COMMUNICATIONS

Performance analysis of modified tent map interleaver in IDMA systems

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In the last years, Interleave Division Multiple Access (IDMA) has been presented as a potential alternate of Code Division Multiple Access (CDMA) system. In IDMA systems, the interleavers are used to separate the users of the system in multiple access environments. Random interleaver is popular and basic taxonomy, which scrambles information bits of craving users with different patterns. However the indispensable characteristics of a random interleaver such as bandwidth requirement, computational complexity, and memory restraint at both transmitter and receiver end is uttermost. Further, it has also been observed that the study of role of chaos in interleaver design is very limited in literature. Hence, in this paper, a low complexity chaos based interleaver named as modified Tent map interleaver is designed for further performance improvement of IDMA system and the characteristic parameters are compared with the random interleaver. The IDMA system model uses a BPSK modulation and repetition coder with a code rate of $1/2$. The system is simulated in MATLAB and results show that the better BER performance without the need of extra memory resources.

K e y w o r d s: IDMA, tent map, chaos, random interleaver, computational complexity

1 Introduction

It is widely known that interleave-division multiple access (IDMA) scheme is the promising candidate for future multiple access communication requirements that employs chip-level interleavers for user separation, unlike CDMA scheme where each user is assigned a spreading sequence. This technique overcomes the limitations of CDMA system such as multiple access interference (MAI), and intersymbol interference (ISI) [1–3]. Beside user separation, interleavers are also used to randomize the error bursts. Hence, an efficient interleaver can improve the performance of iterative IDMA system. However, the design of interleavers for multiple access (MA) systems is quite different from that of Turbo codes. For MA systems the interleavers should be easy to generate, non-colloidal in nature and consumed less bandwidth and memory resources [4–6].

Recent research work has manifested the role of chaos in spread spectrum communication systems, working at the level of code design and random data generation can be more efficient. Moreover, chaotic sequences offer many interesting properties subjected to computational complexity or storage requirement [7–10]. More specifically, chaotic sequences can be used for interleaver design and yield a promising bit error rate performance in IDMA system. In this paper, a new chaotic map based interleaving design is being introduced named as "Modified Tent Map Interleaver" (MTMI) in IDMA scheme. The proposed interleaver has stronger randomness, relatively larger Lyapunov exponent, less computational complexity and memory requirement [11–14]

2 System Model

This is to note that the conventional code-division multiple access (CDMA) systems have some limitations and to mitigate them, IDMA system has been proposed. In IDMA system, users are separated by user specific chip-level interleavers. At the transmitter, the n-length input data sequence $b_k = [b_{k1}, b_{k2}, \ldots, b_{ki}, \ldots, b_{kn}]$ of kth user $k \in (1, 2, 3, \ldots, N)$ is spreaded and encoded into chips $c_k = [c_{k1}, c_{k2}, \ldots, c_{kj}]$, where j is the Chip length. The spreader and encoder are combined and belonging to code word c, which is same for all users. Next, chips are interleaved by a specific interleaving pattern (based on modified chaotic Tent map) to produce transmitted chip sequence x_n [3]. The receiver for IDMA system of k simultaneously transmitting users are comprised of multiuser detector (MUD) and posterior probability (APP) decoders in connection with user specific interleavers. The APP decoders and interleavers exchange the soft information and calculate the log likelihood ratios (LLRs) [10]. These LLRs should be independent from the users and hence called as extrinsic LLRs.

The MUD receives the *a priori* LLR sent from the decoder and can be defined as $L_a^m(c'_{m,n,k}) = \frac{P\{c'_{m,n,k} = +1\}}{P\{c'_{m,n,k} = -1\}}$. With the knowledge of this *a-priori* LLR, the goal of the multi user detector is to compute the posterior LLRs, which can be represented as

$$L^m(c'_{m,n,k}) = \ln \frac{P(c'_{m,n,k} = +1/y_n)}{P(c'_{m,n,k} = -1/y_n)}. \qquad (1)$$

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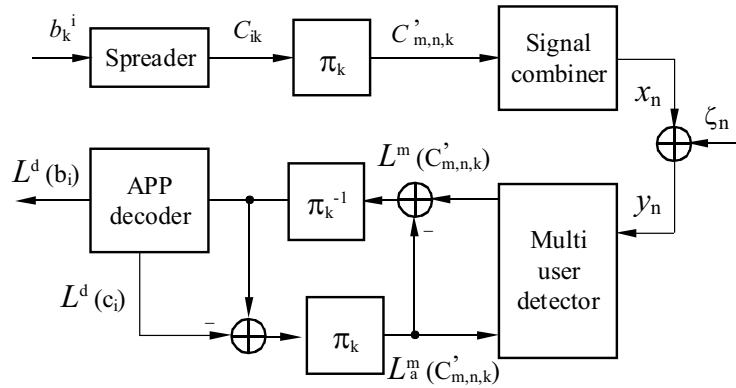
Fig. 1. - Transmitter and Receiver structure of IDMA for k^{th} user

The extrinsic LLRs can be calculated as $L_e^m(c'_{m,n,k}) = L^m(c'_{m,n,k}) - L_a^m(c'_{m,n,k})$ and then sent to the decoder after de-interleaving operation *ie* π_k^{-1}. Further, by using total probability theorem the extrinsic LLR can be written as [2]

$$L_e^m(c'_{m,n,k}) =$$
$$\ln \frac{\sum\limits_{c'_{m,n,k}=+1} P\{y_n \mid x_{n,k}=x\} \prod\limits_{m' \neq m} P\{c'_{m,n,k}=d_{m'}\}}{\sum\limits_{c'_{m,n,k}=-1} P\{y_n \mid x_{n,k}=x\} \prod\limits_{m' \neq m} P\{c'_{m,n,k}=d_{m'}\}}. \quad (2)$$

Here $d_{m'}$ denotes the m-th bit of symbol x. Each of decoder receives the de-interleaved extrinsic LLRs and channel LLRs L_c^d. Now with constraints on number of iterations, the decoder computed posterior LLRs L^d. To get extrinsic LLRs, the channel LLRs are subtracted from posterior LLRs *ie* $L_e^d = L^d - L_c^d$. After 5 to 10 iterations (to optimize delay), the decoder calculates posterior LLRs about the information bits $L^d(b_i)$. Taking the proper sign, it gives an estimate of information bits. Table 1 shows the list of all used notations and parameters.

Table 1. Used parameters

S.no	Symbols	Description
1	$b_{i,k}$	Information bit for user k
2	$c_{j,k}$	Coded bits
3	$c_{m,n,k}$	Interleaver output
4	x_n	Transmitted sequence
5	ξ_n	Noise vector
6	$L^m(c'_{m,n,k})$	Extrinsic LLR
7	L_e^d	Channel LLR

3 Proposed modified tent map interleaver

In the parameterized form, tent map, can be described piecewise by

$$F_m(x) = \begin{cases} mx_n, & 0 \le x \le \frac{1}{2}, \\ m(1-x_n), & \frac{1}{2} << x \le 1, \end{cases} \quad (3)$$

where x_0 is the initial state and $x \in [0,1]$ and parameter m is known as bifurcation parameter. This parameter decides the qualitative behaviour of system and produce chaotic region for the values of $m \in (1,2)$. To increase the randomness of classical tent map, the improved and modified tent map has been suggested [12] and can be written as

$$F_m(x) = \begin{cases} (x_n - a\lfloor x_n/a \rfloor)/a, & \forall \lfloor x_n/a \rfloor \text{ even,} \\ (a(\lfloor x_n/a \rfloor + 1) - x_n)/a, & \forall \lfloor x_n/a \rfloor \text{ odd,} \end{cases} \quad (4)$$

where $x_n \in (0,1)$ and system parameter is taken as $a \in (0, 0.5)$. The state values of improved Tent map shows larger randomness [12], so the interleaver based on modified Tent map provides better BER performance in IDMA system. Further, modified Map has larger values of Lyapunov exponents (LE), which implies that system (4) has better chaotic behaviour than classical Tent map. C_0 Complexity analysis is used to measure the complexity of chaotic system. Larger values of C_0 means for high complexity of system. The value of complexity for classical Tent map and improved map is given in Table 2.

Table 2. C_0 complexity values for different system parameters

System Parameter(a)	Tent Map (C_0 values)	Modified Tent Map (C_0 Values) (approx.)
0.1	0.0012	0.252
0.2	0.0012	0.254
0.3	0.0012	0.223
0.4	0.0012	0.209
0.5	0.0012	0.262

For a wider range of system parameters the Modified Tent map provides different values of C_0 and hence more complex and chaotic than classical Tent map. So the MTMI system is more suitable for application in secure communication and cryptography [4]. The algorithm for proposed modified tent map interleaver shows the method of generation of interleavers.
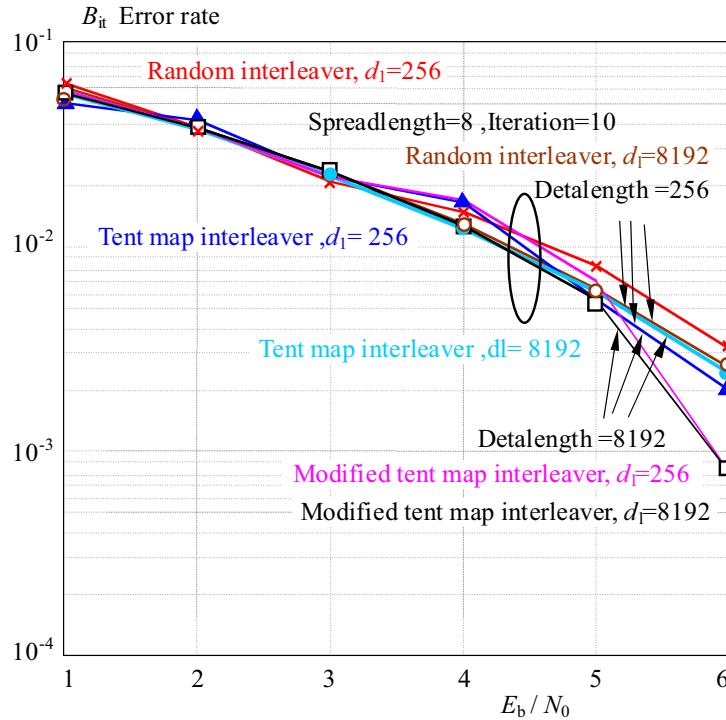
Fig. 2. The BER performance of modified tent map interleaver for data lengths 512, 8192, spread lengths $= 8$, iteration $= 10$

4 Algorithm

1. Initialization: $m \in (1, 2]$, $N =$ Interleaver length, $a = 0.4$,
2. $X_j^k = k^{\text{th}}$ user: $0 < X_j^k < N$, $\xi =$ Foot step,
3. $F_0^k = |X_0^k|$: the first element $(\Pi^k = F_0^k)$, $j = 0$ and $n = 0$,

Main operation:

4. If $\lfloor x/a \rfloor =$ even
5. Calculate X_{j+1}^k,
6. $F_{j+1}^k = |X_{j+1}^k|$,
7. Now check if F_{j+1}^k is in the set Π^k,
8. Increment j by 1 and repeat the main operation,
9. Otherwise $\Pi^k = \Pi^k \cup F_{j+1}^k$,
10. If floor $\lfloor x/a \rfloor =$ odd
11. $F_{j+1}^k = |X_{j+1}^k|$,
12. $\Pi^k = \Pi^k \cup |X_{j+1}^k|$,
13. End.

Finally redundant bits are removed to find the interleaver vector. For the second user, the initial value or first value is modified by foot step ξ and then used as initial state to generate the whole sequence. The whole operation is repeated to get second interleaver and so on.

5 Error–rate analysis

The performance of proposed algorithm is vindicated by the simulation model in MATLAB. Random Interleaver (RI) Tent map interleaver (TMI) and modified Tent map interleaver (MTMI) are considered for bit error rate (BER) analysis of conventional IDMA system. For simplicity, BPSK modulation is considered in multipath Rayleigh fading channel. The data length for each user is assumed 512 and 8192 bits and spreading code for all users is simply a repetition code with the length $S = 8$. Simulation results authenticate the performance of TMI in IDMA system. This is clear in Fig. 2 that the proposed modified Tent map interleaver (MTMI) achieves similar BER performance compared to RI and better for $E_b/N_0 \geq 5$. Hence, modified Tent map algorithm can be more efficient for higher values of E_b/N_0.

6 Computational complexity

Other than BER analysis, Computational complexity is also a crucial parameter to find an efficient interleaver. Here, complexity measure is meant by the number of cycles required for the generation of spreading codes and interleaver matrix in terms of users. In this section, computational complexity is calculated for modified tent map interleaver and compare with the random interleaver and Tent map interleaver. Table 3 shows that the required number of cycles increases with the number of user k for random interleaver. It means that complexity of RI is dependent on users. However, the proposed design of MTMI is independent from the number of users. Computational complexity is presented in Table 3 and verified that computational complexity of modified tent map interleaver is least possible[15–16].

Table 3. Number of cycles requited for the generation of interleaver

No. of Users	Random Interleaver	TMI	MTMI
1	1	1	1
2	2	1	1
4	4	1	1
16	16	1	1
50	50	1	1

7 Memory requirement

To decode or de-interleave the information bits, interleaving pattern must be known to the receiver. So, the key pattern is also sent along with transmitted data sequence, which leads the requirement of memory to store the interleaving pattern at the receiver end. The large amount of memory is required for large no. of users and becomes a major concern in the designing of interleaver for IDMA system. The proposed modified Tent map based interleaver algorithm suggests the need of only initialization parameter to generate a specific interleaver. Hence only single bit *ie* initialization parameter is required to share between transmitter (MS) and receiver (BS). So, the modified TMI is efficient in memory requirement. In Table 4, memory requirement for different interleaver is presented. The spreaded data is represented as chip-length cl and k is no. of users.

Table 4. Memory requirement for interleavers

Interleaver	Memory Requirement (chips/user)
Random Interleaver	$k \times cl \times \log_2(cl)$
Tent map Interleaver	$cl \times \log_2(cl)$
Modified Tent map Interleaver	$cl \times \log_2(cl)$

8 Conclusion

The main contribution of this paper is to propose the new design of modified TENT map interleaver, based on the chaos theory. It achieves good bit error rate performance as well as it is potentially less complex computationally. The simulation results verify that the storage requirement in modified TMI is independent of users. This improved technique is also compared with Random and Tent map interleaver and the superiority is validated through simulation results.

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