A STUDY ON THE INTERLEAVING SCHEME OF LORA PHY LAYER

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Abstract—Long range wide area network (LoRaWAN) is one of the most widely used low power wide area (LPWA) network technologies in the unlicensed ISM bands. LoRaWAN adopts chirp spread spectrum (CSS) based physical layer specification which is Semtech’s proprietary technology; so the details of the physical layer are not fully disclosed. In this paper, we will investigate the performance of the LoRa interleaver which is one of the main blocks of LoRa physical layer. Specifically, through computer simulations, we will compare a conventional block interleaver and the LoRa interleaver in terms of FER performance in AWGN and Rician fading environments.

Keywords— LPWA; LoRaWAN; LoRa PHY layer; LoRa interleaver;

I. INTRODUCTION

As the Internet-of-things (IoT) and machine-to-machine (M2M) industries have evolved, the need for low power wide area (LPWA) networks has increased in order to extend the lifetime of devices and ensure connectivity across a wide range of areas. Most LPWA networks have been developed to operate in the unlicensed ISM band, and long range wide area network (LoRaWAN) is one of the most widely used LPWA network technologies [1-4]. LoRaWAN’s MAC layer is standardized and published by the LoRa Alliance [5], but the physical layer based on chirp spreading spectrum (CSS) was patented by Semtech [6]. So the details of the LoRa physical layer are not fully disclosed.

In this paper, we consider the LoRa interleaver which is one of the main blocks of LoRa physical layer; in order to be robust to frequency offset and Doppler frequency, it writes diagonally from left to right and top to bottom, and reads out column wise from left to right. Through computer simulation of the overall LoRa physical layer in AWGN and Rician fading environments, we will compare a conventional block interleaver and the LoRa interleaver in terms of frame error rate (FER) performance, and verify the usefulness of the LoRa interleaver.

II. LORA PHY LAYER

LoRa employs CSS based modulation, called as 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 chirp signal according to the digital data to be transmitted. Thus, a LoRa symbol means a chirp signal generated with the assigned starting frequency according to the digital data. In addition, when a LoRa symbol conveys $SF$ bits of information, $SF$ is called the spreading factor of LoRa system ($SF \in \{7,8,11,12\}$). LoRa PHY consists of Hamming encoding, data whitening, interleaving, Gray indexing, and CSS based LoRa modulation [7].
Fig. 1 shows the block diagram of the LoRa physical layer. As shown in the figure, input bits are first encoded by Hamming code whose message length is fixed to 4. The number of parity bits is expressed as the code rate (CR) of the LoRa system, and four modes according to the CR value \((CR \in \{1, 2, 3, 4\})\) are supported: (5,4) code is a simple parity code, and (7,4) code is a (7,4) hamming code with a 1-bit error correction capability; (6,4) code and (8,4) code are a shortened Hamming code and a parity extended Hamming code of (7,4) hamming code, respectively [6].

![Block diagram of the LoRa PHY layer](image)

After Hamming encoding, encoded data go through a data whitening filter. Since the exact filter structure is not disclosed, in this paper, the CCITT whitening method [8] is used for data whitening: it is a 9-bit linear feedback shift register (LFSR) structure with a characteristic feedback polynomial, \(g(x) = x^9 + x^5 + 1\), and the initial values of the registers are all set to 0. The interleaving is performed on \(SF\) code words (channel coded and whitened data blocks, each of \((4 + CR)\) bits), and the output is grouped by \(SF\) bits and mapped to LoRa symbols by using Gray indexing. Differences between the conventional block interleaver and the LoRa interleaver are illustrated in Fig. 2. The conventional block interleaver writes row wise from top to bottom and reads out column wise from left to right. On the contrary, the LoRa interleaver writes diagonally from left to right and top to bottom; when it reaches the bottom row during the ‘write’ process, it jumps up to the first row of the next column.

Gray indexing [9] is a method of symbol mapping such that bit sequences corresponding to adjacent symbols differ by only one bit. For a index, \(s = 0, 1, L, 2^{SF}-1\) given by Gray indexing for \(SF\) bits, the \(s\)-th LoRa symbol, \(x_s(n)\), is transmitted [7]:

\[
x_s(n) = e^{j2\pi\left[\frac{1}{2^{SF}}n + \frac{1}{2^{SF}}s\right]}, \quad n = 0, 1, L, 2^{SF}-1
\]

where \(s\) and \(n\) are a LoRa symbol index and a chip index, respectively. Note that the equation (1) is obtained by setting the starting frequency of the \(s\)-th LoRa symbol to \(f_{\text{start},s} = s \times \left(\frac{BW}{2^{SF}}\right)\) and the sampling frequency to the bandwidth of LoRa system (i.e., \(f_s = BW\)) [7]. In addition, each LoRa symbol consists of \(2^{SF}\) chips.

![Comparison between the conventional block interleaver and the LoRa interleaver](image)

Fig. 2 Comparison between the conventional block interleaver and the LoRa interleaver.
In LoRa systems, as the frequency offset (and/or Doppler frequency) gets larger, the probability when a LoRa symbol is incorrectly detected, it falls into the adjacent symbol bins (so-called ±1 position demodulation error) increases. In the case of ±1 position demodulation errors, bit errors concentrate around the least significant bit (LSB) of the decoded SF bits due to Gray indexing [6]. As shown in Fig. 2, while LSBs having a higher error probability concentrate on the first codeword in the conventional block interleaver, the LoRa interleaver spreads LSBs in SF codewords. Thus, the LoRa interleaver can be expected to outperform the conventional block interleaver in large frequency offset and Doppler frequency environments where ±1 position demodulation errors are dominant.

III. PERFORMANCE COMPARISON ACCORDING TO INTERLEAVING SCHEMES

The LoRa PHY frame is composed of {preamble, PHY header, PHY payload, CRC} [5]. Preamble consists of predefined LoRa symbols for initial synchronization at the receiver, and the part of {PHY header, PHY payload, CRC} is transmitted through the process shown in Fig. 1.

To examine the LoRa PHY performance according to interleaving schemes, computer simulations were performed for a LoRa system with 250 KHz channel bandwidth operated in 915 MHz ISM band. Code rate, $CR$ was fixed at 3 (that is, (7,4) systematic Hamming code is used), and the length of PHY payload was fixed to 50 bytes. Both cases of a static interrogator and a moving interrogator (such as a drone) were considered. Table 1 summarizes the simulation environments.

Fig. 3 shows the simulation results for the static interrogator case (for which AWGN channel was assumed). As shown in the figure, performance curves for the conventional block interleaver and the LoRa interleaver almost overlap regardless of the value of SF. This is because if LoRa symbol detection error occurs in AWGN environments, the probability of being determined as any one of the symbols except for itself is the same; in other words, ±1 position demodulation error is not dominant.

Fig. 4 shows the simulation results for the moving interrogator case. Here, SF was fixed at 10 and Rician fading channel with K-factor = 20 (= 13 dB) was considered. As expected, the LoRa interleaver reveals much better performance than the conventional block interleaver as the velocity (more precisely, LoRa symbol-normalized Doppler frequency, $f_d T_{sym}$) increases. This is mainly due to the fact that most of LoRa symbol detection errors in high $f_d T_{sym}$ environments (but, not exceed 0.5) cause ±1 position demodulation error.

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<th>Table 1 Simulation environments.</th>
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<td>carrier frequency</td>
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In this paper, we examined the performance of the LoRa interleaver, compared to that of the conventional block interleaver. In AWGN environments where random position demodulation errors are dominant, both of them reveal the same performance. On the other hand, in Rician fading environments where 1± position demodulation errors are dominant, the LoRa interleaver outperforms the conventional block interleaver. Specifically, the performance gap increases as $f_d T_{sym}$ exceeds 0.3.

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**REFERENCES**