Paper

An Efficient Chaotic Interleaver for Image Transmission over IEEE 802.15.4 Zigbee Network

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Abstract—This paper studies a vital issue in wireless communications, which is the transmission of images over wireless networks. IEEE ZigBee 802.15.4 is a short-range communication standard that could be used for small distance multimedia transmissions. In fact, the ZigBee network is a wireless personal area network (WPAN), which needs a strong interleaving mechanism for protection against error bursts. This paper presents a novel chaotic interleaving scheme for this purpose. This scheme depends on the chaotic Baker map. A comparison study between the proposed chaotic interleaving scheme and the traditional block and convolutional interleaving schemes for image transmission over a correlated fading channel is presented. The simulation results show the superiority of the proposed chaotic interleaving scheme over the traditional schemes.

Keywords—block interleaving, chaotic interleaving, convolutional interleaving, fading channels, ZigBee.

1. Introduction

With the increase in utilization of wireless networks, there are two important factors that deserve consideration; power efficiency and throughput efficiency. Short-range wireless networks such as Bluetooth and ZigBee are widely used for health care and medical applications [1], [2]. The ZigBee network is a low-rate WPAN (LR-WPAN) that is used for short-range and low-cost data communication.

Low power consumption in ZigBee networks can be achieved by allowing a device to sleep, which means waking into active mode for brief periods. Enabling such low duty cycle operation is at the heart of the ZigBee standard [3]. ZigBee is built on top of the IEEE 802.15.4 standard. It offers the additional functionality to implement mesh networking rather than point-to-point networking found in most Bluetooth and Wi-Fi applications. The ZigBee specification document is short, allowing a small and simple stack, in contrast to the other wireless standards such as Bluetooth [4].

The IEEE 802.15.4 standard is intended to conform to established regulations in Europe, Japan, Canada, and the United States. It defines two physical (PHY) layers; the 2.4 GHz and 868/915 MHz band PHY layers. Although the PHY layer chosen depends on local regulations and user preference, only the higher data rate, worldwide, unlicensed 2.4 GHz industrial, scientific and medical frequency band is considered [5]. A total of 16 channels are available in the 2.4 GHz band, numbered from 11 to 26, each with a bandwidth of 2 MHz, and a channel separation of 5 MHz. The channel mapping frequencies are given in Table 1. LR-WPAN output powers are around 0 dBm. LR-WPAN typically operates within a 50-m range. The transmit scheme used is the direct sequence spread spectrum (DSSS) [6].

Table 1
IEEE 802.15.4 frequency bands and data rates

PHY [MHz]	Freq. band [MHz]	Mod.	Channels	Bit rate [kbit/s]
868/915	868-868.6	BPSK	1	20
	902-928	BPSK	10	40
2450	2400-2483.5	O-QPSK	16	250

The ZigBee network involves little or no infrastructure. It also has a primitive error control mechanism, which is the automatic repeat request (ARQ). As a result, this mechanism is unable to reduce the channel effects. So, there is a need for either a coding or interleaving mechanism to combat the bad channel effects [7].

Several papers have studied the transmission of images with the IEEE 802.15.4 standard. In [8], the authors studied the process of image fragmentation for transmission over the ZigBee network. In the case of transmission over mobile networks, there is a probability of burst errors. The burst errors have a bad effect on the transmitted data and image. In this paper, we try to decrease the effect of error bursts on the transmission of images by introducing a powerful chaotic interleaver.

The paper is organized as follows. In Section 2, ZigBee packet format is introduced. In Section 3, the proposed modifications are presented. In Section 4, the simulation assumptions and the simulation results are presented. Finally, the conclusion is presented in Section 5.

2. ZigBee Packet Format

The structure of the ZigBee packet is shown in Fig. 1. The header contains three fields; a preamble of 32 bits for synchronization, a packet delimiter of 8 bits, and a physical header of 8 bits. The physical service data unit (PSDU)

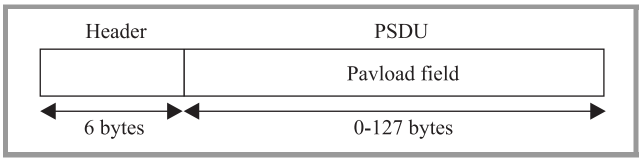

Fig. 1. ZigBee packet format.

field contains a payload of 0 to 127 bytes length. The ZigBee network uses an error detection/retransmission technique. To ensure successful reception of data, an acknowledged frame delivery protocol is supported to increase transfer reliability [9]. The ZigBee network uses the DSSS technique for data transmission, because it increases the immunity to interference. It is based on the multiplication of the original binary stream with a wideband pseudo noise (PN) spreading code, which results in a wideband continuous time scrambled signal. DSSS significantly improves protection against interfering signals, especially narrowband signals. It also provides a multiple access capability, when the several different spreading codes are being used, simultaneously. It also provides a transmission security. DSSS is also used as a technique to generate ultra wide band (UWB) signals [9]. As shown in Fig. 2, the output signal of the modulator $m(t)$ has a much larger bandwidth than the input signal $d(t)$ [10]–[12].

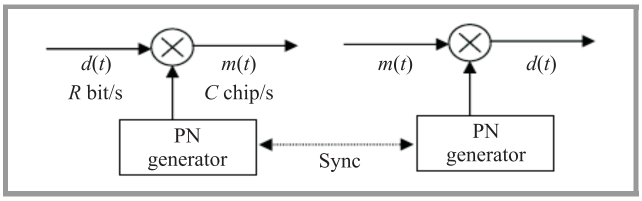

Fig. 2. The direct sequence spread spectrum technique.

Figure 2 shows the stages of the DSSS technique. At the receiver, the wideband signal is despread as shown in the figure. The chip rate C is much larger than the input data rate R.

3. Proposed Modifications

The transmission of multimedia over unreliable data links has become a topic of paramount importance. This type of transmission must reconcile the high data rates involved in multimedia contents and the noisy nature of the channels, be it wireless or mobile. In this paper, we try to improve the transmission of images over the ZigBee network with different interleaving schemes. We study the feasibility of data interleaving prior to transmission over ZigBee networks. The paper presents a new chaotic interleaver and compares it to the traditional block and convolutional interleavers.

3.1. Block Interleaver Scheme

The block interleaving can be used for image transmission with the ZigBee network. After converting the image into a binary sequence, this sequence is rearranged into a matrix in a row-by-row manner, and then read from the matrix in a column-by-column manner. Now take a look at how the block interleaving mechanism can correct error bursts. Assume an error burst affecting four consecutive bits (1-D error burst) as shown in Fig. 3b with shades. After de-interleaving as shown in Fig. 3c, the error burst is effectively spread among four different rows, resulting in a small effect for the 1-D error burst. With a single-error correction capability, it is obvious that no decoding error will result from the presence of such 1-D error burst. This simple example demonstrates the effectiveness of the block interleaving mechanism in combating 1-D error bursts. Let us examine the performance of the block interleaving mechanism, when a 2-D (2×2) error burst occurs [13], as shown in Fig. 3b with shades. Figure 3c indicates that this 2×2 error burst has not been spread, effectively, so that there are adjacent bits in error in the first and second rows. As aeresult, this error burst can not be corrected using a single-error correction mechanism. That is, the block interleaving mechanism can not combat the 2×2 error bursts.

3.2. Convolutional Interleaver Scheme

The convolutional interleaver is constructed by T parallel branches. Each line contains a shift register with a predefined length [14]. The input data is fed into the branches of the interleaver and the output data is taken from the outputs of these branches. In the computer simulations, the length of the interleaver input is 1024 bits, which is the length of the whole payload in ZigBee packets [15].

3.3. Chaotic Interleaver Scheme

As mentioned in the previous subsection, the block interleaver is not efficient with 2-D error bursts. As a result, there is a need for an advanced interleaver for this task. The 2-D chaotic Baker map in its discretized version is a good candidate for this purpose. After rearrangement of bits into a 2-D format, the chaotic Baker map is used to randomize the bits. The discretized Baker map is an efficient tool to randomize the items in a square matrix. Let $B(n_1, \ldots, n_k)$, denote the discretized map, where the vector, $[n_1, \ldots n_k]$, represents the secret key, S_{key}. Defining N as the number of data items in one row, the secret key is chosen such that each integer n_i divides N, and $n_1 + \ldots, +n_k = N$.
Let $N_i = n_1 + \ldots, +n_{i-1}$. The data item at the indices (r, s), is moved to the indices [16]–[20]:

$$B(r, s) = \left[\frac{N}{n_i}(r - N_i) + s \bmod \left(\frac{N}{n_i}\right),\ \frac{n_i}{N}\left(s - s \bmod \left(\frac{N}{n_i}\right)\right) + N_i\right], \quad (1)$$

where $N_i \le r < N_i + n_i$, $0 \le S < N$, and $N_1 = 0$.

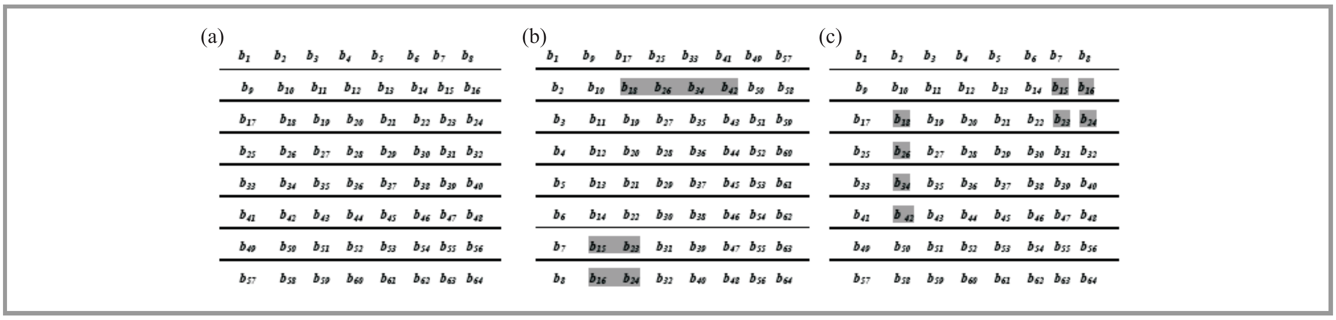

Fig. 3. Block interleaving of an 8×8 matrix: (a) the 8×8 matrix, (b) block interleaving of the matrix, (c) effect of error bursts after de-interleaving.

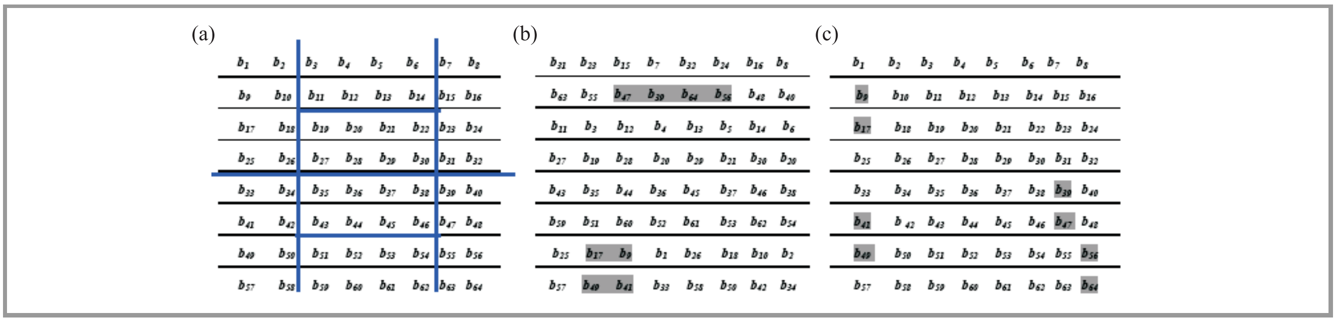

Fig. 4. Chaotic interleaving of an 8×8 matrix: (a) the 8×8 matrix divided into rectangles (shaded bits are bits affected by error bursts), (b) chaotic interleaving of the matrix, (c) effect of error bursts after de-interleaving.

In steps, the chaotic permutation is performed as follows:

1. An $N \times N$ square matrix is divided into N rectangles of width n_i and number of elements N.

2. The elements in each rectangle are rearranged to a row in the permuted rectangle. Rectangles are taken from left to right beginning with upper rectangles then lower ones.

3. Inside each rectangle, the scan begins from the bottom left corner towards upper elements.

Figure 4 shows an example for chaotic interleaving of an 8×8 square matrix (i.e., $N = 8$). The secret key, $S_{key} = [n_1, n_2, n_3] = [2, 4, 2]$. Note that, the chaotic interleaving mechanism has a better treatment to both 1-D and 2-D error bursts than the block interleaving mechanism. Errors are better distributed to bits after de-interleaving in the proposed chaotic interleaving scheme. As a result, a better peak signal to noise ratio (PSNR) of received images can be achieved with this proposed mechanism. Moreover, it adds a degree of security to the communication system. At the receiver of the ZigBee system, a chaotic de-interleaving step is performed.

4. Simulation Results

In this section, the computer simulation results are presented. An important assumption used in the simulation is that a packet is discarded if there is an error in either the header or the payload field [21]. This is a realistic assumption to simulate the real ZigBee system operation. A correlated Rayleigh fading channel is used. The channel model utilized is the Jake's model [22]–[23]. The assumed mobile ZigBee device velocity is 10 miles/hour, and the carrier frequency is 2.46 GHz. The Doppler spread is 36.6 Hz. Figure 5 gives the original cameraman image used in the experiments. It is the Matlab image and it format is tag image file format (TIF).

Fig. 5. Original cameraman image.

The image binary sequence to be transmitted is fragmented into packets. The PSNR of the received images is used as an evaluation metric in this paper.

In the first computer simulation, the cameraman image is transmitted over a correlated fading channel with signal to noise ratio (SNR) = 10 dB. Three scenarios of no interleaving, block interleaving, convolutional interleaving and chaotic interleaving are considered for comparison. The results of this experiment are shown in Fig. 6. From these results, it is clear that the effect of all interleaving schemes is approximately equal at low SNR values.

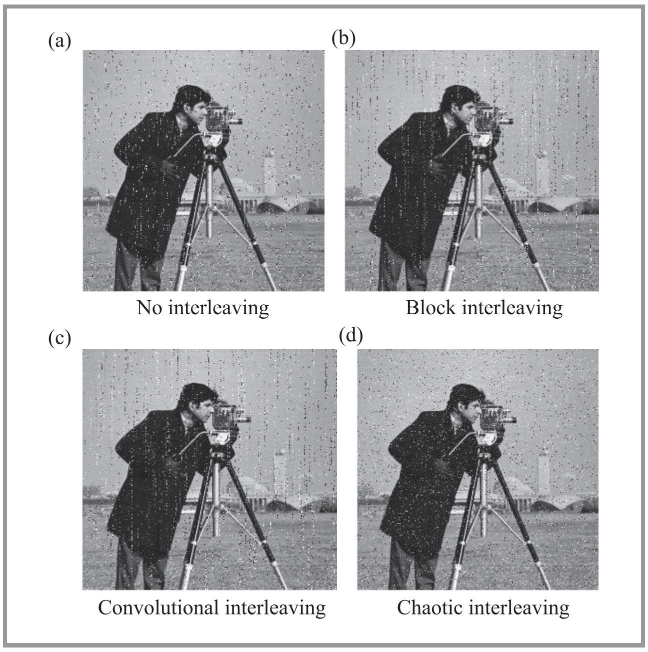

Fig. 6. Received cameraman image over a correlated fading channel at SNR = 10 dB with (a) PSNR = 21.3 dB, (b) PSNR = 21.4 dB, (c) PSNR = 21.1 dB, and (d) PSNR = 21.5 dB.

Other experiments are repeated with SNR = 20 and 30 dB and the results are shown in Figs. 7 and 8, respectively.

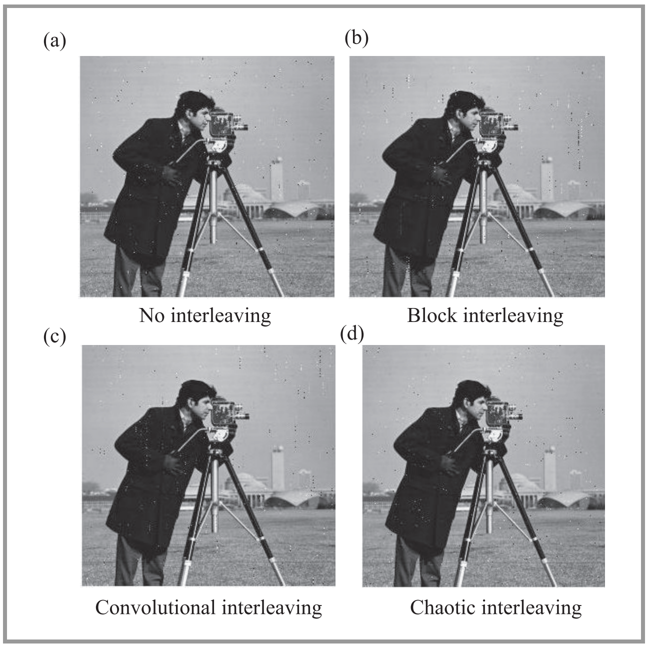

Fig. 7. Received cameraman image over a correlated fading channel at SNR = 20 dB with (a) PSNR = 31.1 dB, (b) PSNR = 31.5 dB, (c) PSNR = 32.1 dB, and (d) PSNR = 33.2 dB.

From these results, we notice that the chaotic interleaver outperforms the other interleavers at moderate to high SNRs.

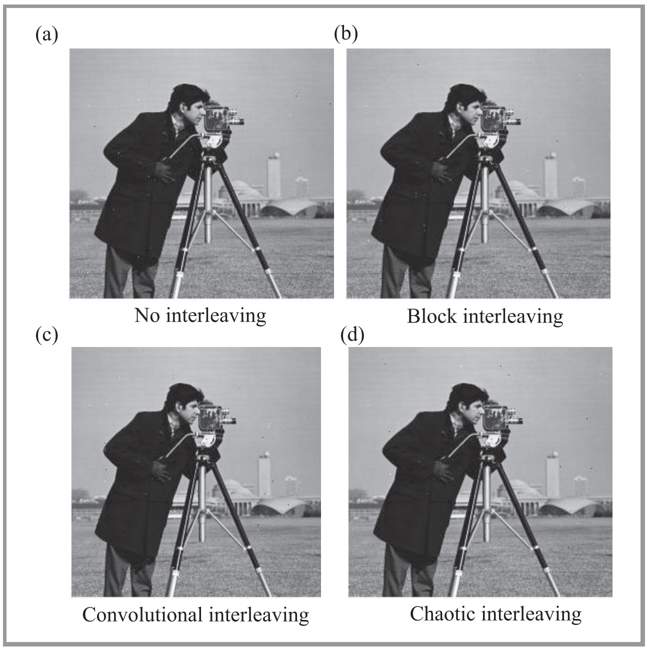

Fig. 8. Received cameraman image over a correlated fading channel at SNR = 30 dB with (a) PSNR = 39.1 dB, (b) PSNR = 41 dB, (c) PSNR = 41.1 dB, and (d) PSNR = 43.1 dB.

For the comparison purpose, the variation of the PSNR of the received image, the number of lost frames and the bit error rate (BER) with the channel SNR are studied and the results are shown in Figs. 9–11. From these results, it is clear the chaotic interleaver enhancement begins at medium SNR values.

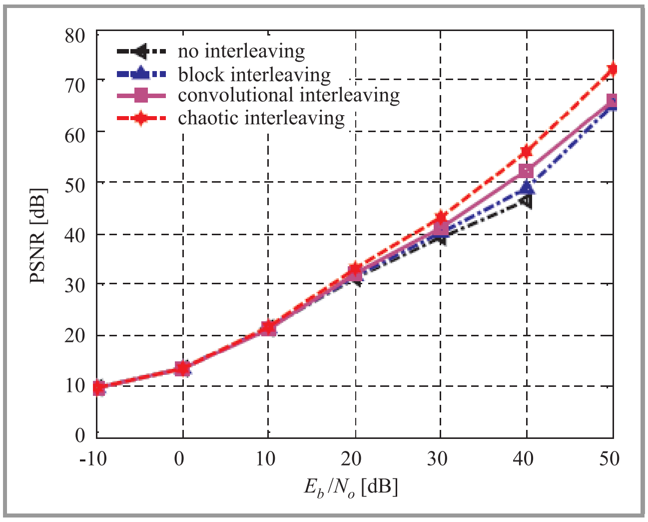

Fig. 9. PSNR versus SNR for the received cameraman image over a correlated fading channel.

As shown in these figures, the proposed chaotic interleaver does not decrease the number of lost frames, but it enhances the PSNR of the received images at medium to high SNR

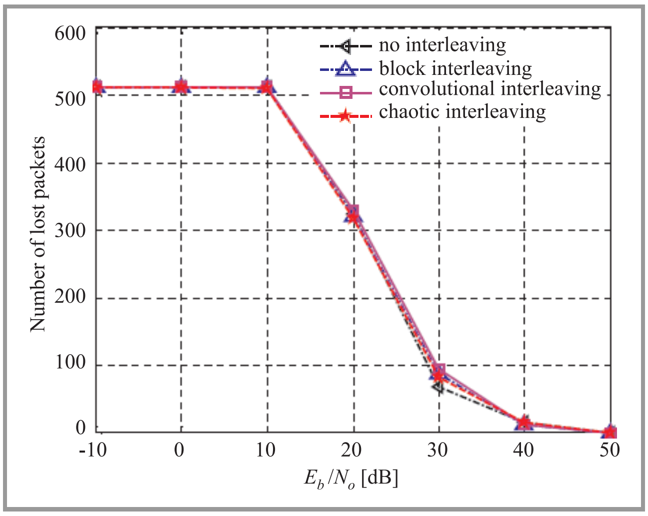

Fig. 10. Number of lost frames versus SNR for the received cameraman image over a correlated fading channel.

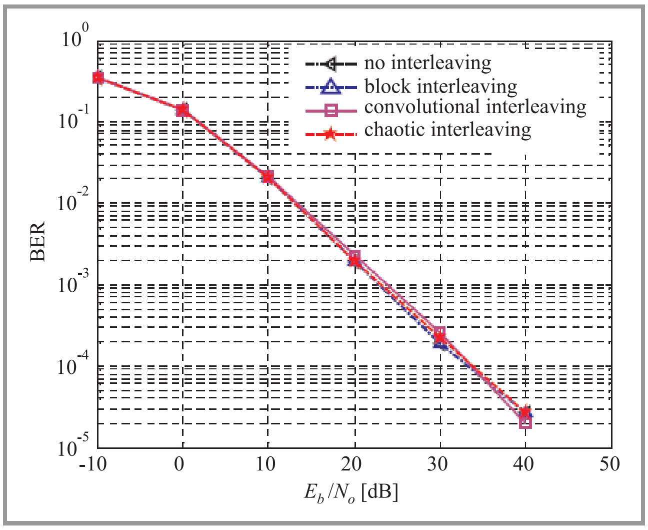

Fig. 11. BER versus SNR for the received cameraman image over a correlated fading channel.

values. The powerful of the proposed technique due to the ZigBee standard doesn't employ error control codes scheme with the transmitted packets. So, there is the possibility using of the chaotic interleaver over the mobile ZigBee network for improve the received image quality with the security enhancing.

5. Conclusion

This paper presented a simple and efficient novel chaotic interleaver for the transmission of images over the ZigBee network. A comparison study between the proposed interleaver and the conventional interleavers has been presented. The computer simulation results have revealed the effectiveness of the proposed interleaver at medium and high SNR values. Also, the proposed interleaver enhanced the security level over the ZigBee network link, as it is based on chaotic map encryption.

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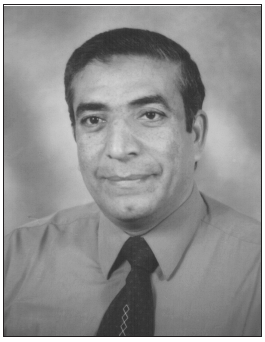

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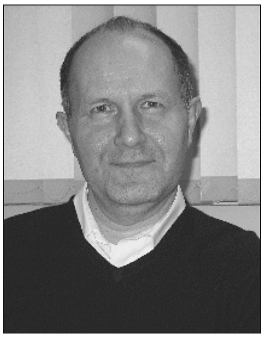

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