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A Fast Computational Interleaver Design for Iterative IDMA Scheme Based on Tent Map and Chaos

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Abstract

Interleave Division Multiple Access (IDMA henceforth) with iterative multi user detector (MUD) is the special case of CDMA and a suitable candidate for future communication requirements. IDMA uses low rate coding for spreading and interleavers for users separation. The random interleaver is the fundamental anatomy in the IDMA system and also related to the system throughput. However indispensable characteristics of random interleavers, such as computational complexity, memory requirement and bit error rate analysis are the crucial performance parameters. Further it has also been observed that, the interleaver design based on chaos theory is presented only in limited volume of research papers. In this paper, a fast computational chaotic Tent map based interleaving scheme is proposed for further performance improvement of IDMA scheme. Improved version of Tent map has also been utilized in the generation of interleaver, which make IDMA system more suitable for secure communication. The IDMA system is simulated in MATLAB. BPSK modulation and repletion coder of rate R_r is used for the purpose to find simulation results to verify that modified Tent map based IDMA is efficient and gives better bit error rate performance without the need of extra memory resources and offers less computational complexity than existing prevailing models in the domain.

***Keywords**: IDMA, chaos theory, Tent map based interleaver, Logistic map, CDMA*

1. Introduction

Multiple access schemes are required to fulfill the needs of communication in the multi-user environment. Code division multiple access (CDMA) can be considered as a suitable and popular for 3G and future communication requirements. In this scheme, all the users are separated on the basis of spreading codes and share the whole spectrum simultaneously. CDMA was deployed in many countries for 2G and 3G services and it was found suitable too. But later, multiple access interference (MAI) and Intersymbol Interference (ISI) were aroused as a major concern [1-3]. To mitigate the concerns and for performance improvement of CDMA, the mixing of spreading and coding is being suggested. The entire bandwidth is devoted to the coding and interleavers are dedicated to distinguish the users. So, the use of interleavers enhances the system throughput in multi-user environment and the bursty channel appears like random error channel. The interleaver based multiple access is popularly named as Interleave division multiple access [4-7].

Many popular interleaver designs are available in the literature and the researchers in the past had given proper attention to the design of an efficient interleaver matrix. Orthogonal Interleaver (OI), Pseudo-random interleaver, Tree based Interleaver (TBI), Helical Interleaver, Nested Interleaver, Shifting Interleaver, Deterministic Interleavers are

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some popular interleavers in the domain [8-12]. The first prominent interleaver design is reported by Ramsey (1970) in which an algorithm is proposed with small delay and less storage capacity. The main limitation of basic Random interleaver is the high memory requirement and so the bandwidth. Pseudo random interleaver has also not performed well with the large number of users due to the unavailability of enough primitive polynomials. Later, other interleavers have also been proposed for performance improvement of IDMA system. Table 1 shows the different interleavers with their major limitations, such as; the limitation for the Nested interleaver (NI) is the large memory requirement and bandwidth. Orthogonal interleaver requires large number of orthogonal signals which are not easy to generate. On the other hand, the use of shifting interleaver provide better performance but not suitable for multi-user detector (MUD) receiver [13-16]. Recently, the use of chaos become popular into spread spectrum communication systems. Randomness and dependency on the initial conditions of chaos may lead the generation of random-like, yet deterministic and reproducible sequences [17-18]. Chaos based sequences are inherently orthogonal in nature and this ensures good decorrelation between users and so reduce multiple access interference (MAI). The popular chaotic maps are Logistic map, Tent map, Bernoulli's map, Baker Map, Henon map *etc*, available for the generation of chaotic sequences and so the interleaving sequences. So far, however the work reported on the use of chaos for interleaver designing is very limited [22].

Table 1. Different Interleavers with their Limitations

S.no	Interleaver	Limitations
1	Random Interleaver	Memory requirement is high
2	Pseudo Random Interleaver	Memory requirement is high
3	Nested Interleaver	Memory and bandwidth requirement is high
4	Orthogonal Interleaver	Unavailability of orthogonal signals for large number of users
5	Deterministic Interleaver	Need of look up table
6	Shifting Interleaver	Not suitable for MUD receiver
7	Tree based Interleaver	Memory requirement is high

In this paper, the classical Tent map and improved version *i.e* modified Tent map is used for interleaver generation. The proposed interleaver is based on Tent map due to the following reasons [19-22].

- ✓ The signals generated by the Tent map present rich and different behavior but easily summarized.
- ✓ Tent map is piecewise linear and their orbits present uniform invariant density which allow analytical calculations.
- ✓ Highly depends upon initial conditions and produce different sequence due to small change in initial parameter.
- ✓ Modified Tent map based sequences make system suitable for secure communication.

The rest of the paper is organized as follows. IDMA system description is given in Section 2. In Section 3 chaos based algorithms for interleaver design has been illustrated. The performance analysis of proposed interleaver with IDMA scheme is prposed in Section 4. Finally, conclusions are drawn in Section 5.

2. IDMA System Model

Figure 1 illustates the general transmitter and receiver structure of IDMA. At the transmitter, the l-length input data sequence $b_{i,k}$ of k[th] , $k \in (1,2,3.....N)$ user is encoded by encoder of rate R converted in to chips after spreading by a repetition coder of rate R_c. The spreaded data chips can be written as $c_{j,k} = \lfloor c_{j1}, c_{j2,..........}c_{kj} \rfloor$, where j is the Chip length. The chips stream are now interleaved with the tent map based interleaver to produce transmitter output *i.e.* transmitted chip sequence $x_k, k \in (1,2,3.....N)$. Multipath fading environment is assumed as a wireless channel with memory length $w-1$. The fading channel coefficients can be assumed as $\{h_{k,0}, h_{k,1}.......h_{k,w-1}\}$ for all k users. In receiver section, the received signal from the K_{th} users with channel coefficient h_k and for samples of fading { ζ_j } can be written as [12]-

$$y_j = \sum_{k=1}^{K}\sum_{w=0}^{W-1} h_{k,w} x_k (j-w) + n(j) \tag{1}$$

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 interleavers. The APP decoders and interleavers 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:

$$L^m(c'_{m,n,k}) = \ln \frac{P(c'_{m,n,k} = +1/y_n)}{P(c'_{m,n,k} = -1/y_n)} \tag{2}$$

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

$$L_c^m(c'_{m,n,k}) =$$

$$\ln \frac{\sum_{C'_{m,n,k=+1}} P\{y_n | x_{n,k} = x\} \prod_{m' \neq m} P\{c'_{m',n,k} = d_{m'}\}}{\sum_{C'_{m,n,k=-1}} P\{y_n | x_{n,k} = x\} \prod_{m' \neq m} P\{c'_{m',n,k} = d_{m'}\}} \tag{3}$$

Here $d_{m'} \in \{+1,-1\}$ 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 some constraints the decoder computed a posteriori LLRs L^d. To get extrinsic LLRs, the channel LLRs are subtracted from posteriori LLRs *i.e.* $L_e^d = L^d - L_c^d$. After 5-10 iteration, the decoder calculates a posteriori LLRs about the information bits $L^d(b_i)$. Taking the proper sign, it gives an estimate of information bits. Table 2 shows the notation and parameters of IDMA system model.

Table 2. Used Parameters and their Description

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	ζ_n	Noise vector
6	$L^m(c'_{m,n,k})$	Extrinsic LLR
7	L_e^d	Channel LLR

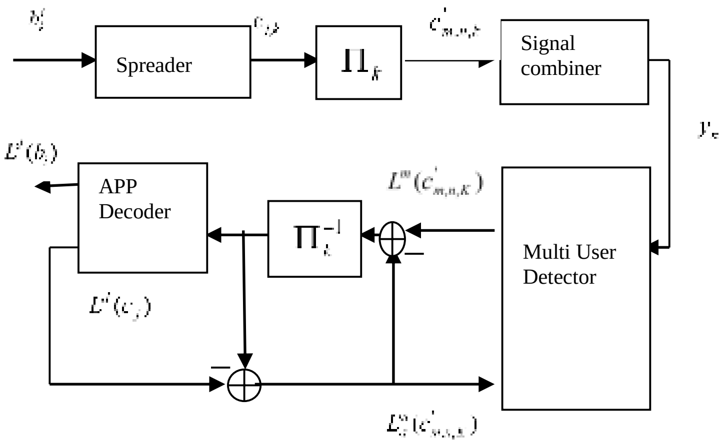

Figure 1. Transmitter and Receiver Block for N[th] user of IDMA System

3. Interleaver Design Based on TENT Map

Adriana *et al* (2013) proposed a new running key approach and apply it on Tent map to generate the zero redundant pseudo random sequences, which leads its application for the generation of random sequences and consequently interleaving sequences too. In the parameterized form, tent map $F_m : [0,1] \to [0,1]$ can be described piecewise by [21]:

$$F_m(x) = \begin{cases} mx_n, if\ 0 \le x \le \frac{1}{2} \\ m(1 - x_n), if\ \frac{1}{2} \le x \le 1 \end{cases} \tag{4}$$

Where x_0 is the initial state and $x \in [0,1]$.The parameter 'm' is known as bifurcation parameter and restricted in the interval (1,2] for the chaotic region of Tent map. Changpin Li (2004) also used Marotto-Li-Chen theorem to determine the chaos- parameter-region for the Tent map [22]. For the proof, say, refer to [22]. 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 (2):

$$\lambda = \lim_{n \to \infty} \left\{ \frac{1}{n} \sum_{j=0}^{n-1} \ln \left| f\ '(x) \right| \right\} \tag{5}$$

Now, if λ is positive then the system exhibit the chaos in behavior. For example, the above said system (2) could be analyzed to find the value of lyapunov exponents. The derivative of tent map equations can be further written as

$$F^{'}(x) = \begin{cases} m, if\, 0 \le x \le 0.5 \\ -m, if\, 0.5 \le x \le 1 \end{cases} \tag{6}$$

Put the outcome of equation (4) in the equation (3) to get Lyapunov constant such as $\lambda = \lim_{n\to\infty}\left\{\frac{1}{n}\sum_{j=0}^{n-1}\ln|\pm m|\right\}$, Further L.E. can be simplified to $\lambda = \lim_{n\to\infty}\left\{\frac{1}{n}\ln|m|^{n}\right\} = \ln|m|$. Thus λ may be positive for $|m| \ge 1$ and hence the system (TENT map) may be chaotic.

3.1. TENT Map Interleaver

The first value or initial state of the system starts from X_0 and then the sequence of states may be written as $\{X_1, X_2 ....X_N\}$. All these states toggle between 0 &1 and N is the length of interleaver. The bifurcation parameter is denoted by 'm'. The integer state of generated sequence can also be found by either using max[X], min[X] or floor[X].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. This new first value is used as initial state to generate the whole sequence. The whole operation is repeated to get second interleaver and so on.

Algorithm: Tent Map Interleaver

1. $m = 2$ (Bifurcation parameter), N= interleaver length, k = no. of users
2. $X_j^k = k^{th} user$: $0 < X_j^k < N$, ξ = Foot step $F_0^k = \left| X_0^k \right|$: the first element $(\Pi^k \equiv F_0^k)$, j=0, n=0
3. If n < N
4. Calculate X_{j+1}^k
5. $F_{j+1}^k \equiv \left| X_{j+1}^k \right|$
6. Now check - If F_{j+1}^k is in the set Π^k, Increment j by 1 and repeat the main operation
7. Otherwise $\Pi^k \equiv \Pi^k \cup F_{j+1}^k$
8. If n >N:
9. $X_{j+1}^k = \{\ \}$
10. $\Pi^k \equiv \Pi^k \cup \left| X_{j+1}^k \right|$
11. End

3.2. Modified TENT Map Interleaver

To increase the randomness of classical tent map, the improved and modified tent map has been suggested [14].In modified Tent map $x_n \in (0,1)$ and system parameter is taken as $a \in (0,0.5)$.The floor(x) function provide the integer value of system state.the modified tent map system is defined in equation (4). The improved Tent map has greater value of randomness. Both the system (3) and (4) are compared for the large set of random parameters. In particular for the values of $x_0 = 0.23$ and $a = 0.24$, system (3) converged to $x_n = 0$ after 56 iterations, however system (4) is distributed states randomly in the range (0, 1).hence modified Tent map shows stronger randomness.

$$F_m(x) = \begin{cases} (x_n - a \times floor(x_n / a)) / a, \forall floor(x_n / a) = even \\ a \times (floor(x_n / a) + 1) - x_n) / a, \forall floor(x_n / a) = odd \end{cases} \tag{7}$$

To compare further, this is also to note that the modified Map has large value of Lyapunov exponents (LE), which implies that system (4) has better chaotic behavior 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 3. For a wider range of system parameters the Modified Tent map provides different values of C_0 and hence more complex than classical Tent map.So the MTMI system is more suitable for secure communication.The algorithm to generate interleavers is similar to the classical Tent map interleaver.

Table 3. 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

Algorithm: Modified Tent Map Interleaver (MTMI)

1. $m = 2$, N= interleaver length, a=0.4 $X_j^k = k^{th} user$ $0 < X_j^k < N$,

2. ξ = Foot step, $F_0^k = |X_0^k|$: The first element $(\Pi^k \equiv F_0^k)$, j=0 and n=0

3. If floor (x_n / a)==even

4. Calculate X_{j+1}^k

5. $F_{j+1}^k \equiv |X_{j+1}^k|$

6. Now check - If F_{j+1}^k is in the set Π^k

7. Increment j by 1 and repeat the main operation

8. Otherwise

9. $\Pi^k \equiv \Pi^k \cup F_{j+1}^k$

10. If floor (x_n / a) == odd

11. $F_{j+1}^k \equiv |X_{j+1}^k|$

12. $\Pi^k \equiv \Pi^k \cup |X_{j+1}^k|$

13. **End**

Table 4. Common Simulation Parameters

S. no.	Parameter	[Figure 2]	[Figure 3]	[Figure 4]	[Figure 5]
1	Information bits	1024,2048	2096	1024	256,8192
2	Repetition code	R_r=1/16,	R_r=1/16,	R_r=1/4	R_r=1/8,
3	Bit interleaver	Uniform random, TMI, logistic map, MTMI			

4	modulation	BPSK			
5	Spreading code length	N_s=16	N_s=16	N_s=4	N_s=8

4. Performance of TENT Map Based IDMA System

4.1. Error -Rate Analysis

In this section, the performance of Tent map and improved Tent map interleaver in IDMA is evaluated by the means of computer simulations. The common simulation parameters are summarized in Table 4. For IDMA, the information bits are encoded by the rate $R_r = 1/16$ repetition code to get coded bits. The repetition code also changes the sign of input bit stream to balance the number of 1 and -1. The code bits C_{kj} are further interleaved by user- distinct chip level interleaver Π_k to get transmitted chip sequence $x_{j1}, x_{j2}.........x_{kj}$ respectively. Figure 2 illustrates the BER performance of Tent map interleaver based IDMA system in comparison with random interleaver. For simulation purpose, BPSK modulation is considered in multipath Rayleigh fading environment.The data length for result is assumed to be 1024 and 2048 bits and spreading code for all users is simply a repetition code with the length S=16. The BER performance of Tent map interleaver is superior to random interleaver at high values of E_b/N_0.

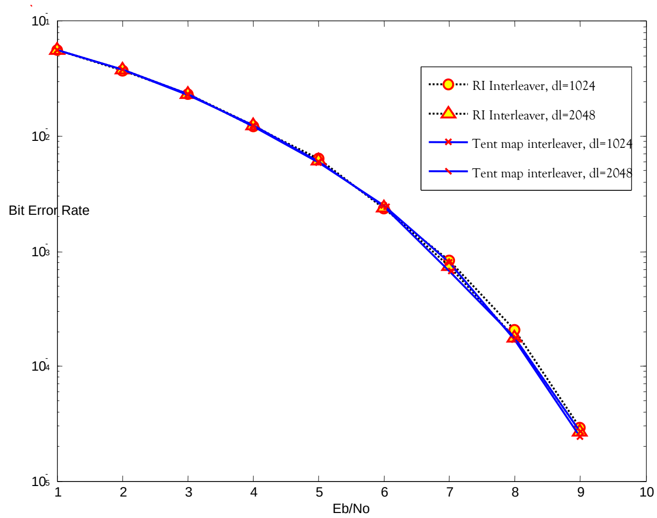

Figure 2. ber PERFORMANCE of TMI and RI after 10 Iterations with N=1024, 2048 Bits

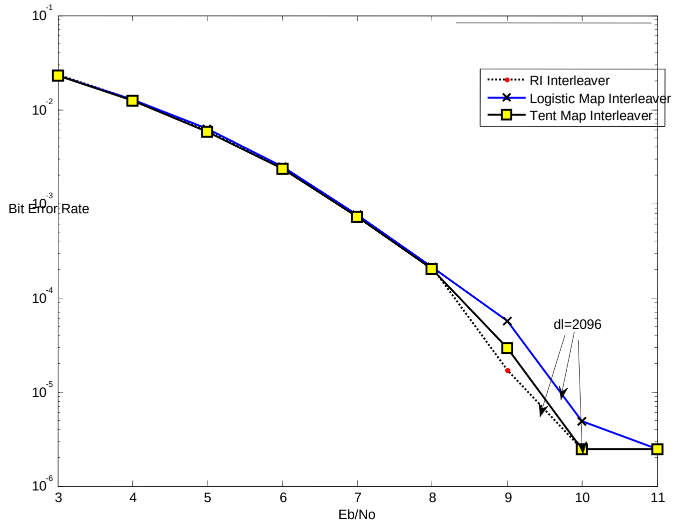

Figure 3. BER Comparison of TMI, Logistic Map Interleaver and RI after 10 Iteration and N=2048

Next, the performance of Tent map interleaver is compared to the logistic map interleaver (belongs to chaos family) to validate its superiority among the chaotic map based interleavers. In Figure 3, the simulation result for Tent map interleaver and logistic map interleaver is presented for the data length (dl) =2048 bits. BER results authenticate that the performance of TMI is better than logistic map in IDMA system.

To step further TMI based IDMA is also compared with recently proposed Tree based interleaver. Figure 4 presents the BER performance of TMI and Tree based interleaver. This can be easily concluded that TMI based system performs better for higher values of E_b / N_0

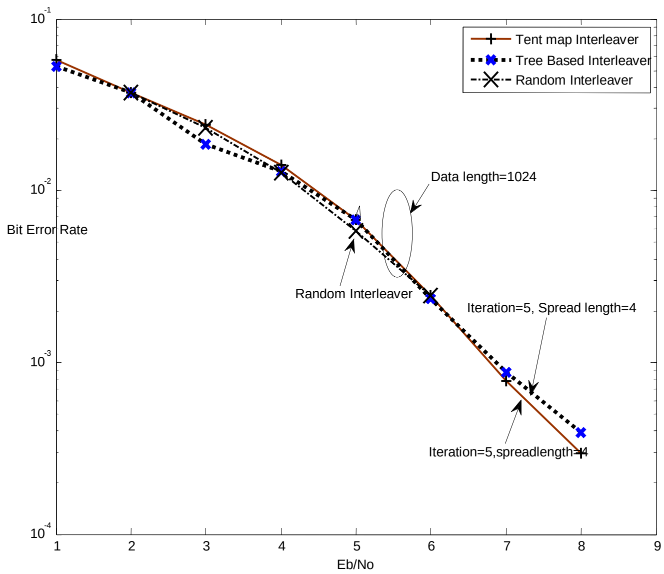

Figure 4. BER Comparison of TMI, TBI and RI after 5 Iteration with N=4 and Spread Length N_s=4

Above all simulation results show that TMI outperforms the other popular interleavers. But in highly insecure scenarios the Tent Map is need to be modify to make its suitability for secure communication. Hence the interleaver based on modified Tent map is proposed. In Figure 5, the performance of modified Tent map interleaver is simulated with Tent map and RI for IDMA system. The data length is assumed to be 256 and 8192 bits, spread length taken as N_s =8 bits repetition code. It can be noted that the modified version of tent map has good BER performance in comparison to classical Tent map at higher values of E_b / N_0.

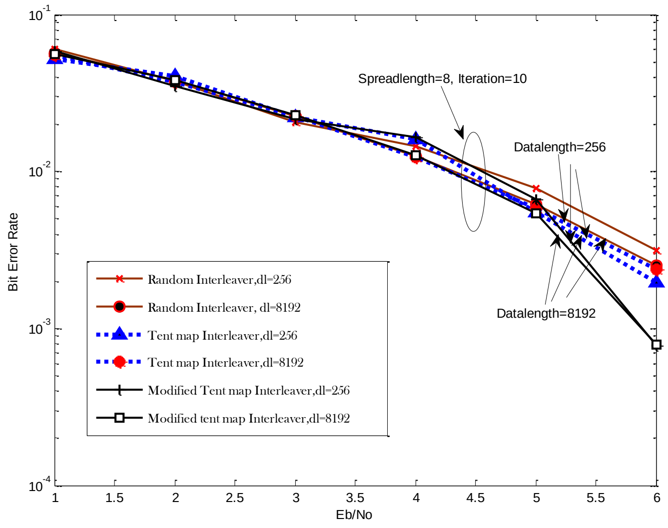

Fig 5. BER Performance of Modified Tent Map Interleaver and Tent Map Interleaver after 5 Iterations, N=256, 8192, Ns=8

4.2. Computational Complexity

Computational complexity is also an important quality check parameter for the interleaver. It is desirable that interleaver should have low computational complexity to minimize the delay. Here complexity of interleaver is defined in the terms of number of iterations required for the generation of desirable interleaver matrix with respect to users. This section presents the comparision of computational complexity of modified tent map interleaver with random interleaver (RI), tree based interleaver (TBI) and classical Tent map interleaver. [22]. Table 5 presents the number of iterations required to generate the interleaver for a specific user count. This can be noted that numbers of cycles are increases as the number of user increases for random interleaver and tree based interleaver, but TMI and MTMI algorithm need only single cycle for interleaver generation. The Table 5 shows that MTMI and TMI have computational complexity independent of user count. It means that complexity can be represents as O (1). Figure 6 present the simulation result of computational complexity for each interleaver with respect to user count and it can be clearly depicted that modified tent interleaver is less complex computationaly or fast conmputational for large number of users.

Table 5. Number of Cycles Required for the Generation of k^{th} Interleaver

USER COUNT	RI	TBI	TMI	MTMI
1	1	1	1	1
2	2	1	1	1
4	4	2	1	1
8	8	3	1	1
16	16	4	1	1

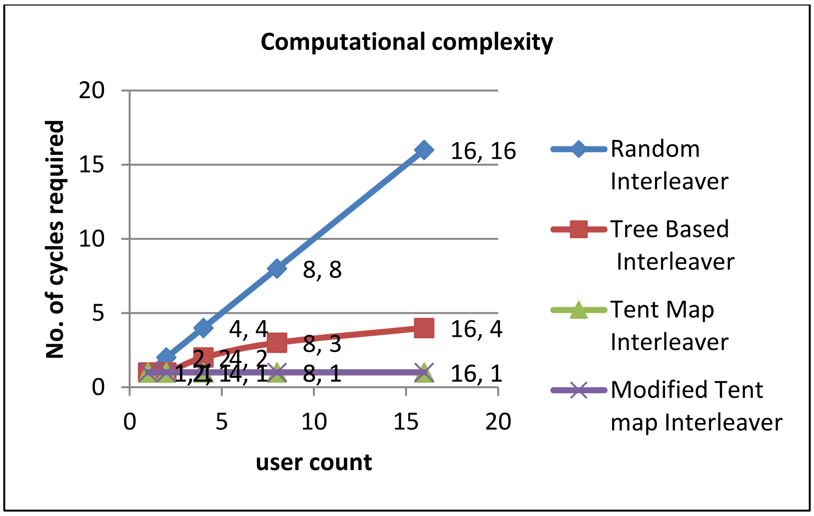

Figure 6. Computational Complexity of Interleavers With Respect To User Count

4.3. Memory Requirements

This is to note that the algorithm or interleaver is required at the receiver to de-interleave the transmitted information bits. Generally, in IDMA communication systems the transmitter sent the interleaving sequences to the receiver with the data sequences for proper de-interleaving. For this the receiver has to store the de-interleaving algorithm and lead to sufficient storage requirement. Large number of users demand large memory requirement which is not desirable. The proposed MTMI interleaver algorithm suggests the need of only initialization parameter to generate a specific interleaver. Table 6 shows the storage requirement for different interleaver algorithm. User count is specified by k, chip length is considered as cl. Figure 7 shows the simulation result for k=8 and cl=256.It can be concluded that modified Tent interleaver is efficient in the requirement of memory without compromising the performance of IDMA.

Table-6. Memory Requirement (chips/user)

S.no.	Interleavers	Memory requirement (chips/user)
1	Random interleaver	$k \times cl \times \log_2(cl)$
2	Tree based interleaver	$2 \times cl \times \log_2(cl)$
3	Tent map interleaver	$cl \times \log_2(cl)$
4	Modified TMI	$cl \times \log_2(cl)$

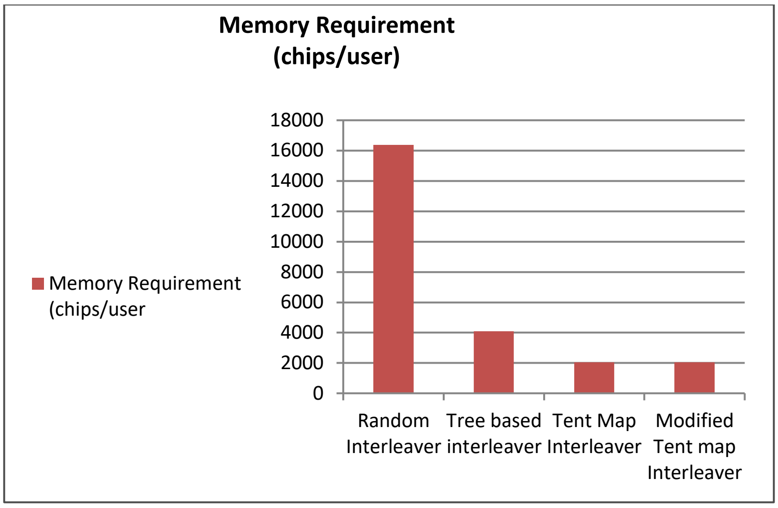

Figure 7. Memory Requirement (Chips/User) For Interleavers

5. Conclusions

This paper presents an efficient and fast computational interleaver algorithm illustrated as 'modified Tent map interleaver'. This method is based on the theory of chaos and generates interleavers for simultaneous users of relevant system. The classical Tent map is modified to get more ergodic uniformity and randomness. This makes IDMA system more suitable for secure communication. In addition MTMI achieves less computational complexity and good bit error rate performance. To step further, the memory requirement is also calculated for proposed interleaver and it is found that storage is also optimally required. Hence, a large number of users can simultaneously process the information without investing additional storage resources. The research and findings also motivates for further rectification and improvements in the method so that Tent map could be modified, to make system more useful and robust to hacking attacks. Thus safety of transmission and more robust interleaver design may be the next direction to study.

References

[1] T. Yoshida, H. Mori, and H. Shigematsu, "Analytic study of chaos of the tent map: band structures, power spectra, and critical behaviors", Journal of Statistical Physics, vol. 31, no. 2, **(1983)**, pp. 279–308.

[2] K. Kusume, G. Bauch and W. Utschick, "IDMA vs. CDMA: Analysis and comparison of two multiple access schemes", IEEE Transactions on wireless communications, vol. 11, no. 1, **(2012)**, pp. 78-87.

[3] H. Khanzadi, M. Eshghi and S. E. Borujeni, "Design and FPGA implementation of a pseudo random bit generator using chaotic maps", IETE Journal of Research, vol. 59, no. 1, **(2013)**, pp. 63-73.

[4] B. Akbil, G. Ferre and D. Aboustajdine, "The NLM Interleaver Design for IDMA system", Proc of IEEE international conference on complex system, **(2012)**, pp. 1-5.

[5] L. Shan, H. Qiang, J. Li and Z. Wang, "Chaotic optimization algorithm based on Tent map", Control and Decision, vol. 20, no. 2, **(2005)**, pp. 179–182.

[6] O. M. Kwon, J. H. Park and S. M. Lee, "Secure communication based on chaotic synchronization via interval time-varying delay feedback control", Nonlinear Dynamics, vol. 63, no. 2, **(2011)**, pp.239–252.

[7] Y. Cao, "A new hybrid chaotic map and its application on image encryption and hiding", Mathematical Problems in Engineering, Article ID 728375, **(2013)**.

[8] M. Eisencraft, R.D. Fanganiello, J.M.V. Grzybowski, D.C. Soriano, R. Attux, A.M. Batista, E.E.N. Macau, L.H.A. Monteiro, J.M.T. Romano, R. Suyama and T. Yoneyama, "Chaos-based communication systems in non-ideal channels", Communications in Nonlinear Science and Numerical Simulation, vol. 17, no. 12, **(2012)**, pp.4707-4718.

[9] M. Eisencraft, D. M. Kato and L. H. A. Monteiro, "Spectral properties of chaotic signals generated by the skew tent map", Signal Processing, vol. 90, no. 1,**(2010)**, pp 385-390.

[10] F.J. Escribano, A. Wagemakers and M. A. F. Sanjuan, "Chaos-based Turbo systems in Fading channels", IEEE Transaction on circuits and systems, vol. 61, no. 2, **(2014),** pp. 530-541.

[11] L. Ping, L. Liu, K. Wu and W. K. Leung, "Interleave-Division Multiple-Access", IEEE Transaction on Wireless Comm., vol. 5, no. 4,**(2006)**, pp. 938-947.

[12] M. Sangeetha and V. Bhaskar, "Performance comparison of various chaotic maps in CDMA-DCSK multiuser SISO systems", International Review on Computers and Software, vol. 7, no. 7, **(2012)**, pp 3402-3408.
[13] S. Manoharan and V. Bhaskar, "PN codes versus chaotic codes: Performance comparison in a Gaussian approximated wideband CDMA system over Weibull fading channels", Journal of the Franklin Institute, vol. 351, no. 6, **(2014)**, pp 3378-3404.
[14] X. Liao, "Improved Tent Map and Its Applications in Image Encryption", International Journal of Security and Its Applications, vol. 9, no. 1, **(2015)**, pp 25-34.
[15] T. Gopalakrishnan and S. Ramakrishnan, "Chaotic Image Encryption with Hash Keying as Key Generator", IETE Journal of Research, **(2016),** pp- 1-16.
[16] I. Pupeza, A. Kavcic and L. Ping, "Efficient generation of interleavers for IDMA", Proc of IEEE International Conference on Communications, **(2006)**, pp. 1508-1513.
[17] M. Shukla, V. K. Srivastava and S. Tiwari, "Analysis and design of optimum interleaver for iterative receivers in IDMA scheme", Wireless Communications and Mobile Computing, vol. 9, no. 10, **(2009)**, pp 1312-1317.
[18] B. V. S. S. N. Raju and K. D. Rao, "Robust multiuser detection in chaotic communication systems over non-gaussian fading channels", IETE Journal of Research, vol. 58, no. 4, **(2012)**, pp. 259-265.
[19] X. Zhang and Y. Cao, "A novel chaotic map and an improved chaos-based image encryption scheme", The Scientific World Journal, **(2014)**.
[20] B. Akbil and D. Aboutajdine, "Improved IDMA for Multiple Accesses of 5G", International Journal of Communication Networks and Information Security, vol. 7, no. 3, **(2015)**, pp. 138.
[21] A. Vlad, "Generating chaotic secure sequences using tent map and a running-key approach", Proceedings of Romanian Academy, Series A, vol. 14, **(2013)**, pp. 295-302.
[22] C. Li, "A new method of determining chaos-parameter-region for the tent map", Chaos, Solitons & Fractals, vol. 21, no. 4, **(2004)**, pp. 863-867.

