Journal of Korea Multimedia Society Vol. 11, No. 6, JUNE 2008(pp. 828-834)

High-Spread Interleaver based Interleave-Division Multiple Access Scheme for the 4G System

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ABSTRACT

This paper presents high-spread (HS) random interleavers based interleave-division multiple access (IDMA) scheme for the 4th generation mobile radio system. High-spread feature of a random interleaver offers high-spread characteristics to interleavers and thus produces extrinsic values with low correlation. As interleavers are key components for user separation in the IDMA, the HS interleavers with this feature are employed and analyzed in the IDMA for performance improvement. In addition, by replacing random interleavers with the HS interleavers in the IDMA, bandwidth efficiency is achieved by means of reducing the length of the repetition code. Performance evaluation shows that the proposed scheme of the IDMA with the HS interleavers provides superior BER performance and improved bandwidth efficiency.

Key words: Multiple Access Scheme, Interleave-Division Multiple Access, Interleaver, 4G system

1. INTRODUCTION

Multiple access schemes are an important means of providing communicational needs in a multi-user environment. Among these, code division multiple access (CDMA) system has been successfully deployed in many countries. To improve performance and power efficiency, CDMA utilizes forward error correction coding (FEC). For a coded CDMA system in multi-user transmission environments, iterative decoding and soft interference cancellation based on MMSE filter as part of multi-user detection (MUD) and decoding has been studied [1].

A new multiple access scheme called interleave-division multiple access (IDMA) was recently proposed [2,3]. The IDMA combined with multiple-input single-output (MISO) has also been proposed, using partial channel state information (CSI) at the transmitters. This system employs iterative receiver structure to achieve partial cancellation of the cross-antenna interference [4]. An interesting comparative analysis between CDMA and IDMA in iterative multi-user detections has been made and showed the superiority of IDMA over CDMA [5]. In addition, in view of the fact that 4G systems require efficient resources allocation and reduction of overhead between the different layers, high data rates, quality of service (QoS) aspects and packet-based services are highly desirable. Among candidate transmission technologies for the 4G, the IDMA is being considered for the uplink of 4G systems [6].

The IDMA solely relies on random interleaver as a means of user separation. As such, it plays an important role in a multi-user detection process of the IDMA. Interleaver is usually employed as a key component in Turbo codes, due to the fact that iterative procedure of the Turbo coding uses interleaved (randomized) version of information iteratively to produce a high coding gain. Among

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Receipt date : Nov. 11, 2007, Approval date : Mar. 25, 2008

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※ This work was supported by Pukyong National University Research Abroad Fund in 2006(PS2006-023)

various interleavers used in Turbo codes, high-spread, high-distance interleavers have been reported in the literature [7]. A HS interleaver indicates high-spread characteristics that produce low correlation. A high-distance feature indicates a high Hamming distance. The high-spread, high-distance interleavers are proposed for use in the Turbo codes for excellent randomness and spread properties. In comparison with random or s-random (spread random) interleavers, high-spread, high-distance interleavers are shown to improve iterative decoding performance of Turbo codes, yet it is easy to implement with very little processing time [7]. The present work is motivated by the superior performance of the HS interleavers. The high-spread feature of the HS interleaver will provide both performance improvement of the IDMA and reasonable bandwidth efficiency by means of reducing the length of the repetition code applied in the IDMA. In this paper, we focus on the interleaver of the IDMA system for a performance and bandwidth efficient IDMA system.

Section 2 describes a review of the IDMA system and is followed by the HS interleaver in Section 3. Section 4 shows representative simulation results and conclusions are drawn in Section 5.

2. IDMA SYSTEM

In multiple access schemes, a unique feature of user separation is necessary. For CDMA systems, signature sequences are used. By spreading the user data with each signature sequence, i.e. bandwidth expansion, user separation and interference rejection capability are achieved. In the IDMA, however, we employ an independent and random interleaver for each user. The transmitter and receiver structures are shown in Figure 1 and 2, respectively. In the transmitter, the user data are first encoded by the convolutional encoder, followed by the repetition code. The repetition code is viewed as a spreader as in the CDMA, except

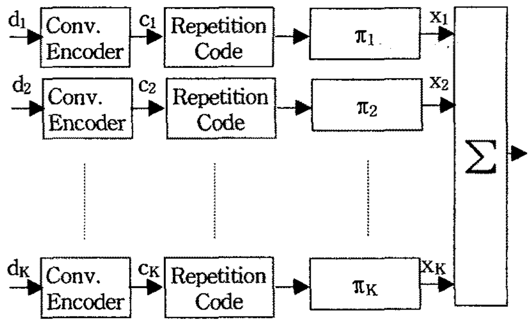

Fig. 1. The IDMA transmitter structure

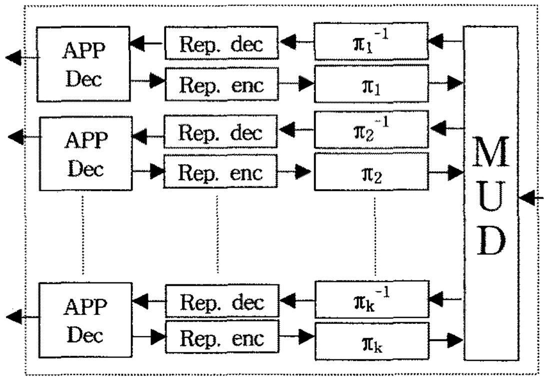

Fig. 2. The IDMA receiver structure

for the fact that this code is common to all users. Therefore, each data bit is convolutionally coded and spread by this repetition code prior to the user-specific interleaver, thus the resultant data of the repetition code being aptly called *chip*. In other words, the IDMA employs a chip-level interleaving process.

We consider BPSK modulated data and use the discrete-time baseband system to describe the operation of the transmitter. We assume that there are K simultaneous users. The data sequence of user k is then denoted by $d_k = [d_k(0), d_k(1), \cdots, d_k(N-1)]^T$, $k = 1,2,\cdots,K$. N is the length of data block. The coded sequence by a convolutional coder is $c_k = [c_k(0), c_k(1), \cdots, c_k(Nc-1)]^T$. That is, the code rate is defined as $R_1 = N/Nc$. As mentioned previously, this coded sequence is repeated by the simple repetition code with a rate of $R_2=1/Nr$, producing the chip signal. Thus, the overall code rate is R_1R_2. This sequence is then permutated by each interleaver independently and randomly generated for each user. Therefore, the interleaved data sequence is then $x_k = [x_k(0), x_k(1), \cdots, x_k(N_t-1)]^T$.

In the receiver, the multi-user detection is first performed. For user k, we can express the received signal as

$$y_k = h_k * x_k + n_k \tag{1}$$

where * denotes convolution, h_k is the channel coefficient for the user k, x_k is the transmitted signal for the user k and n_k is the additive white Gaussian noise. For a length N_t of the transmitted signal and L-multipath coefficients of the channel, the dimension of y_k is $(L+Nt-1) \times 1$.

In matrix form, (1) can be rewritten as

$$\mathbf{y_k} = \mathbf{H_k x_k} + \mathbf{n_k} \tag{2}$$

where H_k is of dimension $(N_t+L-1) \times N_t$.

By defining each column of H_k as $h_k(m)$, we have

$$y_k = \sum_{m=0}^{N_t-1} h_k(m) x_k(m) + n_k \tag{3}$$

In the iterative multiuser detection employed in the IDMA, the *a posteriori* log-likelihood ratio (LLR) is used. That is,

$$\begin{aligned} L(d_k(i)) &= \log\frac{P\{d_k(i)=1|y_k\}}{P\{d_k(i)=0|y_k\}} \\ &= \log\frac{P\{y_k|d_k(i)=1\}}{P\{y_k|d_k(i)=0\}} + \log\frac{P\{d_k(i)=1\}}{P\{d_k(i)=0\}} \\ &= L_e(d_k(i)) + L_a(d_k(i)) \end{aligned} \tag{4}$$

where L_e denotes the extrinsic LLR and L_a denotes *a priori* LLR.

The first step in the IDMA receiver performs the MUD operation. That is, it produces the extrinsic LLRs. Assuming that n_k is Gaussian distributed with the variance of σ_n^2, this extrinsic LLR is found to be

$$\begin{aligned} L_e(d_k(i)) &= \log\frac{P\{y_k|d_k(i)=1\}}{P\{y_k|d_k(i)=0\}} \\ &= \frac{2h_k n_k}{\sigma_n^2} \end{aligned} \tag{5}$$

The extrinsic LLRs are deinterleaved and decoded using the repetition code as shown in Figure 2.

The next step is to perform the APP decoding based on the deinterleaved and derepeated extrinsic LLRs. The output of this operation, $L_e(c_k(i))$, is used to generate the following statistics [3]

$$E(x_k(i)) = \tanh\{L_e(c_k(i))/2\} \tag{6}$$

$$\sigma_{x_k}^2(i) = 1 - \{E(x_k(i))\}^2 \tag{7}$$

In producing $L_e(c_k(i))$, the input to the APP decoder can be subtracted from the output of APP decoder to ensure that the output of the APP decoder is truly extrinsic. However, this would require the storage of the output of the first step operation and more computation. This process can be avoided for reduced computational complexity and memory requirement at the expense of performance loss [3].

3. HIGH-SPREAD INTERLEAVER

Since Turbo codes are introduced for powerful error correcting capability, interleaving has become a key element of the Turbo codes. In particular, good interleaver spreading properties are considered important for fast convergence and good distance property [6]. In addition, high distance property of interleavers is necessary to produce reasonable error performance by lowering an error floor in the Turbo codes.

In most cases, two common interleavers can be considered: random interleaver and spread (or s-random) interleaver. Random or pseudo-random permutation of the input to the interleaver is performed in the random interleaver, whereas spread interleaver uses random permutation with certain constraints.

In the present investigation, we consider the HS interleavers in place of random or s-random interleavers. These interleavers are shown to outperform the random or s-random interleavers in

Turbo code applications [6]. In the IDMA system, interleavers are a unique means of user separation. These independent and random interleavers spread the coded data. Thus, the data (or chips) are approximately uncorrelated. The interleavers that have even higher spread property can ensure that the spread data are highly uncorrelated, thus leading to performance enhancement.

Prior to describing the HS interleaver, the definition of spread measure is described. Interleaver spreads input bits (or symbols) according to a rule (or mapping). The mapping of the input data to the output data can be described using indexes of the input data. Let us say an input data vector $V_{in}[k]$ of length M. The output vector is then written sequentially using indexes of the input vector $V_{in}[k]$. For example, the output vector, V_{out}, can be as follows: V_{out} = {$V_{in}[2]$, $V_{in}[4]$, $V_{in}[0]$, ⋯.}. First, we describe the conventional s-random interleaver. This interleaver operates as follows. It generates a random integer from an interval of [0, M). This integer is then compared with the previously selected L-1 integers, i.e. $V_{out}[1]$, $V_{out}[2]$, ⋯, $V_{out}[L-1]$. The constraint of this interleaver is such that this integer is at least L-1 integers apart. If the selected integer is equal to any of previously selected integers within a distance of ±L, a new integer is generated and compared until all number of integers required are extracted.

The s-random interleaver spread for a given span L can be written as

$$S(i,j)=|V_{out}[i]-V_{out}[j]|, \quad \text{for } |i-j|<L \tag{8}$$

Therefore, the spread associated with the ith element is

$$S(i)=\min_j[S(i,j)] \tag{9}$$

As mentioned previously, the HS interleaver has initially been proposed for the use of Turbo codes as a means of spreading the data prior to the second recursive systematic convolutional code in parallel concatenated coding schemes. Based on the definition of interleaver spread above, the HS interleaver is designed to further improve the distance property of interleaver. That is, a modification is made to the algorithm of s-random interleaver. Instead of an integer index, a *real* index is utilized for the HS interleaver throughout the process. The spread measure of the HS interleaver is then given as [6]

$$S_{hs}(l,m)=|R[l]-R[m]|+|l-m| \tag{10}$$

where R[l] and R[m] are two real indexes from the interval [0, M). The actual spread of HS interleaver is determined by

$$S_{hs}(l)=\min_m[S_{hs}(l,m)] \tag{11}$$

The algorithm begins by selecting a real read index l at random from the real interval [0, M). If $S_{hs}(l)$ is less than the target spread S_t, the selected index is discarded and a new index is chosen randomly. The process continues until the number of indexes satisfying the target spread is selected. The time required to extract all necessary indexes will increase with the target spread of the interleaver. In addition, there is no guarantee that the process ends successfully. The theoretical maximum spread is found to be floor $(\sqrt{2M})$ [6].

When the real index vector satisfying the target spread is found, the next step is to find corresponding write indexes and then assign the integer read indexes. Figure 3 illustrates the HS interleaver operation with M = 5. When **R′** vector is determined according to a predefined spread target, the integer read index vector **A** corresponding to **R′** vector is obtained.

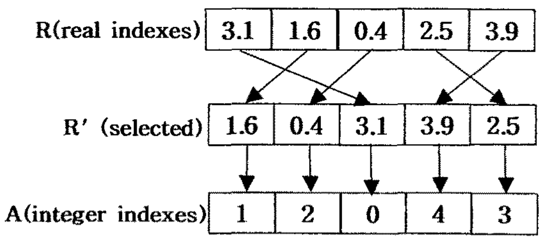

Fig. 3. Illustration of the HS interleaver (M=5)

4. SIMULATIONS AND RESULTS

In this section, the performance of the IDMA based on the HS interleavers is presented. The parameters used in the simulation are as follows. The data length of each block is 256. Different lengths of the repetition code (thus different target spread of the HS interleavers) are used for evaluating how the length of the repetition code (N_r) affects the performance. For a forward error correcting (FEC) code and extrinsic LLRs described in Section II, we use the convolutional code of $(23,35)_8$ in the simulation. In addition, BPSK modulation scheme is used for data modulation throughout evaluation. The use of this simple modulation scheme is justified, since the present study focuses on interleaver of the IDMA.

As mentioned in Section 3, the computationally efficient method in computing extrinsic LLRs has been adopted. Although the use of full extrinsic LLRs computation would provide slightly higher performance gain, this alternative method is employed to reduce its computational complexity in conducting comparative performance analysis.

Figure 4 shows the performance comparison between the random interleaver based IDMA and HS interleaver based IDMA with 5 simultaneous users present with R_2 = 0.25. For the two different iterations of 5 and 10, the HS interleaver based IDMA outperforms the random interleaver based IDMA. As expected, the higher number of iteration improves the BER performance even further. When we increase the length of the repetition code from N_r = 4 to N_r = 8, the performance shows a significant gain as shown in Figure 5. It can be said that the repetition code plays an important role in the performance of the IDMA system.

The observation of the significant performance gain from the HS interleaver leads to a further evaluation for bandwidth efficiency. That is, we reduced the length of the repetition code (increased bandwidth efficiency) of the proposed HS interleaver

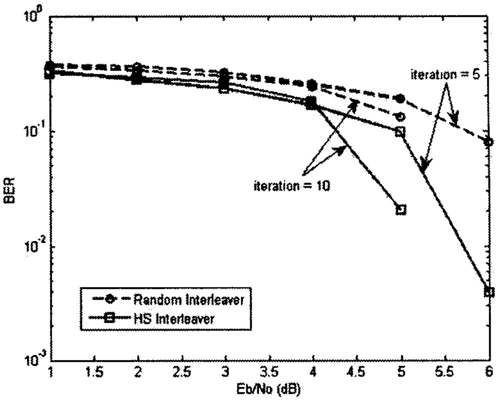

Fig. 4. Performance comparison for K = 5 and Nr = 4.

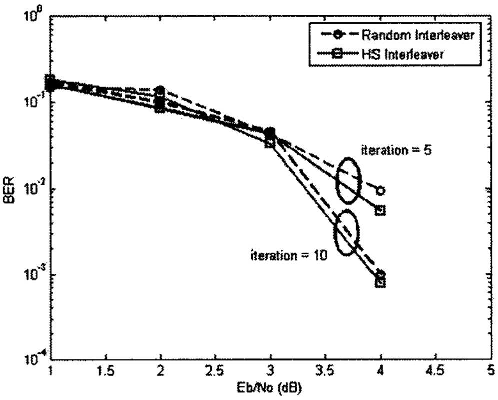

Fig. 5. Performance comparison for K = 5 and Nr = 8.

based IDMA system and have evaluated if the system still yields a comparable performance to the random interleaver based IDMA system.

Figure 6 shows a performance comparison of the random interleaver based IDMA with K = 5, Nr = 8 and iteration = 5 and the HS interleaver based IDMA with K = 5, Nr= 4 and iteration = 15. Although the performance degradation exhibits at low Eb/No values, bandwidth efficiency can, to some extent, be achieved by the HS interleaver with lower N_r at the expense of higher iterations at the receiver.

For Figures 7-9, the proposed system has been evaluated using different length of the repetition code and different number of users. Figure 7 shows

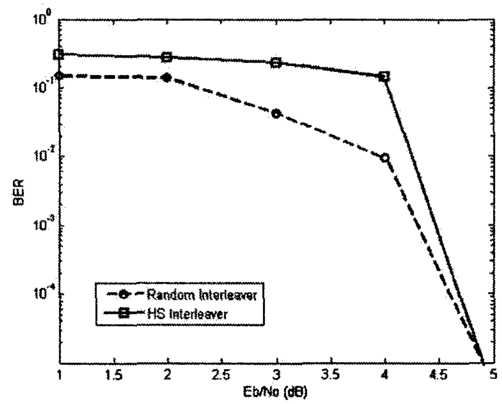

Fig. 6. Performance comparison between random interleaver IDMA with K = 5, Nr = 8 and HS interleaver IDMA with K = 5, Nr = 4.

a performance comparison between the two systems with K = 10 and N_r = 8. Figure 8 demonstrates that when the length of the repetition code increases, the performance improves significantly. For this simulation scenario, Table 1 shows the exact values of BER's for a numerical comparison. Therefore, it can be concluded that the repetition code is a key element for a reasonable BER performance in the IDMA system.

For K = 10, a similar observation can also be made for improved bandwidth efficiency. That is, even with reduced length of the repetition code in the HS interleaver based IDMA, its performance is still comparable to the random interleaver based

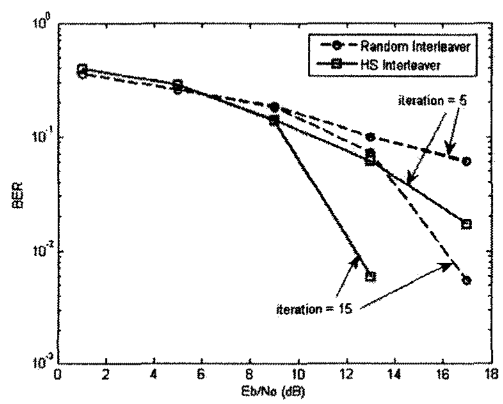

Fig. 7. Performance comparison for K = 10 and Nr = 8.

IDMA. This bandwidth efficiency is a direct result from the use of the HS interleaver. It should be noted that this gain is obtained at the expense of increased processing time at the receiver.

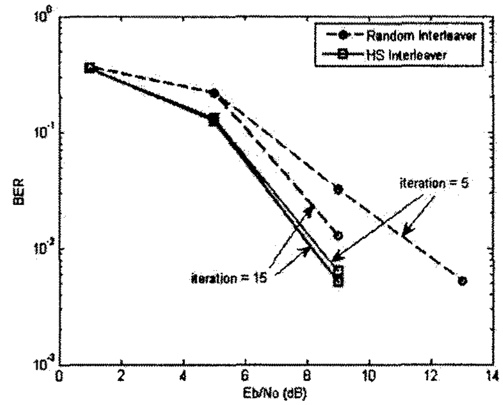

Fig. 8. Performance comparison for K = 10 and Nr = 10.

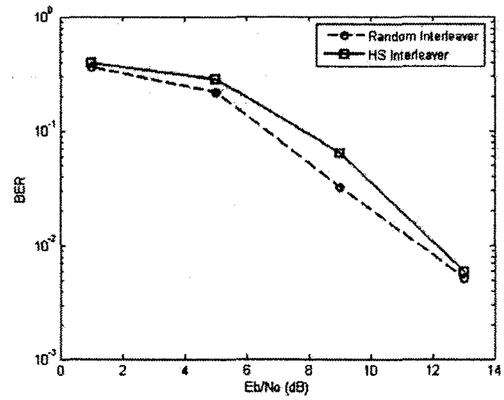

Fig. 9. Performance comparison between random interleaver IDMA with K = 10, Nr = 10 and HS interleaver IDMA with K = 10, Nr = 8.

Table 1. Numerical values of BER's for K = 10 and Nr = 10

Eb/No (dB)	Random Interleaver		HS Interleaver	
	Iter = 5	Iter = 15	Iter = 5	Iter = 15
1	0.3555	0.3521	0.3516	0.3516
5	0.2195	0.2195	0.1301	0.1238
9	0.0320	0.0129	0.0063	0.0051
13	0.0052	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0

5. CONCLUSIONS

An IDMA system with the HS interleaver has been proposed to improve the performance and bandwidth efficiency of the IDMA system. Performance comparison shows that the proposed HS interleaver based IDMA outperforms the random interleaver based IDMA. It is found that the repetition code employed in the IDMA is a key element for a reasonable performance of the IDMA system. In addition, as a higher length of the repetition code will increase the system bandwidth, the proposed system renders bandwidth efficiency by reducing the length of the repetition code while maintaining a comparable performance to the random interleaver based IDMA system.

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