Iterative IDMA Receivers with Random and Tree Based Interleavers

Kulbhushan Gupta [1] C.K. Shukla[2] M. Shukla[3*]

3. Sam Higginbottom Inst. of Agriculture Tech. & Sciences (Deemed University), Allahabad, India
4. Sam Higginbottom Inst. of Agriculture Tech. & Sciences (Deemed University), Allahabad, India
5. Harcourt Butler Technological Institute, Kanpur, India

* E-mail of the corresponding author: manojkrshukla@gmail.com

Abstract

In recent days, on the horizon of wireless world, newly proposed multiple access scheme known as Interleave-Division Multiple-Access (IDMA) has made its remarkable impact. Researchers all over world, are making hard marks to establish the scheme to establish its claim as potential candidate for 4th generation wireless communication systems. This paper is concerned with the performance enhancement of iterative IDMA systems under coded & uncoded environment. The performance of an interleave division multiple access (IDMA) system can be improved by the optimized power allocation techniques. Based on the optimized power allocation technique we compare the performance of coded & uncoded IDMA system with random interleaver & tree based interleaver. During the simulation, it has been observed that tree based interleaver demonstrate the similar bit error rate (BER) performance to that of random interleaver however on other fronts including bandwidth and memory requirement at transmitter and receiver ends, it outperforms the random interleavers.

Keywords: Tree Based Interleaver, Random Interleaver, IDMA, linear programming, power allocation, BER.

1. Introduction

The well established Direct-Sequence code-division multiple-access (DS-CDMA) which is also known as simply CDMA has been adopted in second and third generation cellular mobile standards. The CDMA scheme possesses many attractive features such as dynamic channel sharing, mitigation of cross-cell interference, asynchronous transmission, ease of cell planning, and robustness against fading.

In CDMA system, many users share the same transmission media so that signals from different users are superimposed, causing the multiple access interference (MAI) problems. At the receiver side, it is necessary to separate the mixed signals. Multi-user detection (MUD) is a technique to improve performance by jointly processing the signals forms all of the users.

Recently, it has been shown that multiuser detection together with unequal power control can enhance the performance of code division multiple access (CDMA) systems. The complexity and computational cost is the major problem of CDMA systems.

Interleave Division Multiple Access (IDMA) scheme in which interleavers are employed as the only means of user separation. Interleave division multiple access (IDMA) is a special case of random waveform CDMA, and the accompanying chip-by-chip (CBC) estimation algorithm is essentially a low cost iterative soft cancellation technique [Ping L. & Lihai L. (2004)].

The chip-by-chip (CBC) MUD algorithm for IDMA is an iterative soft cancellation technique for treating multiple access interference (MAI). Its computational cost is very low, being independent of the total number of users when normalized to each user [Wang P., Ping L. & Liu L. (2006)].

With equal power control, it has been shown in [Liu L., Tong J. & Ping L. (2006)] that IDMA together with CBC algorithm can achieve performance close to the theoretical limits. Unequal power allocation is a technique to further enhance system performance. In [3], a linear programming technique is employed for power optimization of IDMA systems over additive white Gaussian noise (AWGN) multiple access channels (MACs).

In this paper, we use the unequal optimized power allocation technique to the uncoded-IDMA system with random interleavers & tree based interleavers. After that we compare their performance and reach to the conclusion.

Section 2 contains an introduction of the IDMA communication system. In section 3, we discussed about tree based interleaver. In section 4 we discussed the power allocation techniques in brief. Section 5 presents the simulation results of uncoded-IDMA with random interleaver and tree based interleaver. Section 6 concludes the paper.

2. Iterative IDMA System

2.1. System Model

Consider an IDMA system with k users. At the transmitter side, the information bits for user k are first encoded by an encoder (ENC) based on a FEC code and then interleaved and transmitted over a Gaussian multiple access channel (MAC). The received signal can be written as;

$$r(j)=\sum_{k=1}^{K} h_k x_k(j)+n(j), \qquad j = 1,2,...J \qquad (1)$$

Where $x_k(j)\in\{+1,-1\}$ is the jth chip transmitted by user-k, h_k the coefficient for user-k representing the combined effect of power control and channel loss, and $\{n(j)\}$ are samples of an AWGN process with zero-mean and variance $\sigma^2 = N_0/2$ [4].

The receiver consists of an elementary signal estimator (ESE) and k a posteriori probability (APP) decoders (DECs), operating iteratively.

For each user k, we rewrite (1) as;

$$r(j)=h_k x_k(j)+\xi_k(j) \qquad (2)$$

where,

$$\xi_k(j)=\sum_{k'\neq k} h_{k'} x_{k'}(j)+n(j) \qquad (3)$$

2.2 The CBC Algorithm

$$E(x_k(j))=\tanh\left(e_{DEC}(x_k(j))/2\right),\forall k,j \qquad (4)$$

$$Var(x_k(j))=1-\left(E(x_k(j))\right)^2,\forall k,j \qquad (5)$$

$$E(\xi_k(j))=\sum_{k'\neq k} h_{k'} x_{k'}(j),\forall k,j \qquad (6)$$

$$Var(\xi_k(j))=\sum_{k'\neq k} |h_{k'}|^2 Var(x_{k'}(j))+\sigma^2,\forall k,j \qquad (7)$$

$$e_{ESE}=\{2h_k/Var(\xi_k(j))\}\left(r(j)-E(\xi_k(j))\right),\forall k,j \qquad (8)$$

After (8), the APP decoding in the DECs is performed to generate the LLRs $\{e_{DEC}(x_k(j)),\forall k,j\}$ .Then go back to (4) for the next iteration.

3. Tree Based Interleaving Mechanism

In iterative IDMA system each user has a specific interleaver $\{\pi_k\}$ having length equal to chip length 'J'. A considerable amount of memory will be required to store the indexes for these interleavers. The tree based interleaver is basically aimed to minimize the computational complexity and memory requirement that occurs in power interleaver & random interleavers respectively [Shukla M., Srivastava V.K. & Tiwari S. (2009)].

In a tree based interleaver generation, two randomly generated interleaver are chosen. Let π_1 and π_2 be the two random interleavers. The combinations of these two interleavers in a particular fashion as shown in the figure 2 are used as interleaving masks for the users [Shukla M., Srivastava V.K. & Tiwari S. (2009)].

The allocations of the interleaving masks follow the binary tree format. The interleaving masking diagram is shown upon 14 users for simplicity. It is clearly shown through the figure that, for obtaining the interleaving sequence of the 14[th] user, it need only 2 cycles, as in [Shukla M., Srivastava V.K. & Tiwari S. (2009)].

$$\pi_{14} = \pi_2\left(\pi_2\left(\pi_2\right)\right)$$

4. Power Allocation Strategy for Users

This section is concerned with the power optimization technique for IDMA systems over AWGN channels.

4.1 Problem Formulation:

For simplicity, we assume that, for all users, the same FEC code is used and the same BER performance is required. Let $\left\{\gamma_k^{(l)}\right\}$ be the average SNIR for the outputs of the ESE after the l-th iteration & $f_k\left(\gamma_k^{(l)}\right)$ be the average variance of the outputs of DEC_k driven by an input sequence with SNIR $\gamma_k^{(l)}$ [Shukla M., Srivastava V.K. & Tiwari S. (2006), Shukla M., Srivastava V.K. & Tiwari S. (2009)].

We can approximately track $\gamma_k^{(l)}$ using the following recursion;

$$\gamma_k^{(l+1)} = \frac{P_k \left|h_k\right|^2}{\sum_{i\neq k} P_i \left|h_i\right|^2 f_i\left(\gamma_i^{(l)}\right) + \sigma^2}, \forall k, l = 0,1,....(L-1) \quad (10)$$

where L is the maximum number of iterations.

For AWGN channels, we have,

$$\left|h_k\right|^2 = 1, \forall \kappa$$

Then recursion (10) reduces to,

$$\gamma_k^{(l+1)} = \frac{P_k}{\sum_{i\neq k} P_i f_i\left(\gamma_i^{(l)}\right) + \sigma^2}, \forall k, l = 0,1,....(L-1) \quad (11)$$

Our objective now is to minimize total power $\sum_k P_k$ while achieving the required performance $\gamma_k^{(l)} \geq \Gamma, \forall k$, for specified Γ [2]. This power optimization problem can be formulated as follows.

4.2 Power optimization over AWGN channels:

Find the distribution $\left\{P_k\right\}$ that minimizes,

$$\Phi = \sum_k P_k \quad (12)$$

subject to,

$$\gamma_k^{(l)} \geq \Gamma, \forall k \quad (13)$$

where $\left\{\gamma_k^{(l)}\right\}$ are obtained through the following SNIR evolution process with initialization $\gamma_k^{(0)} = 0$, for all k.

$$\gamma_k^{(l+1)} = \frac{P_k}{\sum_{i\neq k} P_i f_i\left(\gamma_i^{(l)}\right) + \sigma^2}, \forall k, l = 0,1,....(L-1) \quad (14)$$

Problem (14) is generally nonlinear and non-convex. The problem considered above is to find the minimum sum-power solution within the feasible region [Shukla M., Srivastava V.K. & Tiwari S. (2009)].
We define the total interference after the l-th iteration of recursion (11) as,

$$I^{(l)} = \sum_{k=1} P_k f_k\left(\gamma_k^{(l)}\right) + \sigma^2 \tag{15}$$

Then (11) can be rewritten as

$$\gamma_k^{(l+1)} = \frac{P_k}{I^{(l)} - P_k f_k\left(\gamma_k^{(l)}\right)}, \forall k, l = 0,1,....(L-1) \tag{16}$$

B. Linear Programming Approach:

In problem (12), the constraints (13) & (14) are nonlinear with respect to the optimization variables $\{P_k\}$, which makes the problem complicated. We therefore consider a linearization technique to solve this problem.
We quantize the power levels $\{P_k\}$ into (M+1) discrete levels : { P(m), m=0,1,……M} with P(m-1) < P(m), m=1,2,…….M, and partition the k users into (M+1) groups according to their power levels. Letting $\lambda(m)$ denote the number of users assigned with power level P(m) [Shukla M., Srivastava V.K. & Tiwari S. (2009)].
Then total power (12) is rewritten as

$$\phi = \sum_m \lambda(m)P(m) \tag{17}$$

and the number of users k can be represented as,

$$k = \sum_m \lambda(m) \tag{18}$$

$\gamma^{(l)}(m)$ be the SNIR of the ESE outputs for the users in the group with power P(m) after the *l*-th iteration and assume that user-k has power P(m). Then (15) & (16) can be rewritten as,

$$I^{(l)} = \sum_m \lambda(m)P(m)\ f\left(\gamma^{(l)}(m)\right) + \sigma^2 \tag{19}$$

$$\gamma^{(l+1)}(m) = \frac{P(m)}{I^{(l)} - P(m) f\left(\gamma^{(l)}(m)\right)}, \forall k, l = 0,1,....(L-1) \tag{20}$$

Since $\left\{I^{(l)}\right\}$ is a monotonically decreasing sequence, i.e.,

$$I^{(l+1)} \le I^{(l)}, \quad l=0, 1,\ldots.. (L-1) \tag{21}$$

Substituting (21) into (20) and introducing a delay factor $\delta(0 < \delta < 1)$ to control the convergence speed of the iterative detection, we get,

$$\sum_m \lambda(m)P(m) f\left(\gamma^{(l)}(m)\right) + \sigma^2 \le (1-\delta) I^{(l)} \tag{22}$$

l=0, 1,………… (L-1)

Now we take $\{\lambda(m)\}$ as optimization variables. In this case both the target function (17) and the constraints (18) & (22) appear linear with respect to $\{\lambda(m)\}$. However $\gamma^{(l+1)}(m)$ in (20) is dependent on $\{\lambda(m)\}$. Now, $\gamma^{(l+1)}(m)$ can be treated as pre-calculated parameter when linear programming is applied.
Using an approximation,

$$\gamma^{(l+1)}(m) \approx \gamma^{*}(m) = \frac{P(m)}{I^{(l)}} \tag{23}$$

* denotes approximation.
We can rewrite (22) as

$$\sum_{m} \lambda(m)P(m)\, f\left(\frac{P(m)}{I}\right) + \sigma^2 \le (1-\delta)I \quad , I_{\min} \le I \le I_{\max} \tag{24}$$

where $I_{\max}$ & $I_{\min}$ specify the total interference at the beginning and end of the iterative detection and the iteration index *l* for $I^{(l)}$ is omitted. We evaluate (24) at a set of quantized values of I:{I(n),n=0,1,..N}. By pre-calculating $\left\{ f_{m,n} = f\left(P(m)/I(n)\right)\right\}$ and using $\left\{ f_{m,n} \right\}$ as constants, we obtain a group of linear constraints with respect to $\{\lambda(m)\}$ [2].
In summary, we have

$$\phi = \sum_{m} \lambda(m)P(m) \tag{25}$$

subject to

$$\sum \lambda(m) = k \tag{26}$$

$$\lambda(m) \ge 0, m = 0,1,\ldots.M \tag{27}$$

$$\sum_{m} \lambda(m)P(m)\, f\left(\frac{P(m)}{I}\right) + \sigma^2 \le (1-\delta)I \quad , I_{\min} \le I \le I_{\max} \tag{28}$$

Let y (m) denotes the total power of these $\lambda(m)$ users. As such,

$$y(m) = \lambda(m)\, P(m) \tag{29}$$

Substituting (29) into (25),(27) & (28) we get

$$\phi = \sum_{m} y(m) \tag{30}$$

subject to,

$$\sum_{m} y(m)\, f\left(\frac{P(m)}{I}\right) + \sigma^2 \le (1-\delta)I \quad , I_{\min} \le I \le I_{\max} \tag{31}$$

$$y(m) \ge 0, m = 0,1,\ldots.M. \tag{32}$$

In practice in [1], both P and I should be quantized. We need to determine the searching ranges $P_{\min}, P_{\max}, I_{\min}$ & $I_{\max}$. Let us quantize P and I as

$$P(m) = \alpha^m P_{\min}, m = 0,1,\ldots.M \tag{33}$$

$$I(n) = \beta^n I_{\min}, n = 0,1,\ldots.N \tag{34}$$

with P(0)= $P_{\min}$ >0, P(M)= $P_{\max}$,I(0)= $I_{\min}$ >0, I(N)= $I_{\max}$, α >1 and β >1.
Then (31) becomes,

$$\sum_{m} y(m)\, f\left(\alpha^m \beta^{-n}\gamma\right) + \sigma^2 \le (1-\delta)\beta^n I_{\min} \tag{35}$$

$$\text{Since} \quad \gamma = P_{\min}/I_{\min} \tag{36}$$

The minimum SNR is obtained at the end of the iterative decoding process. Here γ can be determined by the desired BER. For more details about the relation between γ and BER see in [1]. Since

$$k = \sum_{m} \lambda(m) = \sum_{m} \frac{y(m)}{P(m)} = \sum_{m} \frac{y(m)\alpha^{-m}}{\gamma I_{\min}} \tag{37}$$

We get,

$$\sum_{m} y(m)\alpha^{-m} - k\gamma I_{\min} = 0 \tag{38}$$

We can replace (31) by (35). We can also include (38) as part of the LP constraints. In this way $I_{\min}$ becomes an optimization variable and $P_{\min}$ can be determined from $I_{\min}$ by (36) [1].

We still need to determine M and N in (33) & (34). In general, we just use a sufficient large M, since the LP will automatically determine the maximum power level used. We start with a relatively small N.
If after the LP,

$$I_{\max} = \sum_{m} y(m) \times 1 + \sigma^2 > I(N) \quad (39)$$

then the quantization range in (34) is not sufficient and we increase N and repeat the LP until $I_{\max} \le I(N)$.

5. Simulation Results

The power profiles for 32, 48, 64 users are given below in the Table 1.
As we see that the performance improves with increased data lengths. We can also see that a data length of 512 is sufficient to achieve relatively good performance. Performance enhancement is marginal with information block longer than 512.
If user count is $k \le 32$, then fewer than 20 iterations are sufficient (measured at 10^{-4}) and more iterations do not bring about significant performance improvement. However, when user count is $K \ge 48$, more iteration can be beneficial [Shukla M., Srivastava V.K. & Tiwari S. (2008), Shukla M., Srivastava V.K. & Tiwari S. (2006)].

6. Conclusion

As we see from the simulation results that in unequal power allocation technique with Tree based interleaver based uncoded and coded IDMA system gives the better results in comparison to random interleaver based IDMA system.
So using Tree based interleaver in IDMA system with unequal optimized power allocation technique will enhance the performance in comparison to random interleaver and also reduce the memory cost & computational complexity.

References

Ping L. & Lihai L. (2004), "Analysis and Design of IDMA Systems Based on SNR Evolution and Power Allocation", *Proceedings of Vehicular Technology Conference VTC 2004-Fall*, IEEE, 1068-1072.

Wang P., Ping L. & Liu L. (2006), "Power Allocation for Multiple Access Systems with Practical Coding and Iterative Multi-User Detection", *Proceedings of International Conference ICC`06*, **11,** IEEE, 4971-4976.

Liu L., Tong J. & Ping L. (2006), "Analysis and Optimization of CDMA Systems with Chip-Level Interleavers", *Journal Selected Areas in Communication*, **24**, IEEE, 141-150.

Ping L., Wu Y. & Leung W. (2006),"Interleave-Division Multiple-Access", *Transaction on Wireless Communication*, **5 (4)**, IEEE. 938-947.

Shukla M., Srivastava V.K. & Tiwari S. (2009), "Analysis and Design of Optimum Interleaver for Iterative Receivers in IDMA Scheme", *Journal of Wireless Communication and Mobile Computing*, **9(10)**, Wiley 1312-1317.

Shukla M., Srivastava V.K. & Tiwari S. (2006)**, "**Interleave Division Multiple Access for Wireless Communication**",** *Proceedings of International Conference on Next Generation Communication Systems: A Perspective', "ICONGENCOM 06***"**, J.K. Institute, Allahabad, India, 150-154**.**

Shukla M., Srivastava V.K. & Tiwari S. (2008), **"**Analysis and Design of Tree Based Interleaver for Multiuser Receivers in IDMA Scheme**",** *Proceedings of International Conference on Networks "ICON 2008"*, Delhi, India, IEEE, 1-4.

Shukla M., Shukla A., Srivastava V.K., & Tiwari S. (2009), "Different Designing Factors for IDMA Systems", *Proceedings of International Conference on Computer, Communication, and Control and Information Technology "C3 IT 2009"*, Calcutta, India, Academy Publishers, 748-756.

Shukla M., Srivastava V.K. & Tiwari S. (2006), "A Novel Interleaver for Interleave Division Multiple Access Scheme", *Proceedings of International Conference on Information and Communication Techniques "ICCT 07"*, Dehradun, India, 843-846.

Shukla M., Srivastava V.K. & Tiwari S. (2009), "Analysis of Optimum Interleaver for Iterative Receivers in IDMA Scheme", *Proceedings of International Conference on Computing and Networking "ICDCN 2009"*, Springer, 400-407.

Shukla M., Srivastava V.K. & Tiwari S. (2009), "Performance Analysis of Tree Based Interleaver with IDMA Systems using Optimum Power Allocation Algorithm", *Proceedings of International Conference on Emerging Trends in Engineering & Technology "ICETET-09"*, IEEE, 1173-1177.

Table 1
Power Profile For 32, 48 & 64 Users

	(power level(dB))×(user number)
K=32	0×25, 5.3811×7
K=48	0×26, 7.4509×8, 10.3484×8, 10.7623×6
K=64	0×25, 7.8645×7, 8.2784×7, 13.2455×5 13.6594×7, 18.6266×13

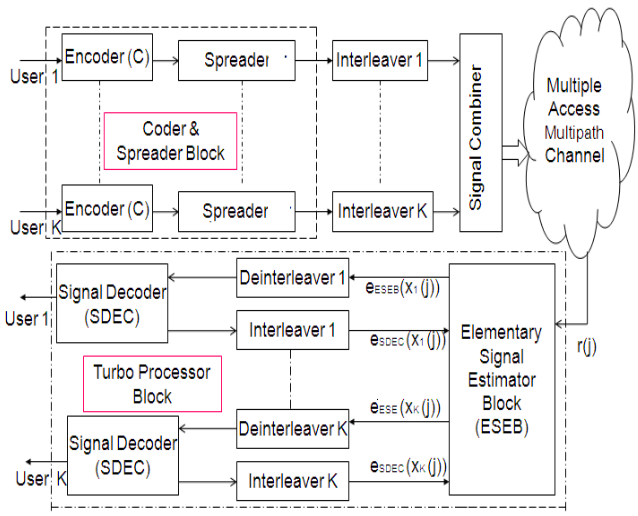

Figure 1. (a) The transmitter for user-k. (b) A part of the receiver related to user-k.

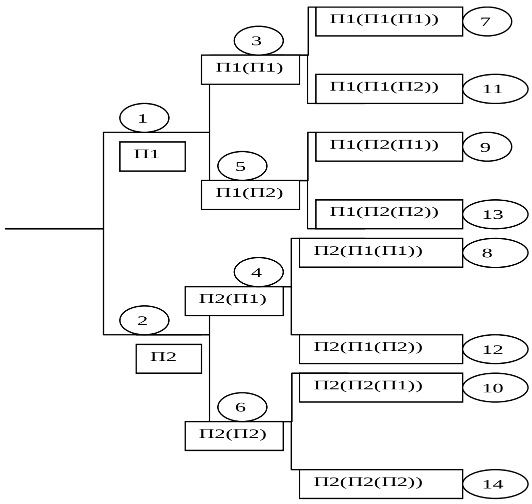

Figure 2. Interleaving mask allocation for the proposed Tree based interleaving scheme

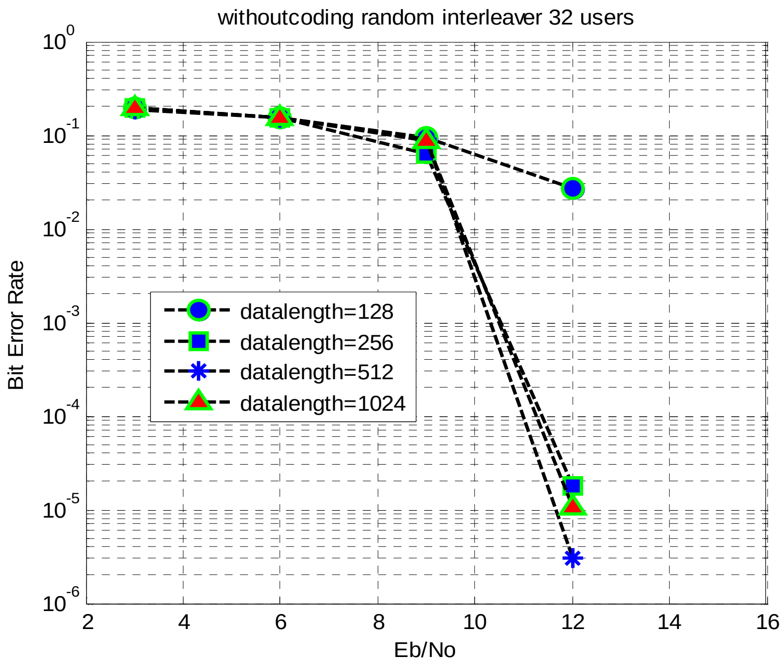

Figure 3 (a). 32 users Random Interleaver

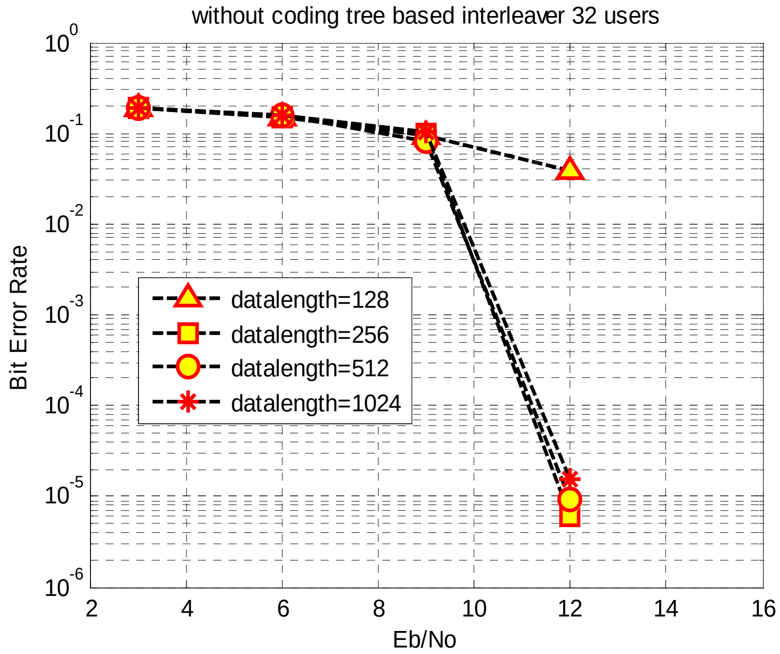

Figure 3 (b). 32 users Tree Based Interleaver

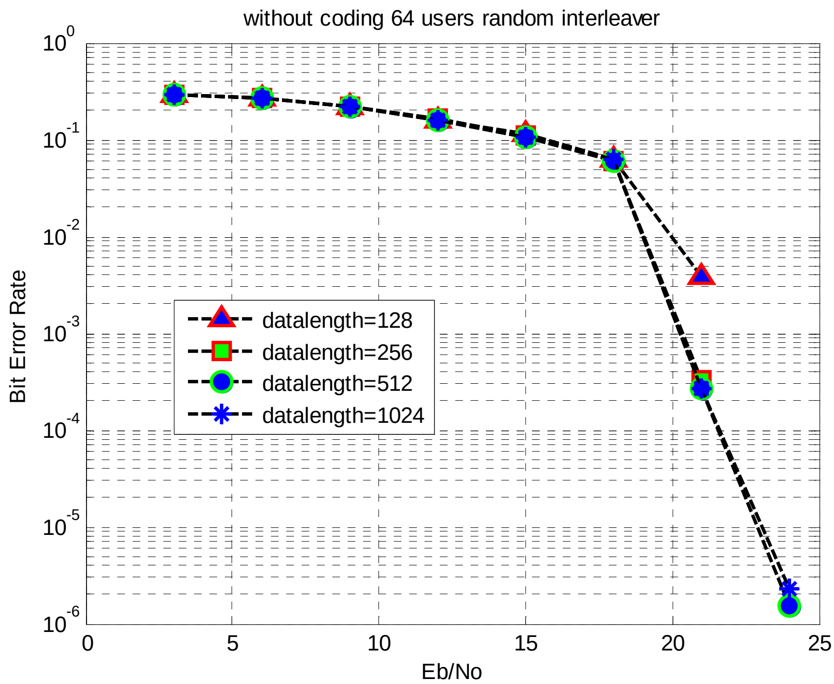

Figure 4 (a). 64 users Random Interleaver

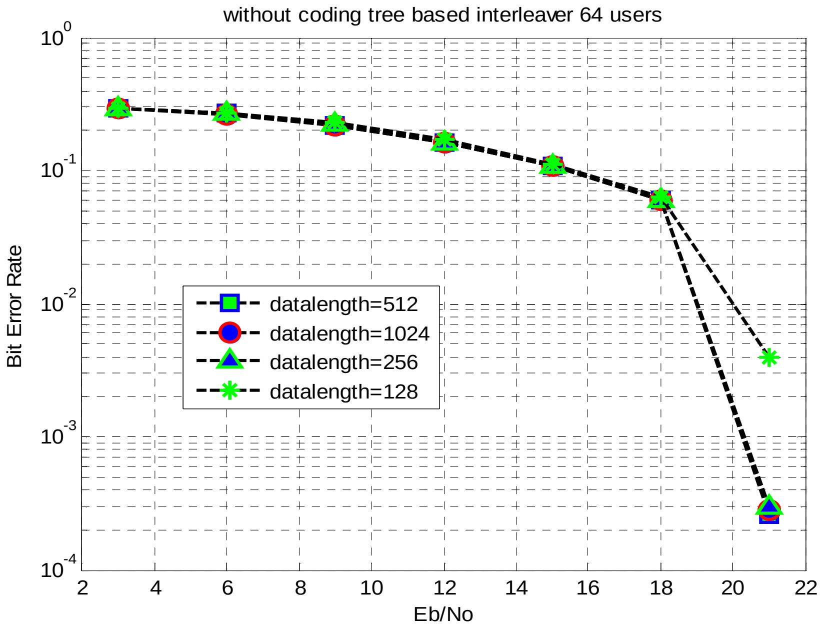

Figure 4 (b). 64 users Tree Based Interleaver

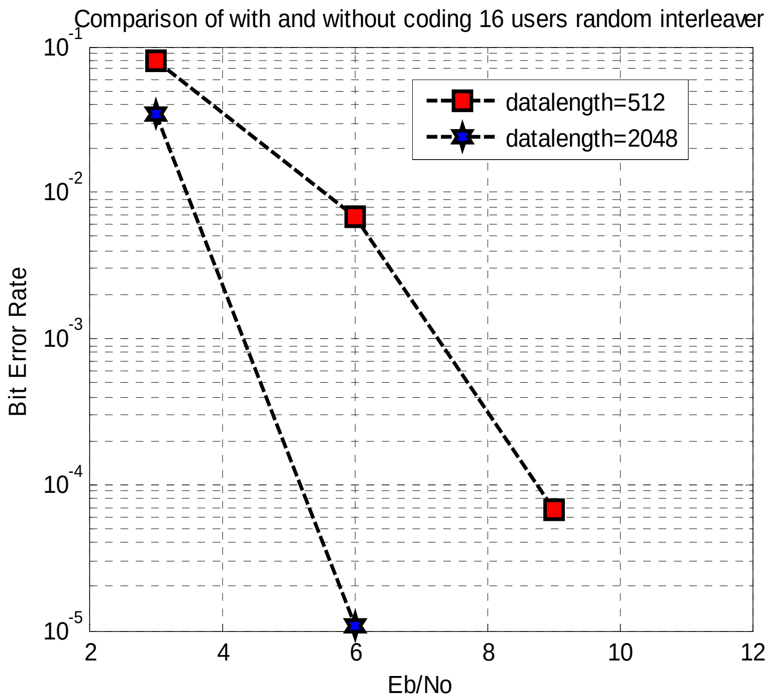

Figure 5 (a). 16 users Random Interleaver with and without coding

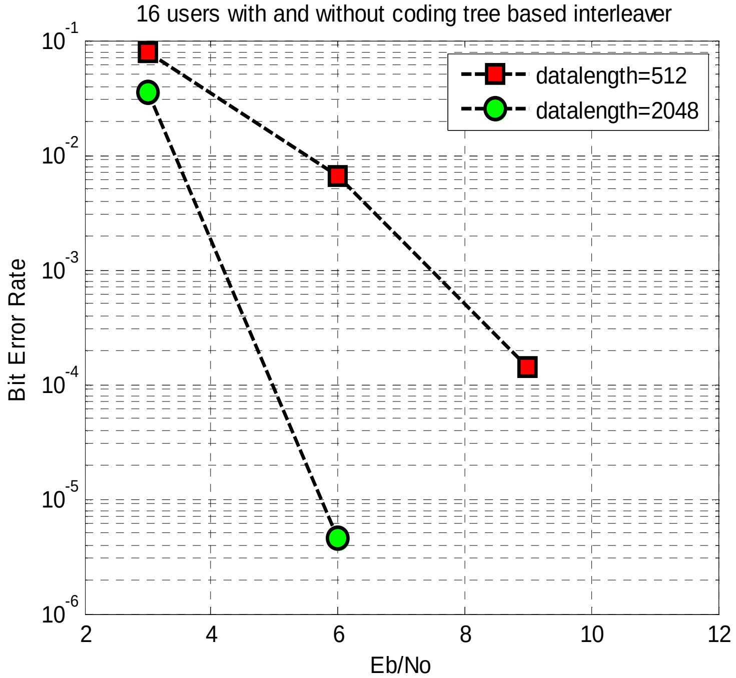

Figure 5 (b). 16 users Tree-Based Interleaver with and without Coding

Kulbhushan Gupta is engaged as Assistant Professor in B.B.S. College of Engineering, Allahabad, India and is perusing Ph.D. form Sam Higginbottom Inst. of Agriculture Tech. & Sciences (Deemed University), Allahabad, India. His area of interest is Ad-Hoc Neworks, Multiple Access Scheme and Modulation Schemes.

C.K. Shukla is associated with Sam Higginbottom Inst. of Agriculture Tech. & Sciences (Deemed University), Allahabad, India as Professor in Electronics & Communication Engineering Department. At present he is working in the area of Ad-Hoc Networks, routing algorithms, and Mobile Computing mechanisms. He has published several papers in national and international conferences of repute apart from various journal publications. He is also member of various professional bodies and is active in research areas. He may be contacted at http://shiats.edu.in/faculty/Colleges/dept/staff/facProfile.asp?txtOpt=1519 .

M. Shukla is associate professor of Electronics Engineering Department in Harcourt Butler Technological Institute, Kanpur, India. As an engineer-scientist-turned-faculty, Dr. Shukla's research agenda has been extensive, ranging from information systems development to case-driven strategic technological issues. His current research interests include network security, neural network and fuzzy applications in electronics engineering, design and analysis of interleavers for multiple access schemes in wireless and mobile networks, channel coding, QOS issues, VHDL coding of communication models, and next generation networks. He has more than eighteen years of teaching and research experience in the area of circuit design and Communication Engineering. He has supervised a number of M. Tech. theses. He has worked as reviewer for several conferences and journals of repute. He has published more than fifteen research papers in different journals and conferences. Dr. Shukla's papers have appeared in journals such as Wiley Transactions on Wireless Communication and Mobile Computing, International Journal of Applied Engineering Research, The

IUP Journal of Telecommunications, and Springer Lecture Notes on Computer Science, among others. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), Institution of Electronic and Telecommunication Engineers (IETE), International Society of Electronics & Electrical Engineers (ISEEE), and the Indian Society for Technical Education (ISTE). He may be 'virtually' reached at http://www.hbti.ac.in/Dept/ET/manoj.htm and http://www.manojkrshukla.weebly.com.