**IRJCS:** International Research Journal of Computer Science
Volume 10, Issue 01, January 2023
ISSN: 2393-9842
https://www.irjcs.com/archives

# On the Use of Polar Code for LoRa PHY

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**Publication History**
Manuscript Reference No: IRJCS/RS/Vol.10/Issue01/JACS10080
Research Article | Open Access | Double-blind Peer-reviewed
Article ID: IJIRAE/RS/Vol.10/Issue01/JACS10080
Received: 07, January 2023 | Accepted: 14, January 2023 | Published: 31, January 2023
Volume 2023 | Article ID JACS10080 http://www.irjcs.com/volumes/Vol10/iss-01/01.JAACS10080.pdf
**Article Citation:** Jung Suk Joo(2023).On the Use of Polar Code for Lora PHY. International Research Journal of Computer Science (IRJCS), 10, 01-03. **doi:** https://doi.org/10.26562/irjcs.2023.v1001.01
**BibTex key: joo2023polar**
**Academic Editor-Chief**: Dr.A.Arul Lawrence Selvakumar, IRJCS, AM Publications, India
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**Abstract:** LoRa (long range) PHY adopts simple hamming codes with maximum one-bit error correction capacity, which is one of the main causes of poor performance in fading environments. As one approach to improve performance in fading environments, in this paper, we will investigate the use of a polar code for LoRa. Specifically, through computer simulations, we will compare the performance gain in Rician fading channels according to the application of a polar code with code rate 0.5 instead of the original (8,4) hamming code in LoRa PHY.
**Keywords:** LoRa PHY, hamming code, polar code, fading environments

## I. INTRODUCTION

Recently, low power wide area (LPWA) network technologies working on the unlicensed bands have been actively developed for supporting internet of things (IoT) communications, and LoRa system is the most widely used one [1],[2]. Although LoRa has many attractive advantages, such as long-range capability, low power transmission, and strong anti-interference ability, it experiences severe performance degradation in fading environments mainly due to using a relatively weak channel-coding scheme it adopts hamming code with maximum one-bit error correction capability [3]. Polar codes are constructed using the channel polarization transform where bits' positions in a codeword are divided into two groups, one of highly reliable positions (called good channels) and one of unreliable positions (called bad channels) information bits are transmitted over good channels and fixed known bits (called frozen bits) are transmitted over bad channels [4],[5]. Polar code have attracted much interest due to good performance for short block sizes and relatively low encoding/decoding complexity, and were also adopted as channel coding schemes for control channels of 5G new radio (NR) systems. In this paper, we consider systems where flying objects such as drones are used as interrogators to collect information from widely distributed IoT devices and the line-of-sight (LOS) path is guaranteed. Thus, in Rician fading environments, we will investigate the use of polar code for LoRa. Specifically, through computer simulations, we will compare FER performances according to the application of a polar code with code rate 0.5 instead of the original (8,4) hamming code in LoRa.

## II. LORA PHY LAYER

LoRa employs chirp spread spectrum (CSS) based modulation called LoRa modulation. The chirp signal refers to a frequency-modulated signal whose frequency varies linearly with time, and the LoRa system transmits digital information by changing the starting frequency of the base chirp signal according to the information bits to be transmitted. In this paper, we consider the LoRa PHY structure described in [6], whose block diagram is shown in Fig. 1. As shown in the figure, source data is first encoded by hamming code in which message length is fixed to 4 and the number of parity bits expressed as CR in LoRa can be one of {1,2,3,4}. Note that both (7,4) hamming code (CR=3) and (8,4) hamming code (CR=4) have one-bit error correction capability. In addition, $SF\ (\in\{7,8,\mathrm{L}\ ,12\})$ represents the spreading factor of LoRa system each LoRa symbol consists of $2^{SF}$ chips and conveys *SF* bits information.

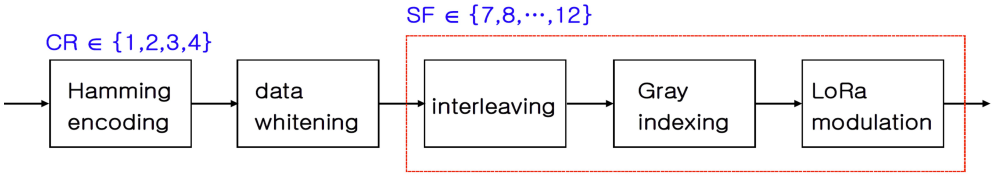


Fig. 1 Block diagram of the LoRa PHY [6]

## III. POLAR CODE FOR LORA

Polar codes only allow for power of two code length, i.e., $N=2^n$. In this paper, we consider an *(N,K)* polar code it uses the basic polarization kernel for a binary eraser channel (BEC) shown in Fig. 2 [4],[5]; with erasure probability $\delta$,

It identifies *K* good channels and *N-K* bad channels; *K* information bits are transmitted over good channels and *N-K* frozen bits (here, 0's) are transmitted over bad channels.

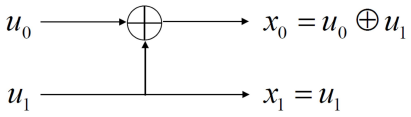


Fig. 2 Basic polarization kernel

We use the successive cancellation (SC) decoding scheme. The trellis of *(N,K)* polar code consists of *n* stages and *N* levels ($N = 2^n$), and the SC decoder performs soft and hard message passing over the trellis [5]. At the start of SC decoding, initial log-likelihood ratio (LLR) values are calculated from the received channel outputs for soft message passing. Note that LoRa demodulation gives only hard decision values for information bits conveyed on the chirp signal. So, in this paper, we use hard decision values for information bits as initial LLR values for soft message passing, unlike the original SC decoding: for hard decision value of '0', the initial LLR is set to +1, and for hard decision value of '1', the initial LLR is set to -1.

## IV. PERFORMANCE COMPARISON

The LoRa PHY frame is composed of {preamble, PHY header, PHY payload, CRC} [3]. Since the performance of channel coding schemes is our main concern, we assume perfect synchronization and consider only the case PHY payload is transmitted through the process described in Fig. 1. The specific simulation parameters are as follows: center frequency is 915 MHz in ISM band; channel bandwidth is set at 250 KHz ($T_{chip} = 4\ \mu\text{sec}$); SF is set at 10 ($T_{sym} = T_{chip} \times 2^{SF} = 4.096$ msec); the length of PHY payload is fixed at 32 Bytes (= 256 bits). In addition, the code rate of channel codes is set at 0.5 (8,4) hamming code and (512,256) polar code are considered. For the (512,256) polar code encoding, the erasure probability was set at $\delta = 0.5$ for channel polarization, and 256 good channels were selected for transmitting PHY payload of 256 bits.

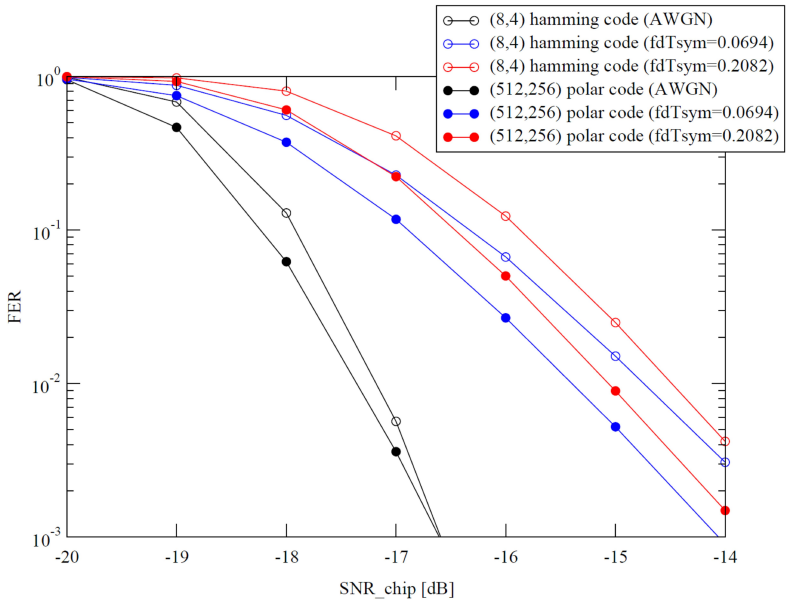


Fig. 3 FER Performance comparison according to the application of polar code in LoRa (here, K-factor of Rician fading channels is fixed at 13 dB).

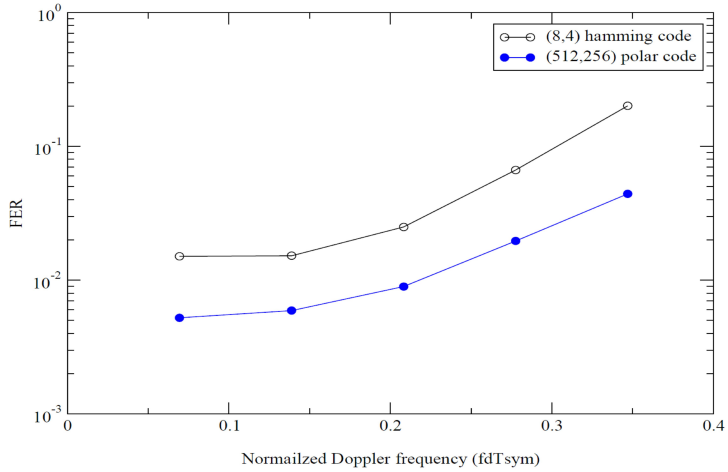


Fig. 4 FER Performance comparison according to the normalized Doppler frequency (chip SNR = -15 dB).

Note that flying objects such as drones can be used as interrogators to collect information from widely distributed IoT devices, and in these cases, LOS path is generally guaranteed. Therefore, we consider Rician fading channels with a relatively large K-factor (here, K-factor is set at 13 dB) for modeling the environments where the LOS path is dominant. Figure 3 shows frame error rate (FER) performance comparison between the original LoRa using (8,4) hamming code and the modified LoRa adopting (512,256) polar code. Here, the normalized Doppler frequency is defined as the maximum Doppler frequency normalized by the LoRa symbol time, i.e., $f_d T_{sym}$. As expected, the modified LoRa outperformed the original LoRa: specifically, at FER=0.01, performance gain is about 0.8 dB for both the cases of $f_d T_{sym} = 0.0694$ $f_d T_{sym} = 0.2082$. Figure 4 compares FER performances as the normalized Doppler frequency was varied, while the chip SNR was fixed at 15 dB. It can be seen from the results that the using of polar code achieved consistent performance gain regardless of the normalized Doppler frequency.

## V. CONCLUSION

In this paper, we examined the use of a polar code for LoRa instead of the original hamming codes. It was demonstrated through computer simulations that the using of a polar code could improve FER performance in Rician fading environments. In addition, if a polar code is adopted in LoRa, we can flexibly adapt the code rate according to channel conditions, since the number of information bits transmitted, *K* in *(N,K)* polar code can take any value in $\{1,2,\mathrm{L}\ ,N\}$. Therefore, in applications where flying objects are used as interrogators, it is worthwhile to consider the using of a polar code as one of the approaches to improve receiver performance while minimizing the modification of LoRa PHY.

## ACKNOWLEDGMENT

This work was supported by Hankuk University of Foreign Studies Research Fund of 2022

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