PERFORMANCE IMPROVEMENT OF IDMA SCHEME USING CHAOTIC MAP INTERLEAVERS FOR FUTURE RADIO COMMUNICATION

Aasheesh Shukla¹ and Vinay Kumar Deolia²
Department of Electronics and Communications Engineering, Institute of Engineering and Technology, GLA University, India

Abstract
In this paper, chaos based interleavers are proposed for the performance improvement of Interleave Division Multiple Access (IDMA henceforth) for future radio communication (FRC) requirements. ‘IDMA’ can be mean as the modified case of direct sequence code division multiple access (DS-CDMA) with the same spreading sequences and user specific interleavers for distinguishing the users in multi-user environment. In IDMA systems, the roles of interleavers are pre-eminent and an efficient interleaver contributes in optimizing the system performance. Random interleaver is the popular and basic taxonomy in IDMA. The performance of chaos based interleavers is compared to random interleaver. Simulation results authenticate the performance of chaos based IDMA. Further the proposed chaotic map-interleavers have the less computational complexity and efficient in bandwidth compared to the existing prevailing interleaver algorithms in the domain. The IDMA system model uses a BPSK modulation and repetition coder with a code rate of ½. The system is simulated in MATLAB and results show the BER superiority of chaotic interleaver based IDMA without the need of extra storage resources and less computational complexity.

Keywords:
IDMA, Chaos, Tent Map, Logistic Interleaver, CDMA

1. INTRODUCTION

IDMA is one of the popular spread spectrum multiple access scheme which can be seen as a special case direct sequence code division multiple access (CDMA for short henceforth). In IDMA interleavers are used for user separation rather than by spreading sequences like in CDMA. Interleavers are the crucial part of wireless communication, specifically over noisy channel. Chip interleaving was first introduced to combat the effect of burst impulsive noise disturbance. The interleaver scrambles the ordering of bits in sequences and hence converts the bursty channel into random error channel [1].

CDMA was widely used in third generation mobile communication system but the performance of this technique has been limited due to the mutual interference among multiple users (MAI) and inters symbol interference (ISI). Although several researches are given for the cancellation of MAI such as successive interference cancellation (SIC) and parallel interference cancellation (PIC), but these challenges in CDMA restrict its role in future communication. In order to enhance the spectrum efficiency, Ping et al. proposed a new multiple access scheme i.e. Interleave division multiple access (IDMA) [2]. However the performance of IDMA is improved, because the entire bandwidth expansion is devoted to the coding and interleavers are dedicated to distinguish the users. Hence IDMA inherits many advantages of CDMA and also allows a simple iterative Multi User Detection (MUD) strategy [3]. With many benefits, IDMA offers some challenges too. Some of them can be listed as:

• **Bandwidth requirement**: Interleaving sequence is also sent along with information bits and hence it increases the bandwidth requirement.
• **Computational Complexity**: Each user is assigned a different interleaver which enhances the system complexity.
• **Storage resources requirement**: Interleaving algorithm is needed to store at the side of transmitter as well as at receiver which may become a major challenge, especially when number of user is large.

To conquer above limitations, researchers have suggested different design and algorithms of interleavers. There are many popular interleaver designs available in the literature such as Orthogonal Interleaver (OI), Pseudo-random interleaver, Tree based Interleaver (TBI), Helical Interleaver, Nested Interleaver, Shifting Interleaver, Deterministic Interleavers and many more [4][5][6]. Based on the work carried in the research, it can be concluded that the choice of optimum interleaver may have a great impact on the performance of IDMA system. Ramsey reported the basic interleaver design in 1970.

The paper focus on the random interleaving algorithm to minimize the delay and storage resources requirement. However, the randomly generated interleaving pattern also has some limitations, such as large storage requirement and high complexity. Pupeza et al. [7] proposed the generation of Nested interleaver (NI), which choose the first interleaver sequence from pseudo-random interleaver and rest interleavers are generated by re-ordering procedure with the limitation that, it consumes large memory and bandwidth, although, the bit error rate (BER) performance was better than random interleaver. Pupeza et al. also presented Orthogonal Interleaver (OI), which guarantee the users to be orthogonal and hence diminish the effect of multiple access interference [7][8]. However the performance of OI is limited due the requirement of large number of orthogonal sequences for simultaneous users. Zhang proposed a shifting interleaver for IDMA scheme and cyclically shifting interleaver. Both the interleavers were not suitable for MUD receiver. Tseng et al. suggested a novel design of deterministic interleaver which was firstly used in turbo codes. The design of this interleaver was less complex and more bandwidth efficient with the only limitation that the use of look up table, the need of the table increases the memory requirement at the transmitter [8]. Shukla et al. also suggested a new Tree Based Interleaver with the scope of further improvement in memory requirement. Many other algorithms of interleaver design also have been proposed by researchers but the journey towards the search of optimum interleaver is still on for making IDMA suitable for future communication [9].
1.1 MOTIVATION

Recently the use of chaos in spread spectrum communication drawn the attention of researchers and this is found that the use of chaos into spread spectrum communication systems offers many advantages as well as provides several opportunities for the improvement is system performance. Chaotic systems are a basically non-dynamical system which highly depends upon on initial conditions and consequently, may help in the generation of uncorrelated, random-like, yet deterministic and reproducible signals or sequences [10]. Manoharan et al. presented the analysis of chaos based codes and assured the better performance of chaotic codes in comparison of p-n code. Chaotic sequences shows good decorrelation properties and hence reduce multiple access interference (MAI) [11]-[14]. Further different chaotic maps are used to generate sequences and so for interleave for IDMA system. The popular chaotic maps are Logistic map, Tent map, Bernoulli’s map, Baker Map, Henon map etc. The current work proposes a solution for the search of an efficient interleaver. In this article, the logistic and tent map based interleavers are analyzed in IDMA scheme and assures the better performance.

The content of the paper is organized as follows. Section 2 presents the IDMA system description. Section 3 defines chaos based algorithms for interleave design. Section 4, develops the performance analysis of proposed interleave with IDMA schemes and section 5 discusses the conclusions drawn on the basis of BER performance analysis and computational complexity.

2. SYSTEM DESCRIPTION

Chip level interleaving was popularly used to mitigate the effect of burst impulsive noise disturbances of the channel. It also motivates that the users should be separated by chip level interleaver rather than by spreading codes as in conventional CDMA system. The system is popularly named as Interleave division multiple accesses. The block diagram of Interleave Division Multiple Access (IDMA) system with K users is presented in Fig.1. At the transmitter, the information bits $b_{i,k}$ are encoded by the encoder of rate R. The spreader code is simply a repetition code of rate R. The resulting code bits $c_{i,k}$, $i\in[1,...,N_b]$ are interleaved by user specific interleave $\Pi_k$ to get $c_{i',n,m,k}$ i.e.

$c_k = [c_1, c_2,..., c_k]$, where j is the chip length. Using the effective channel the received signal can be represented as $y_n$.

Here the transmitted symbol can be written as $x_0 \triangleq [x_01,..., x_0K]^T$ and noise vector may be $\zeta_{nI} \triangleq [\zeta_01+...+\zeta_{nI}(t+1)]^T$. In receiver section, the received signal can be described as:

$$y_n = H_n x_n + \zeta_{n}$$

(1)

The partition of effective channel matrix can be further defined as

$$H_n = [h_{n,1},...h_{n,1,k} ... h_{n,2},...h_{n,2,k} ... h_{n,K},...h_{n,K,k}]$$

The input to the receiver can be written as:

$$y_n = \sum_{K=1}^{k} \sum_{i=1}^{j} h_{n,i,k} x_{n-i,k} + \zeta_{n}$$

(2)

The receiver for IDMA system of K simultaneously transmitting users are comprised of multiuser detector (MUD) and K posteriori probability (APP) decoders in connection with user specific interleave. The APP decoders and interleave exchange the soft information and calculate the log likelihood ratios (LLRs) [4]. These LLRs should be independent from the users and hence called as extrinsic LLRs. The goal of the multi user detector is to compute the a posteriori LLRs, which can be represented as,

$$L'(\hat{c}_{m,n,k}) = \ln \left( \frac{P(\hat{c}_{m,n,k} = +1|y_n)}{P(\hat{c}_{m,n,k} = -1|y_n)} \right)$$

Now the extrinsic LLRs can be calculated accordingly i.e. $L_e^{(k)}(\hat{c}_{m,n,k}) = L'(\hat{c}_{m,n,k}) - L_e^{(k)}(\hat{c}_{m,n,k})$ are sent to the decoder after de-interleaving operation i.e. $\Pi_k^{-1}$. Now by using total probability theorem the extrinsic LLR can be written as,

$$L_e^{(k)}(\hat{c}_{m,n,k}) = \ln \left( \frac{\sum_{c_{m,n,k}} P(y_n|c_{m,n,k} = x) \prod_{m,n} P(c_{m,n,k} = d_m)}{\sum_{c_{m,n,k}} P(y_n|c_{m,n,k} = x) \prod_{m,n} P(c_{m,n,k} = d_m)} \right)$$

(4)

Here, $d_m = \{+1,-1\}$ denotes the mth bit of symbol x. Each of decoder receives the de-interleaved extrinsic LLRs and channel LLRs $L_e^{(k)}$. Now with some constraints the decoder computed a posteriori LLRs $L_e^{(k)}$. To get extrinsic LLRs, the channel LLRs are subtracted from posteriori LLRs i.e. $L_{e}^{(k)} = L_{e}^{(k)} - L_{e}^{(k)}$. After some iteration, the decoder calculates a posteriori LLRs about the information bits $L_e^{(k)}$. Taking the proper sign, it gives an estimate of information bits.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_{i,k}$</td>
<td>Information bit user k</td>
</tr>
<tr>
<td>$c_{i,k}$</td>
<td>Coded bits</td>
</tr>
<tr>
<td>$c_{m,n,k}$</td>
<td>Interleaver output</td>
</tr>
<tr>
<td>$x_n$</td>
<td>Transmitted sequence</td>
</tr>
<tr>
<td>$\zeta_n$</td>
<td>Noise vector</td>
</tr>
<tr>
<td>$L_{e}^{(k)}$</td>
<td>Extrinsic LLR</td>
</tr>
<tr>
<td>$L_{e}^{(k)}$</td>
<td>Channel LLR</td>
</tr>
</tbody>
</table>
3. INTERLEAVER DESIGN

It is noted that any system may be chaotic if it follows certain properties, such as the system should be deterministic, noise like random in nature and its sensitive dependence on initial conditions so that different signals could be generated. Some of the popular chaotic maps are shown in Table 2, such as Logistic map, Tent map, Bernoulli’s map, Baker Map, Henon map etc. Here the algorithm of interleaver design is proposed on the basis of logistic map and tent map. The performance of chaotic IDMA is evaluated and compared using conventional and popular interleavers.

3.1 LOGISTIC MAP INTERLEAVER

Here, first the modified logistic map [15] is used for the generation of interleaver sequence. The NLM is described as,

\[ F_{m1}(x) = \mu x \left( 1 - \frac{x}{N} \right) \]  

(5)

where, \( x_0 \in [0,N] \) and \( N \) is the interleaver length. Further the above system Eq.(5) exhibits chaotic behavior for positive Lyapunov exponents and for bifurcation parameter, \( \mu \geq 3.58 \). In this paper the value of \( \mu = 4 \) is taken for the purpose of simulation. To design the interleaver, first the states are calculated for some predefined initial value. All of these states belong to the set of real values between 0 and \( N \). Now either by maximizing or ceiling function, all the states transit to integer values and remove the decimal values. Finally, the first interleaver sequence can be obtained after eliminating the redundant bits. Further, to get second interleaver sequence, the initial value of state is modified by adding a foot step to the previous state value i.e. \( x'_0 = x'_0 + \zeta \).

However all of the above mentioned steps are repeated to get the second interleaver and so on [13-15].

Table 2. Chaotic Maps

<table>
<thead>
<tr>
<th>Chaotic Map</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistic Map</td>
<td>( F_{m1}(x) = \mu x \left( 1 - \frac{x}{N} \right) )</td>
</tr>
</tbody>
</table>
| Tent Map      | \( F_m(x) = \begin{cases} 
mx_n & \text{if } 0 \leq x \leq 0.5 \\
mx_n + m & \text{if } 0.5 \leq x \leq 1 
\end{cases} \) |
| Baker Map     | \( F(x,y) = \begin{cases} 
\frac{2x-y}{2} & 0 < x < 0.5 \\
(2x-1), (y+0.5) & 0.5 < x < 1 
\end{cases} \) |
| Henon Map     | \( X_{n+1} = 1-aX_n^2 + Y_n \\
Y_{n+1} = bX_n \) |

3.2 TENT MAP INTERLEAVER

Some properties of Tent map are also very encouraging and make this map suitable for the generation of random sequences and consequently interleaving sequences too. Tent map satisfies all above-said conditions required for a map to be chaotic. In the parameterized form, tent map, can be described piecewise by,

\[ F_m(x) = \begin{cases} 
mx_n & \text{if } 0 \leq x \leq 0.5 \\
m(1-x_n) & \text{if } 0.5 \leq x \leq 1 
\end{cases} \]  

(6)

where, \( x_0 \) is the initial state and \( x \in [0,1] \) and parameter ‘\( m \)’ is known as bifurcation parameter. The Lyapunov exponent (L.E) can also be used to find that either system is chaotic or not. The value of L.E for the particular orbit of function \( f(x) \) can be written as [6],

\[ \lambda = \lim_{n \to \infty} \frac{1}{n} \sum_{j=0}^{n-1} \ln |f'(x)| \]  

(7)

Now, if \( \lambda \) is positive then the system exhibit the chaos in behavior. For example, the above said system Eq.(6) could be analyzed to find the value of lyapunov exponents. The derivative of tent map equations can be further written as,

\[ F'(x) = \begin{cases} 
m & \text{if } 0 \leq x \leq 0.5 \\
-m & \text{if } 0.5 \leq x \leq 1 
\end{cases} \]  

(8)

Put the outcome of Eq.(8) in the Eq.(7) to get Lyapunov constant such as,

\[ \lambda = \lim_{n \to \infty} \left( \frac{1}{n} \sum_{j=0}^{n-1} \ln |f'(x)| \right) = \ln |m|. \]

Further L.E can be simplified to,

\[ \lambda = \lim_{n \to \infty} \left( \frac{1}{n} \sum_{j=0}^{n-1} \ln |m| \right) = \ln |m|. \]

Thus, \( \lambda \) may be positive for \( |m| \geq 1 \) and hence the system (TENT map) may be chaotic. Hence Tent map sequences can be used for the generation of interleavers. The flow diagram to generate first interleaver is shown in Fig.2.

![Flow diagram for the generation of first interleaver using Tent map](image)

Here the states of tent map are transit to integer value and redundant bits are removed to generate a distinguished interleaver.
sequence. For the second user, the initial value or first value is modified by foot step $\xi$. Due to change in initial value and chaotic behavior of Tent map, the entirely different interleaver sequence is generated. The process can be repeated to get desired number of interleaver.

### 3.2.1 Algorithm:

- $m = 2$ (Bifurcation parameter),
- $N = $ interleaver length,
- $k = $ no. of users.
- $X_k^{(j)} = k^{th}$ user $: 0 < X_k^{(j)} < N$.
- $\xi =$ Foot step
- $F_{n}^k = \left[ X_{n}^{(j)} \right]: $ First element $(\Pi_k = F_{0}^k)$,
- $j=0, n=0$
- If $n < N$
  - Calculate $X_{j+l}^{(k)}$
  - $F_{j+l}^k = \left[ X_{j+l}^{(k)} \right]$
  - Now check: If $F_{j+l}^k$ is in the set $\Pi_k$, Increment $j$ by l and repeat
  - the main operation
- Else $\Pi_k = \Pi_k \cup F_{j+l}^k$
- If $n > N$
  - $X_{j+l}^{(k)} = \{ \}$
  - $\Pi_k = \Pi_k \cup \left[ X_{j+l}^{(k)} \right]$
- End

### 4. PERFORMANCE ANALYSIS

Table 3. Simulation parameters for BER analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information bits</td>
<td>Fig.3</td>
</tr>
<tr>
<td></td>
<td>Fig.4</td>
</tr>
<tr>
<td></td>
<td>Fig.5</td>
</tr>
<tr>
<td>Repetition code</td>
<td>$R_s=1/16,$</td>
</tr>
<tr>
<td></td>
<td>$R_s=1/16,$</td>
</tr>
<tr>
<td></td>
<td>$R_s=1/16$</td>
</tr>
<tr>
<td>Bit interleaver</td>
<td>Uniform random, TBI, TMI, logistic map</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Spread length</td>
<td>$N_s=16$</td>
</tr>
<tr>
<td></td>
<td>$N_s=16$</td>
</tr>
<tr>
<td></td>
<td>$N_s=16$</td>
</tr>
</tbody>
</table>

### 4.1 BIT-ERROR RATE ANALYSIS

In this section, the quality of transmission of conventional IDMA is evaluated for proposed chaos based interleaver. Random Interleaver, tree based (TBI), logistic map interleaver and Tent map interleaver are considered for bit error rate (BER) analysis in conventional IDMA system. For simplicity, BPSK modulation is considered in multipath Rayleigh fading channel. The data length for each user is assumed 1024 bits and repetition code is used as a spreading code with the length $s_l = 16$. Simulation parameters are shown in Table 3 for all simulation results.

In Fig.3, simulation results show the comparative BER performance of logistic map based interleaver with random interleaver. The data length is assumed 1024 bits, number of iterations are 10 and spread length $s_l = 16$ is considered. Simulation figure concludes that the performance of logistic map is nearly same as compared to RI and somewhat better for higher values of $E_b/N_0$. Hence, Logistic map algorithm can be more efficient for higher values of $E_b/N_0$.

In Fig.4, simulation results show the comparative BER analysis of one more chaos based Tent map interleaver with random interleaver. The data length is assumed 1024 bits, number of iterations are 10 and spread length $s_l = 16$ is considered. Simulation result verifies the performance of tent is better than random interleaver for higher values of $E_b/N_0$.

The comparative performance of logistic map and Tent map interleaver with conventional random interleaver is shown in Fig.5. The data length is considered to be 2096 bits, spread length=16 and iteration=10 is taken for performance analysis. Simulation results show that the Tent map based interleavers outperform the logistic map and random interleaver.

![Fig.3. BER comparison of logistic map and random interleaver for data length = 1024, spread length = 16, iteration = 10](image1)

![Fig.4. BER comparison of Tent map, random interleaver for data length = 1024, spread length = 16, iteration = 10, Block = 5](image2)
generate a specific interleaver. Hence only single bit i.e. initialization parameter is required to share between transmitter (MS) and receiver (BS). So, the TMI is efficient in memory requirement. In Table 5, memory requirement for different interleaver is presented. The spreaded data is represented as chip-length cl and k is the number of users.

Table 5. Memory requirement (per user) for different interleavers

<table>
<thead>
<tr>
<th>Interleavers</th>
<th>Memory requirement (chips/user)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random interleaver</td>
<td>(k \times c \times \log_2(cl))</td>
</tr>
<tr>
<td>Tree Based Interleaver</td>
<td>(2 \times c \times \log_2(cl))</td>
</tr>
<tr>
<td>Nested Interleaver</td>
<td>(c \times \log_2(cl))</td>
</tr>
<tr>
<td>Tent Map Interleaver</td>
<td>(c \times \log_2(cl))</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This paper proposes the chaos based algorithms for an efficient interleaver design. The interleaver design is based on the chaos theory and uses the logistic map and Tent map to generate interleavers for simultaneous users of pertinent system. The method achieves good bit error rate performance as well as it is potentially less complex computationally. The memory requirement is one of the major challenges in designing the interleavers but the simulation results verify that the storage requirement in chaos based interleavers is independent of users. Hence, a large number of interleaving sequences can be generated without investing additional resources. The research and findings also pave the path for further rectification and improvements in the method such as Tent map can be modified, so that IDMA based on TMI can be more suitable for secure communication.

REFERENCES


