 | Manuscript published on 30 November 2023.**

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In work [3][9] the authors present a solution for multiplexing the image in several spreading factors (SF), to decrease the time of image transmission. Other approach is presented in [4][10] where the authors propose 239 bytes for payload and image compression. Packet loss is studied in [5], where an experimental setup is used for image transmission until 6 km for several SF.

In this paper it is presented the impact of each SF value in image transmission time for multiple resolutions. The adopted metric for image evaluation is based on peak-to-signal noise ratio (PSNR), whose values can change between 20 and 25 dB, where it is considered that the received image is perceptible [1]. The channel model based on an additive with Gaussian noise (AWGN) with a configurable signal-to-noise ratio (SNR). With these parameters it is possible to infer bit error rate (BER) and symbol error rate (SER) in function of SNR.

This paper is organized as follows. Section II presents the LoRa CSS modulation scheme, packet structure and channel access policy. The proposed model for image evaluation is presented in section III. In section IV it is presented the system evaluation based on SER, BER and PSNR. The conclusions of this work and future work are shown in section V.

## II. LORA CHIRP SPREAD SPECTRUM MODULATION

In this section it is presented the CSS modulation scheme used in LoRaWAN communication.

### A. CSS Signal

LoRaWAN uses CSS modulation scheme that modulates base-band signals in sub-GHZ ISM band [1,6]. 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 $\beta$ corresponds to the carrier frequency and slope, respectively [1].

This modulation technique is based on linear frequency variation within a specific bandwidth (*BW*) during symbol duration ($T_{symb}$), given by (2)

$$T_{symb} = \frac{2^{SF}}{BW}, \quad (2)$$

where *SF* corresponds to the spreading factor and can have values between 7 to 12 [1,6]. The frequency carrier, $f_c$, may change according to ISM frequency region standard. The BW may assume three typical values: 125 kHz, 250 kHz and 500 kHz [6].

In the demodulation process the signal is processed through a matched filter technique by correlating a down-chirp signal with the received CSS signal to detect the presence of the phase shift. In other words, the received CSS signal (up-chirp) is convoluted with a conjugate time-reversed version of the raw signal. This process allows the extraction of the LoRa symbol comprised within 0 to $2^{SF}$-1 [6].

### B. LoRaWAN Packet Structure and Channel Access

The size of each image may change according to its resolution and type (black and white or color). Due to LoRaWAN packet structure and channel access policy, the image size is a constraint that must be considered for transmission time optimization.

LoRaWAN packet structure is composed by five fields. The preamble is used for synchronization process between the gateway and each end device. The header and its respective Cyclic Redundancy Check (CRC) is used only in LoRaWAN explicit mode. The payload field allocates the transmitted data and may assume different code rates (CR). The last field structure is the payload CRC. The described data structure is represented in Fig, 1 [6].

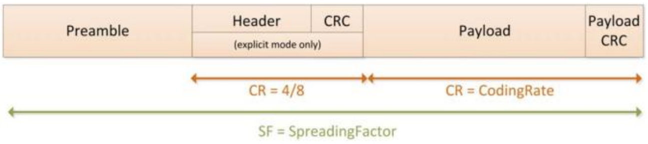

**Fig. 1. LoRa ED uplink packet structure**

Each uplink LoRaWAN packet has time duration that corresponds to preamble and payload combined, as presented in equation (3).

$$T_{packet} = T_{preamble} + T_{payload} \qquad (3)$$

The preamble and payload duration are given by equations (4) and (5), respectively. As depicted, each of this field depends on LoRaWAN symbol duration. This is an important feature to be considered since it depends on the CSS modulation parameters, namely the spreading factor. The payload length depends on the SF, message length and CRC [6].

$$T_{payload} = n_{payload} \times T_{symb} \qquad (4)$$

$$T_{preamble} = \left(n_{preamble} + 4.25\right) \times T_{symb} \qquad (5)$$

LoRaWAN channel access policy is based on 1% duty cycle [6]. This value represents the time percentage that a specific end device allocates the radio channel. Thus, after each transmission, it is mandatory fulfil a waiting time given by (6).

$$T_{wait} = T_{packet}\left(\frac{1 - duty\ cycle}{duty\ cycle}\right) \qquad (6)$$

Thus, the time duration between each LoRaWAN packet transmission is given by $T_{packet}$+$T_{wait}$, corresponding to equations (3) and (6), respectively. Assuming there are no collisions between LoRaWAN frames, it is possible to infer the transmission time of each image resolution.

In Table I it is presented the transmission time for images with 64x64, 128x128 and 256x256 pixels, with 8 bits per pixel, assuming a payload of 58 bytes for each transmission. This is the adopted value, considering typical LoRa radios [7].

**Table- I: Image Transmission time for different image resolution and SF**

| Resolution [pixels] | *SF* | *Time* [*s*] |
|---|---|---|
| 64x64 | 7 | 13.28 |
| | 8 | 22.96 |
| | 9 | 43.51 |
| 128x128 | 7 | 53.15 |
| | 8 | 91.84 |
| | 9 | 174.04 |
| 256x256 | 7 | 212.6 |
| | 8 | 367.36 |
| | 9 | 696.17 |

Increasing the SF value results in doubling the image transmission time. This factor is important to consider, as the increase in the SF value may be related to the distance between the ED and the gateway. Another factor to consider is related to the resolution of the image to be transmitted. When the resolution doubles, for the same SF, the transmission time increases by at least four times.

### C. Image Evaluation Metrics

The metric used to compare the transmitted and received images is PSNR whose expression is given by (7) [1,5]

$$PSNR_{dB} = 10 \log\left(\frac{Ps}{Pe}\right) \qquad (7)$$

where *Ps* corresponds to signal power of each pixel with 8-bit resolution. The variable *Pe* is the error mean squared root, that corresponds to the average of the squared difference in the pixel intensity between the original (I) and decoded (K) images. This variable is calculated based on the equation (8), where $l_m$ and $l_n$ correspond to the image length and width [1,5].

$$Pe = \frac{1}{l_m l_n} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i,j) - K(i,j)]^2 \qquad (7)$$

## III. PROPOSED MODEL FOR IMAGE TRANSMISSION

In Fig. 2 it is presented the proposed model for image transmission using LoRa CSS modulation scheme. First step is to decompose the image into a bit stream, where the resultant sequence is clustered in *SF* bits. Each cluster generates a decimal value corresponding to a LoRa symbol. The CSS signal is generated and applied to a AWGN channel model with a configurable SNR. The received signal is applied to the CSS demodulator, obtaining the received symbol, which allows the SER computation. For each received symbol, the binary sequence is decoded to obtain the BER value.

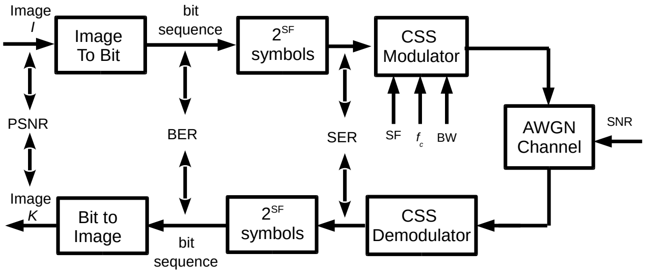

**Fig. 2.Proposed Simulation Model for Image Transmission**

## A. Image Segmentation

In this paper it is only considered images in gray scale, therefore, each one is interpreted as a matrix of *i* x *j* pixels, where each pixel is quantified by 8 bits. In Fig. 3 it is represented the image segmentation and decomposition into a bit stream. The presented example corresponds to the transmitted image *I* with *j* columns and *i* lines.

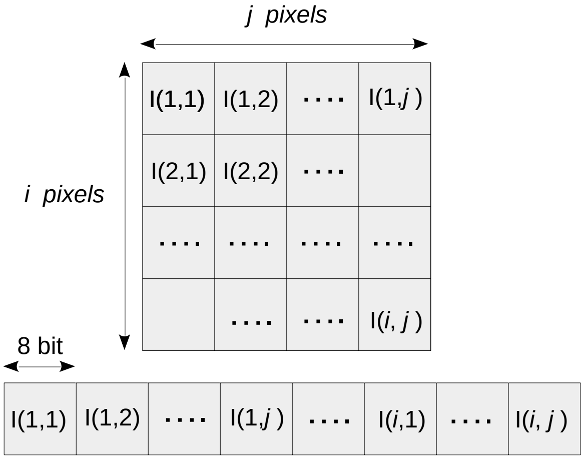

**Fig. 3.Image Segmentation**

The decomposed image corresponds to a matrix with 1 line and *i* x *j* columns. As an example, for an image with 64 x 64 pixels, the decomposed matrix has 1 line and 4096 columns. For an 8-bit pixel this image size will be converted in 32768 bit.

## B. Simulation Results

The simulation results of the proposed model are shown in Fig. 4, where each image corresponds to the received signal. These results are obtained with an image with 128x128 pixels and SF=8, for different SNR values.

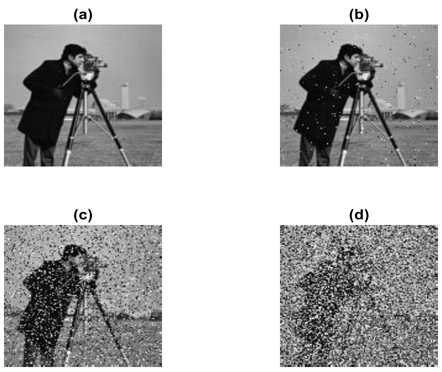

**Fig. 4.Decoded Images under AWGN for SF=8**

In Table II are presented, for each image, the correspondent SNR, SER BER and PSNR. As depicted, decreasing the SNR in 3dB the PSNR decrease but with a higher rate.

**Table- II: SER and BER for different SNR values (SF=8)**

| Image | *SNR* [dB] | *SER* | *BER* | *PSNR* [dB] |
|---|---|---|---|---|
| (a) | -9.082 | 1.22e-7 | 3.82e-5 | 38.83 |
| (b) | -12.08 | 0.0178 | 0.009 | 20.56 |
| (c) | -15.08 | 0.27 | 0.13 | 9.1 |
| (d) | -18.08 | 0.68 | 0.34 | 5.02 |

## IV. SYSTEM EVALUATION

In this section it is presented the system evaluation based on SER and PSNR as a function of SNR and SF.

### A. SER Evaluation

Fig. 5 denotes the SER evolution vs SNR for SF values of 8, 9 and 10. As depicted for SNR values lower than -20 dB, SER is greater than 10%, corresponding to the AWGN channel effect. When SNR is greater than -17 dB it denoted that, for the same SER it is necessary to increase the SNR in 3dB. As an example, for SF=7 and SER=0.01 this is achieved with SNR = -12dB. However, for SF=8, for the same SER value, decreases 3dB, corresponding to SNR = -15dB. This is an important factor to consider, since increasing SF by one SER, and consequently BER, will decrease. However, increasing SF image transmission time will double, as presented in Table I.

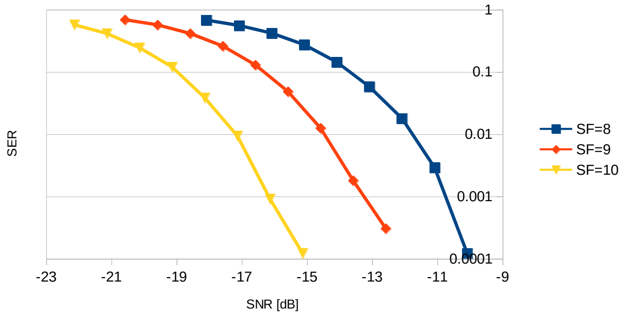

**Fig. 5. SER evolution vs SNR for different SF values**

### B. PSNR Evaluation

Image analysis based on the proposed model is presented in Fig. 6 as a function of PSNR and SNR, for different SF values. The PSNR values are obtained by expression (8). As depicted, the impact of LoRa CSS modulation scheme is noticed for values of PSNR above 15 dB, since when SF decreases PSNR decreases 3dB. When PSNR is below 5 dB the received image is imperceptible due to AWGN. The obtained results are like work [1], however it was not necessary to make any image compression.

Assuming the criteria proposed in papers the papers [1] and [6], for SF = 8 the minimal PSNR is obtained for SNR=-12dB.

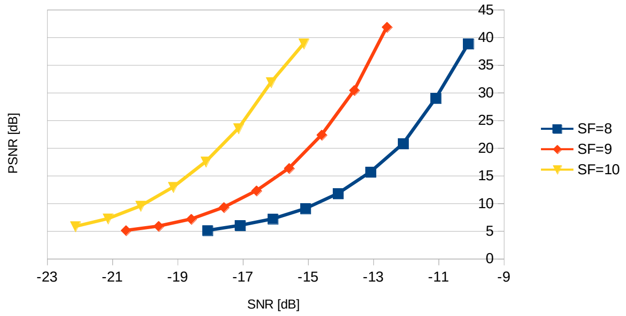

**Fig. 6. PSNR evolution vs SNR for different SF values**

## V. CONCLUSIONS

This work presented an analysis of image transmission using LoRa CSS modulation scheme. The main parameters used in this study were SER, BER and PSNR as a function of AWGN SNR values and LoRa spreading factor. In LoRaWAN protocol, SF may increase to achieve longer distances. However, increasing the SF value leads to an increase in image transmission time, reaching values of more than an hour for 58-byte packets. Therefore, a compression relationship must be established between the SF value and the transmission time. If there is a need to increase the SF value by more than one unit, it is suggested to introduce more gateways so that it is not necessary to increase the SF value. Regarding to PSNR, the obtained results show that for SNR values higher than -17dB the AWGN effect is negligible, since PSNR is greater than 20dB. In these conditions it is recommended that SF decreases to reduce the transmission time. Also, it is important to consider the battery lifetime of the end device responsible for this type of communication.

As future work it is proposed the study of prior image processing, to transmit only the differences between the last image and the new one. This option may involve greater pre-processing but will optimize transmission time.

## DECLARATION STATEMENT

| | |
|---|---|
| Funding/ Grants/ Financial Support | No financial support or any kind of funds, grants, or financial support received. |
| Conflicts of Interest/ Competing Interests | There is no conflicts of interest to the best of my knowledge. |
| Ethical Approval and Consent to Participate | The article does not require ethical approval and consent to participate. |
| Availability of Data and Material/ Data Access Statement | Not relevant. |
| Authors Contributions | I am only the sole author of the article. |

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