INDEXED RANDOM INTERLEAVING TECHNIQUE FOR IDMA SYSTEMS

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ABSTRACT

IDMA is a recently proposed technique for multiple access communications, which is known for property of orthogonality amongst its user-specific interleavers. The interleavers are therefore referred as the heart of IDMA transceivers. Thus, the interleaver must be carefully designed to ensure good performance, low memory requirements and low computational complexity. In this paper we propose a new interleaver technique named indexed random interleaver. Simulation results show that the proposed interleaver gives better average bit error rate performance than conventional random interleaver.

Keywords- Chip-by-Chip, Indexed Random Interleaver, Multi-User Detection, Random Interleaver.

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. In multiple access schemes, as a means of improving performance, forward error correction coding (FEC) has been utilized. 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 MISO has also been proposed, using partial 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].

Interleaver is the only means to separate users in IDMA system [1]-[5]. In order to immunize noise and Multiple Access Interference (MAI) at the receivers, choosing interleavers which are weakly correlated between different users is very important.

In this paper we are giving a new interleaving technique which is a modification of random interleaving. Section II describes the IDMA system model. Section III describes the random and proposed
interleaving techniques. Simulation results are given in section IV. Finally we conclude the paper in section V.

II. IDMA SYSTEM MODEL

IDMA is a multiple access technology with chip-level interleaving and iterative detection. Figure 1 shows the model of IDMA system with K users. At the transmitter side, the nth bit \( d_n^{(k)} \in \{+1,-1\}, n = 1,2,...,N \), in the input data stream \( d^{(k)} \) from user-\(k\) is spread using a length-\(S\) spreading sequence \( s^{(k)} \) in the form \( d_n^{(k)} \rightarrow d_n^{(k)} s^{(k)} \). We write the chip sequence obtained after spreading as \( \{d_n^{(k)}\}_{n=1}^{N} \). We use a common spreading sequence for all users, i.e., setting \( s^{(1)} = s^{(2)} = ... = s^{(k)} = ... = s^{(K)} = s \), and employ user-specific interleavers \( \{\pi^{(k)}\}_{k=1}^{K} \) for user separation.

We assume the channel without memory, so the received signal from \( K \) users at time instant \( j \) can be written as:

\[
 r_j = \sum_{k=1}^{K} h^{(k)} x_j^{(k)} + n_j, j = 1,2,...,J \tag{1}
\]

Where \( x_j^{(k)} \in \{+1,-1\} \) denotes the transmitted chip from user-\(k\) at time instant \( j \), \( \{h^{(k)}\} \) the channel coefficient for user-\(k\), and \( n_j \) zero-mean additive white Gaussian noise (AWGN) with variance \( \sigma^2 = N_0/2 \). We will assume perfect knowledge of the channel coefficients at the receiver. To simplify discussion, we also assume that the channel coefficients \( \{h^{(k)}\} \) are real. The iterative chip-by-chip receiver in Figure 1 consists of an elementary signal estimator (ESE) and a bank of \( K \) single-user a posteriori probability decoders for the disspreading operation (DES) working in a turbo-type manner, as shown in Figure 1. The ESE performs a coarse chip-by-chip estimation. We concentrate on \( x_j^{(k)} \) and re-write (1) as:

\[
 r_j = h^{(k)} x_j^{(k)} + \xi_j \tag{2}
\]
Where \( c_j^{(k)} = r_j - h^{(k)}x_j^{(k)} \) represents a distortion term with respect to \( x_j^{(k)} \). We treat each \( x_j^{(k)} \) as a random variable with mean \( E(x_j^{(k)}) \) and variance \( Var(x_j^{(k)}) \) (initialized to 0 and 1 respectively). Then from (1), we have

\[
E(r_j) = \sum_{k=1}^{K} h^{(k)} E(x_j^{(k)}) \quad (3a)
\]
\[
Var(r_j) = \sum_{k=1}^{K} |h^{(k)}|^2 Var(x_j^{(k)}) + \sigma^2 \quad (3b)
\]

Using the central limit theorem, \( c_j^{(k)} \) in (2) can be approximated by a Gaussian random variable with

\[
E\left(\xi_j^{(k)}\right) = E(r_j) - h^{(k)}E(x_j^{(k)}) \quad (4a)
\]
\[
Var\left(\xi_j^{(k)}\right) = Var(r_j) - |h^{(k)}|^2 Var(x_j^{(k)}) \quad (4b)
\]

The ESE outputs are the logarithm likelihood ratios (LLRs) about \( x_j^{(k)} \) computed based on (3) (using 4)) [8] as:

\[
L\left(x_j^{(k)}\right) = \frac{2h^{(k)}(r_j - E(\xi_j^{(k)}))}{\text{Var}(\xi_j^{(k)})} \quad (5)
\]

For user-\( k \), the corresponding ESE outputs \( \{L\left(x_j^{(k)}\right), j = 1, 2, ..., J\} \) are de-interleaved to form \( \{L\left(c_j^{(k)}\right), j = 1, 2, ..., J\} \) and delivered to the DES for user-\( k \). The DES performs a soft-in/soft-out chip-by-chip de-spreading operation as detailed below. For simplicity, we focus on the chips related to \( d_1^{(k)} \), the first bit of user-\( k \). The treatment for other chips is similar. Recall that \( d_1^{(k)} \) is spread into the chip sequence \( d_1^{(k)} s^{(k)} = \{c_j^{(k)}, j = 1, 2, ..., S\} \), where \( s^{(k)} = \{s_j^{(k)}\} \) is the binary signature sequence (over \{+1, -1\}) for user-\( k \). We assume that \( L\left(c_j^{(k)}\right) \) are uncorrelated (which is approximately true due to interleaving [8]). Let the interleaving for user-\( k \) be expressed as \( \pi_j^{(k)} = j^* \), i.e., \( c_j^{(k)} = x_{j^*}^{(k)} \) (see Figure 1). Then based on (5), the \textit{a posteriori} LLR for \( d_1^{(k)} \) can be computed using \( \{L\left(c_j^{(k)}\right)\} \) as

\[
L\left(d_1^{(k)}\right) = \sum_{j=1}^{S} s_j^{(k)} L\left(c_j^{(k)}\right) \quad (6)
\]

The extrinsic LLR for a chip \( c_j^{(k)} \) within \( d_1^{(k)} \) is defined by

\[
\text{Ext}\left(c_j^{(k)}\right) \equiv \log \frac{\Pr\left(c_j^{(k)} = +1 \mid r\right)}{\Pr\left(c_j^{(k)} = -1 \mid r\right)} - L\left(c_j^{(k)}\right)
\]

We notice that \( c_j^{(k)} = +1 \) if \( s_j^{(k)} = d_1^{(k)} \) and \( c_j^{(k)} = -1 \) otherwise. Therefore we have[8]

\[
\text{Ext}\left(c_j^{(k)}\right) = s_j^{(k)} L\left(d_1^{(k)}\right) - L\left(c_j^{(k)}\right) \quad (7)
\]

The extrinsic LLRs \( \{\text{Ext}\left(c_j^{(k)}\right)\} \) form the outputs of the DES and are fed back to the ESE after interleaving (see figure 1). In the next iteration, \( \text{Ext}\left(x_j^{(k)}\right) \) are used to update \( \{E(x_j^{(k)})\} \) and \( \{Var(x_j^{(k)})\} \) as [8]

\[
E\left(x_j^{(k)}\right) = \tanh\left(\frac{\text{Ext}(x_j^{(k)})}{2}\right) \quad (8a)
\]
\[
Var\left(x_j^{(k)}\right) = 1 - E(x_j^{(k)})^2 \quad (8b)
\]

This iterative process is repeated a preset number of times. In the final iteration the DES produces hard decisions \( \hat{d}^k \) on information bits \( d^{(k)} \) based on (6).
III. INTERLEAVING

The interleaver design has an important role in the efficiency of IDMA system. Not only does it provide un-correlation between adjacent bit sequences as in the case of orthodox turbo coding and decoding, it also provides a mean to uncorrelated different users [6]. The correlation between interleavers should measure how strongly signals from other users affect the decoding process of a specific user. The better the interleaver un-correlation, the lesser the iterations required for detection in IDMA MUD. The un-correlation among the interleavers provides a mean to reduce the MAI from other users thus helping in the convergence of detection process.

A. Earlier Random Interleavers

Random interleavers are generated randomly and independently. Random interleavers for IDMA need to satisfy two design criteria [7]:

- They are easy to specify and generate, i.e., the transmitter and receiver can send a small number of bits between each other in order to agree upon an interleaver, and then generate it.
- The interleavers do not “collide”.

The collision among interleavers is interpreted in the form of the un-correlation among the interleavers.

If the interleavers are not randomly generated, the system performance degrades considerably and the MUD is unable to resolve MAI problem at the receiver resulting in higher values of Bit Error Ratio (BER). On the other hand if the interleaving patterns are generated more and more random, the MUD resolves the MAI problem more quickly and better values of BER are obtained for the same parameters.

B. Proposed Indexed Random Interleaver

In the proposed interleaver, we generate a matrix of \( m \times n \) where \( m \) is the number of users and \( n \) is the chip-length. The matrix is then filled with random numbers ranges from 1 to chip-length. The matrix is then permuted according to the seeds generated for rows and columns. The chip is then transmitted according to the index values of the generated matrix. The algorithm of proposed interleaver is given below:

- Create a matrix of \( m \times n \) where, \( m \) is number of users and \( n \) is chip-length.
- Permute columns according to the column seed.
- Permute rows according to the row seed.

Above discussed algorithm can be understood with the help of following example. Suppose the number of users, \( m=4 \) and chip-length, \( n=6 \).

Seed for column permutation \([C_4, C_6, C_2, C_5, C_1, C_3]\)
Seed for row permutation \([R_3, R_1, R_4, R_2]\)

<table>
<thead>
<tr>
<th>TABLE I</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATRIX WITH ( m ) ROWS AND ( n ) COLUMNS</td>
</tr>
<tr>
<td>( m \times n )</td>
</tr>
<tr>
<td>( C_1 )</td>
</tr>
<tr>
<td>( R_1 )</td>
</tr>
<tr>
<td>( R_2 )</td>
</tr>
<tr>
<td>( R_3 )</td>
</tr>
<tr>
<td>( R_4 )</td>
</tr>
</tbody>
</table>
The index values of above matrix are then used to transmit the chip.

IV. SIMULATION RESULTS

For all the simulations in this paper IDMA decoding algorithm described in section II is used, and all the simulations are implemented on MATLAB. For simplicity, we assume IDMA systems with BPSK signaling in single path AWGN channels and $h_k=1$, $k=1,2,\ldots,K$. The only constraint in selecting the spreading sequence for IDMA is that it should contain a balanced number of $\{+1,-1,+1,-1\ldots\}$ we used Spreading Length(SL)=16 for all users and 5 iterations are performed.

![Figure 2](image.png)

Figure 2. Performance comparison of uncoded IDMA systems in single path AWGN channels, using two kinds of interleavers for single user. Data-length=1024, spread-length=16 and 100 blocks are transmitted per user.
Figure 3. Performance comparison of uncoded IDMA systems in single path AWGN channels, using two kinds of interleavers for 8 users. Data length=1024, spread-length=16 and 100 blocks are transmitted per user.

Figure 4. Performance comparison of uncoded IDMA systems in single path AWGN channels, using two kinds of interleavers for 16 users. Data length=512, spread-length=16 and 20 blocks are transmitted per user.
Figure 5. Performance comparison of uncoded IDMA systems in single path AWGN channels, using two kinds of interleavers for 32 users. Data length=512, spread-length=16 and 20 blocks are transmitted per user.

Figure 6. Performance comparison of uncoded IDMA systems in single path AWGN channels, using two kinds of interleavers for 64 users. Data length=512, spread-length=16 and 20 blocks are transmitted per user.
V. CONCLUSION

Above shown simulation results prove that the proposed interleaver gives better average bit error rate performance than random interleaver for IDMA systems. The degree of randomization in proposed interleaver is greater than conventional random interleaver.

We can also see that when the number of users increase the average bit error rate improves in proposed interleaving as compared to conventional random interleaving for IDMA systems.

In proposed interleaver, the base station (BS) has to employ a considerable amount of memory to store these interleavers at transmitter and receiver side, which may cause serious concern in case of large user count. Also, during the initial link setting up phase, there should be messages passing between the BS and mobile stations (MSs) to inform each other about user specific interleavers. Extra bandwidth resource will be consumed for this purpose if the interleavers used by the BS and MSs are long and randomly generated.

Therefore, we can conclude that if memory consumption is not an issue the proposed interleaver can be very efficient for IDMA systems.

REFERENCES


