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Performance of IDMA system with Optimal Spreading Mechanism and Tree Based Interleaver

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Abstract: IDMA is being thought as a strong candidate for radio access in cellular mobile communication systems. It is attractive for wireless access because of its numerous advantages over TDMA, FDMA and CDMA. The Interleave-Division Multiple-Access (IDMA) scheme is known for property of orthogonality amongst its user-specific interleavers. The interleavers are, therefore, referred has the heart of IDMA Transceivers. In the literature, researchers have proposed Tree Based Interleaver (TBI) which not only reduces the bandwidth requirement in comparison to that required in case of Random Interleavers (RI) but also reduces computational complexity drastically when compared with that of power interleavers. The memory requirement at receiver end and its cost problem are also solved by tree based interleaver with further reduction of the amount of information exchange between mobile stations and base stations required to specify the user-specific interleavers. Here we are using IDMA system using tree based interleaver .On comparing different spreading techniques as repition, Gold code and Walsh code spreading from simulation results, the performance is almost same for all. But from implementation point of view repition spreading requires less memory, less computational complexity, easy implementation and also defines larger number of users as compared to Gold code and Walsh code for same spreading length. During the simulation, it has been observed that IDMA system with repition spreading employing TBI outperforms its counterparts optimally.

KEYWORDS- Modulation mechanism, Channel Model, Multiple Access Scheme, IDMA receiver,Tree Based Interleaver, random interleaver, spreading codes .

I. Introduction

Interleavers have been as the only means for user separation in iterative interleave-division multiple-access (IDMA) systems. IDMA system inherits many advantages from CDMA systems, including diversity against fading and mitigation of the worst- case other- cell user interference problem. Furthermore, it allows a very simple chip by chip iterative MUD strategy. The normalized MUD cost (per user) is independent of the number of users. Also, during the initial link setting-up phase during start of transmission, there should be messages passing between the BS and mobile stations (MSs) to inform each other about their interleavers. If the interleavers used by the BS and MSs are long and randomly generated, extra bandwidth resource will be consumed for this purpose.

The problem of high memory requirement has been solved by [2]. In this paper, the user specific interleavers are generated by master random interleaver method [2], but the computational complexity required to generate the interleaving sequence is increased extensively, especially when the number of users is large. At the receiver section, frequent interleaving and deinterleaving is required during the process of iterative decoding in turbo processor. Therefore, large amount of calculations are required in receiver section and hence, the computational complexity is increased drastically with high user count.

In [3] Tree Based Interleaver (TBI) has been proposed to alleviate the concerns related to bandwidth and memory requirements in addition to problem of computational complexity optimally. The TBI requires extremely less bandwidth and memory devices when compared with power interleaver [2] and consumes marginally higher bandwidth to that of random interleavers. On the other hand, it merits very less computational complexity when compared to power interleavers.

Interleave division multiple access (IDMA) is a technique where interleaving is the only means for user separation. IDMA not only inherits many advantages in comparison to conventional CDMA, such as robustness against fading and mitigation of cross-cell interference, but also allows very simple chip-by-chip (CBC), iterative multiuser detection (MUD) strategy while achieving impressive performance. In [1], an IDMA system that uses randomly and independently generated interleavers is presented. The IDMA system with random interleaver [1] performs better than a comparable CDMA system with random interleaver.

Meanwhile this process combines coding and spreading operation to maximize coding gains using low-rate codes ,and make the system nearer multiple access channel (MAC) capacity[4][5]. Spreader used in IDMA only functions for bandwidth expansion. The reason for using spreading is not the processing gain. A real gain of spreading concerning the range of data transmission can be achieved in a frequency-selective fading environment. The increased bandwidth of a spread signal provides us with increased frequency diversity as compared to a narrowband FDMA system. Such frequency diversity can only be exploited if the signaling bandwidth significantly exceeds the correlation frequency (i.e. the coherency bandwidth) of the channel. Comparing the spread spectrum and the TDMA technique at the same signal bandwidth, at the same data rate and mean transmission power (energy per transmitted bit), roughly the same performance will result since the receive *Eb/N*0 is the same. Nevertheless, having in mind the discussion on electromagnetic compatibility of mobile phones, spreading may have an advantage since it uses a continuous transmission while transmission in time multiplex systems is pulsed. For this reason, sometimes the peak transmission power of systems is limited by regulatory bodies. Obviously, at equal peak transmit power the performance of spread spectrum systems is higher than that of TDMA systems.

Each of the known types of codes fulfills one requirement to a higher and the other to a lower degree. Therefore, the codes giving the best compromise for the respective applications have to be selected. Here we are comparing these codes on the basis of performance, construction, memory, computational complexity , number of users defined and ease of implementation.

In Section 2, an introduction to IDMA system is presented. In section 3, different types of codes, Walsh-Hadmard, Gold code and repition spreading is discussed and last section 4 present simulation results comparing different codes using tree based interleaver.

II. IDMA SYSTEM

Here, we consider an IDMA system [1], shown in Figure 1, with *K* simultaneous users using a single path channel. At the transmitter, a N-length input data sequence $d_k = [d_k(1), \ldots, d_k(i), \ldots d_k(N)]^T$ of user k is encoded into $c_k = [c_k(1), \ldots, c_k(j), \ldots c_k(J)]^T$ based on low rate code *C*, where J is the Chip length.

In encoder-spreader block, the code C is constructed by serially concatenating a forward error correction (FEC) code and repletion code of length-*sl*. The FEC code used here is Memory-2 Rate-1/2 Convolutional coder. We may call the elements in c k ‘chips’.

Then c_k is interleaved by a chip level interleaver ‘Π_k’, producing a transmitted chip sequence $x_k = [x_k(1), \ldots, x_k(j), \ldots x_k(J)]T$. After transmitting through the channel, the bits are seen at the receiver side as $r = [r_k(1), \ldots, r_k(j), \ldots r_k(J)]T$. The Channel opted is additive white Gaussian noise (AWGN) channel, for simulation purpose.

In receiver section, after chip matched filtering, the received signal form the *K* users can be written as

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

where h_k is the channel coefficient for user and {n(j)} are the samples of an additive white Gaussian noise (AWGN) process with mean as zero and variance $\sigma^2 = N0 / 2$. An assumption is made that $\{h_k\}$ are known priori at the receiver.

The receiver consists of a primary signal estimator block (PSE) and a bank of *K* single user a *posteriori* probability (APP) decoders (DECs), operating in an iterative manner. The modulation technique used for simulation is binary phase shift keying (BPSK) signaling. The outputs of the PSE and DECs are extrinsic log-likelihood ratios (LLRs) about {x *k* } defined as

$$e\left(x_k(j)\right) = \log\left(\frac{p(y \mid x_k(j)) = +1}{p(y \mid x_k(j)) = -1}\right), \quad \forall K, j \qquad (2)$$

These LLRs are further distinguished by the subscripts i.e., $e_{PSE}x_k(j)$ and $e_{DEC}x_k(j)$, and, depending upon whether they are generated by SEB or DECs.

$$r(j) = h_k x_k(j) + \xi_k(j) \qquad (3)$$

Where

$$\xi_k(j) = r(j) - h_k x_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j) \qquad (4)$$

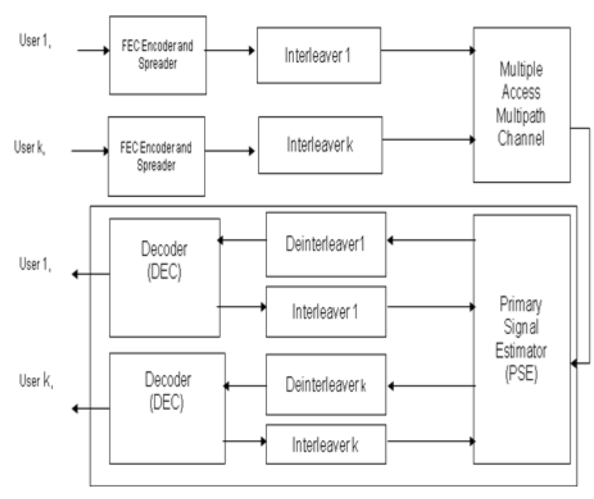

FIGURE 1: TRANSMITTER AND RECEIVER STRUCTURES OF IDMA SCHEME WITH *K* SIMULTANEOUS USERS

$\xi_k(j)$ is the distortion (including interference-plus-noise) in $r(j)$ with respect to user-k. From the central limit theorem, $\xi_k(j)$ can be approximated as a Gaussian variable, and

$r(j)$ can be characterized by a conditional Gaussian probability density function; Due to the use random interleavers {Π_k}, the SEB operation can be carried out in a chip-by-chip manner, with only one sample r(j) used at a time.

III. SPREADING CODES

Constructions of some codes are discussed in following subsections.

A. WALSH-HADAMARD CODES

Walsh-Hadamard codes make useful sets for CDMA based wireless systems because of their orthogonality and VSF characteristics. Walsh functions are generated by mapping codeword rows of special square matrix called Hadamard matrix [6]. The Hadamard matrix of desired length can be generated by the following recursive procedure:

H_1= [0];

$$H_{2N} = \begin{vmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{vmatrix} \qquad (5)$$

Where N is a power of 2 and over score denotes the binary complement. Each row of the matrix presents a Walsh-Hadamard code by mapping 0 to 1 and 1 to –1. These codes have zero cross-correlation between each other and therefore these codes are orthogonal. However, these codes have poor ACF characteristics. The support for multiple and variable data rates can be provided by the VSF property of Walsh-Hadamard codes.

B. GOLD CODES

Methods for generating PN sequences with better periodic cross correlation properties than m-sequences have been developed by Gold [7],[8] and by Kasami. A set of Gold codes of length *M* can be obtained by combining specific pairs of *m*-sequences *c, c'* which are called *preferred m*-sequences. This set of Gold codes Γ is given by *c, c'* and the modulo-2 sums of *c* and all *M* different cyclically shifted versions of *c*, hence it contains *M* + 2 elements. Another way to number the Gold codes generated by *c*, and *c'* is:

$\Gamma = \{c_0, c_1, \text{-------------} c_M, c_{M+1}\}$

Where c_0=c c_{M+1}=c'and c_μ=c+c'(μ) , μ=1,-------- M.

where the sum has to be understood as a modulo-2 sum and c'(μ). is the *m*-sequence given by the binary representation of *μ* as the initial setting for the generating shift register. This process is illustrated in figure 2.Concerning the decrease of auto- and cross-correlation functions Gold proofed the following proposition: the cross-correlation functions of Gold sequences take only the three values $-1/M, -t(M), t(M) - 2$, where *t (M)* decreases as $2/\sqrt{M}$ for large even *M* and as $\sqrt{2/M}$ for large odd $M = 2m - 1$. To summarize, for large *M* the peak values of the cross-correlation functions of Gold codes are much smaller than for the *m*-sequences, but at the expense of higher (but also decreasing) values of the autocorrelation functions. Gold sequences allow construction of long sequences with three valued Auto Correlation Function ACFs. The combined codes in the set of Gold codes are no *m*-sequences. These codes are used in asynchronous CDMA systems. The use of Gold sequences permits the transmission to be asynchronous. The receiver can synchronize using the auto-correlation property of the Gold sequence.

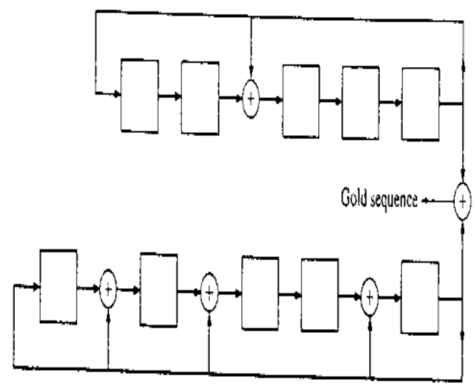

FIGURE2: GENERATION OF GOLD SEQUENCES OF LENGTH 31

C. REPITION SPREADING

A very naive idea for spreading is a simple repetition of the bits, another type of spreading used in IDMA, that is, without the need for separating different users, is given by the so-called *repition spreading*. These are characterized by minimizing certain kinds of reduced autocorrelation functions defined by,

$R_c(m) = \sum c_1 c_{1+m} \qquad 0 \le m \le L-1 \qquad (6)$

$R_c(m)$= L for m=0 and even

$R_c(m)$= -L for m is odd

The size of the off-peak values of $R_c(m)$ relative to the peak value $R_c(0)$ i.e., the ratio $R_c(m)/R_c(0)$=+1 for m even or -1 for m odd.

Since in IDMA interleavers are the means used for user separation, the orthogonality condition must be satisfied by these. Repition spreading in IDMA is only used to increase the bandwidth occupancy and hence bandwidth efficiency. The code rate $R_c=1/L$, *L* is spreading length. Repition spreading is just another word for diversity, and, in a fading channel, it has a diversity gain if the fading amplitudes of the received coded symbols are sufficiently independent.

The implementation of repition spreader is given in figure 3. Firstly clear the output Q with the help of clear input, apply clock. The required spreading length can be obtained by the same number of clocks. The sequence is 1010101010------- and it can mapped as +1 -1 +1 -1 +1 -1 +1 -1 +1 -1 ------

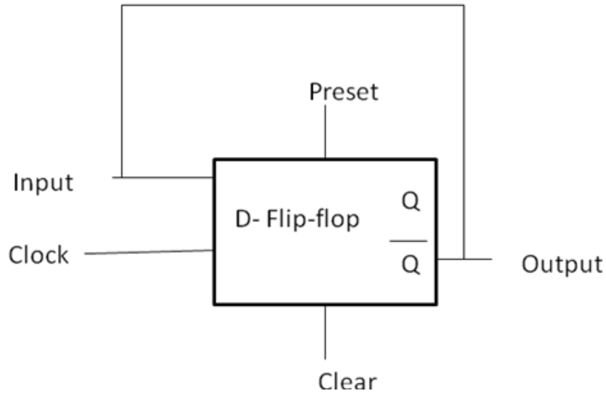

FIGURE 3: GENERATION OF REPITION SPREADING

IV SIMULATION RESULT

From the plot, memory requirement for repition spreading is same for all user count, where as there is linear increment in memory required with different user count in both Walsh and Gold. The plot for both Walsh and Gold spreading overlaps.

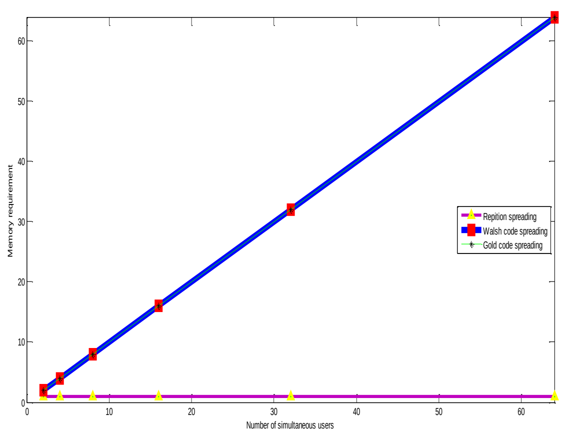

FIGURE 4: COMPARISON OF RP, WC, AND GC FOR MEMORY REQUIREMENT

Following plot represent that for repition spreading the maximum user count accessed are constant for different spreading length, where as for Walsh code, maximum user accommodated is same as spreading length and for Gold code it is sum of spreading length and two. Once again repition spreading is overcoming the remaining spreading technique.

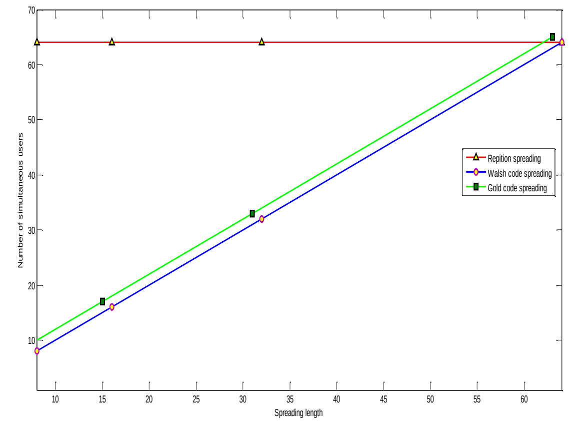

FIGURE 5: COMPARISON OF USER CAPACITY FOR GIVEN SPREADING LENGTH IN RP, WC AND GC

Figure 6.shows B.E.R performance with variation in number of users for random interleaver comparing for different spreading as repition, Gold code and Walsh code spreading in both uncoded and coded IDMA environment with BPSK modulation. Different parameters are data length m=512, iterations it=15 and Eb/No=3dB. The plot is B.E.R. performance with respect to number of users for different spreading length as sl=16, 32, 64. From this plot comparative B.E.R. improvement is for sl=32, but with consumption of large bandwidth. As number of users increase the performance degrades.

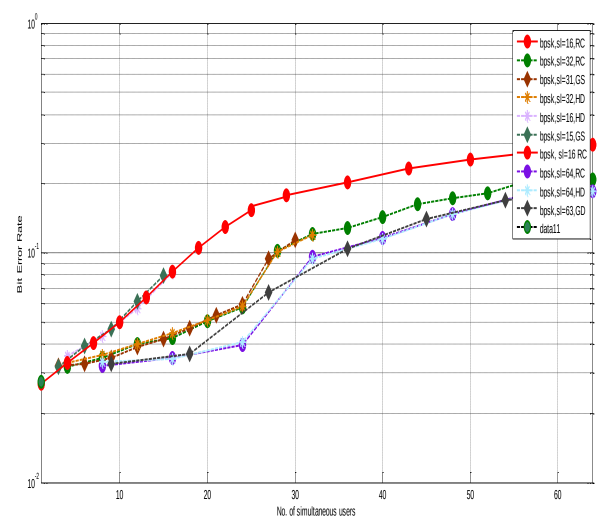

FIGURE 6: UNCODED IDMA WITH TBI USING BPSK FOR VARIATION IN USER COUNT AT EB/NO=3DB COMPARING AT DIFFERENT SPREADING

The figure 7. is B.E.R. performance for different values of Eb/No with variation in user count n=4, 8, 16, 30 of uncoded

IDMA with random interleaver using both BPSK modulation. Other parameters are data length m=512, iterations it=15 and optimal spreading length sl=32 with repition, Gold code and Walsh code spreading. Performance improve for increasing values of Eb/No.

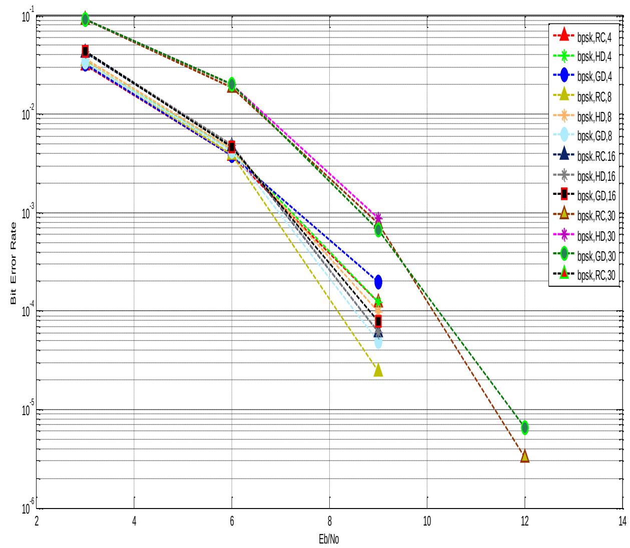

FIGURE 7:SIMULATION OF UNCODED IDMA USING TBI WITH BPSK FOR VARIATION IN USER COUNT FOR sl=32

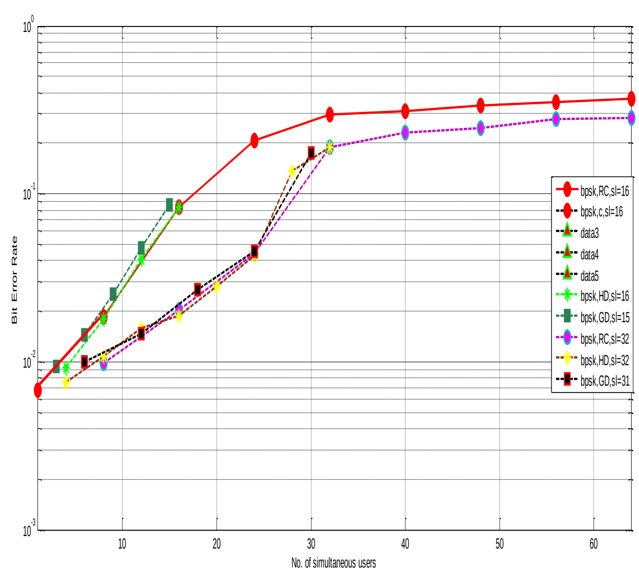

FIGURE 8: CODED IDMA WITH TBI USING BPSK FOR VARIATION IN USER COUNT AT E_B/N_O=2dB COMPARING AT DIFFERENT SPREADING LENGTH

In figure 8. coded IDMA is considered with random interleaver,1/2 rate convolutional coding, using BPSK modulation, different spreaders are used as repition, Gold code and Walsh code. Different parameters are data length m=512, iterations it=15 and Eb/No=2dB. The plot is B.E.R. performance with respect to number of users for different spreading length as sl=16, 32, 64. From this plot comparative B.E.R. improvement is for sl=32, but with consumption of large bandwidth. As number of users increase the performance degrades.

Figure 9 is B.E.R. performance for different values of Eb/No with variation in user count n=4, 8, 16, 30 of coded IDMA using ½ rate convolutional coding with random interleaver using BPSK modulation. Other parameters are data length m=512, iterations it=15 and optimal spreading length sl=32 with repition, Gold code and Walsh code spreading. Performance improve for increasing values of Eb/No.

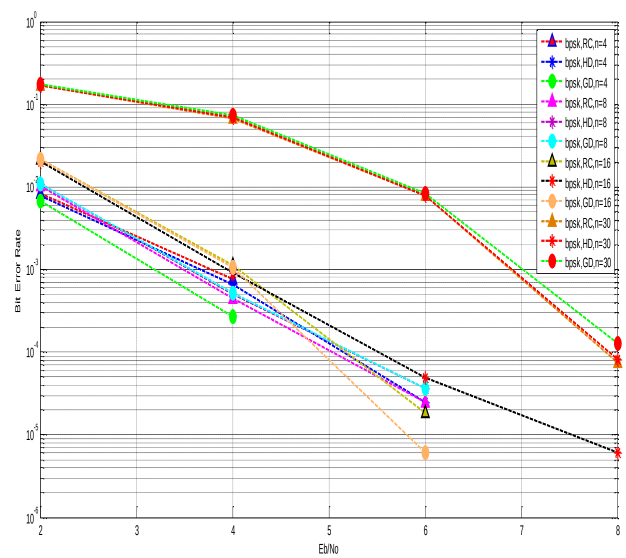

FIGURE 9: SIMULATION OF CODED IDMA USING TBI WITH BPSK FOR VARIATION IN USER COUNT FOR sl=32.

In figure 10, uncoded IDMA is considered using tree based interleaver and random interleaver, simulation is done taking parameters as data length 512, spreading as repition code of length 16, iteration numbers 15and Eb/No=3dB. BER performance is compared for BPSK for different number of users n=1,4,7,10,13,16,19,22,25,27,38,51,6 . On comparing BER performance of Tree Based interleaver and random interleaver, both have almost same performance for different values of users. Tree Based interleaver can replace random interleaver as memory requirements for Tree Based interleaver is less as compared to random interleaver.

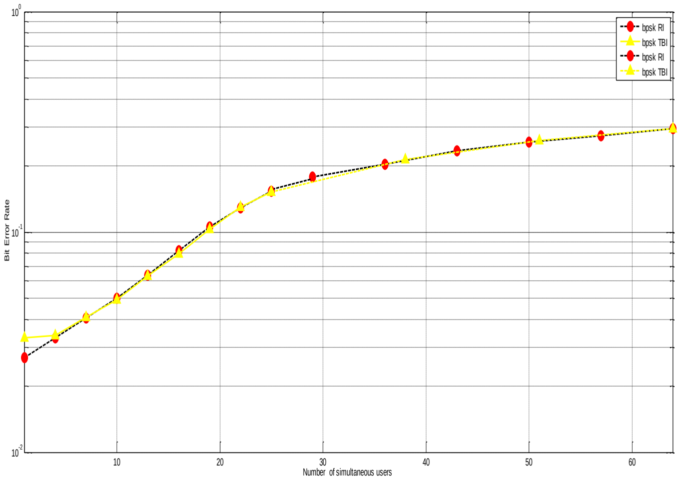

FIGURE 10: UNCODED IDMA COMPARING TBI WITH RI USING BPSK FOR VARIATION IN USER COUNT AT Eb/No=3dB

In figure 11, coded IDMA is considered , FEC code convolutional ½ rate coding is used ,using tree based interleaver and random interleaver, simulation is done taking parameters as data length 512, spreading as repition code of length 16, iteration numbers 15and Eb/No=3dB. BER performance is compared for BPSK for different number of users n=1,4,7,10,13,16,19,22,25,27,38,51,6 .

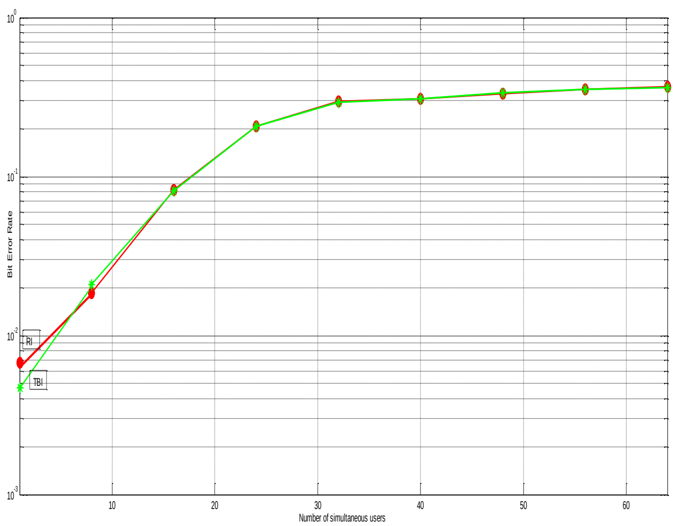

FIGURE 11: CODED IDMA COMPARING TBI WITH RI USING BPSK FOR VARIATION IN USER COUNT AT Eb/No=2dB

On comparing BER performance of Tree Based interleaver and random interleaver, both have almost same performance for different values of users. Tree Based interleaver can replace random interleaver as memory requirements for Tree Based interleaver is less as compared to random interleaver.

IV. CONCLUSIONS

In this paper it is concluded that on comparing different spreading techniques as repition, Gold code and Walsh code spreading from simulation results, the performance is almost same for all. But from implementation point of view repition spreading requires less memory, less computational complexity, easy implementation and also defines larger number of users as compared to Gold code and Walsh code for same spreading length. It is shown that tree based interleaver has almost same BER performance as of random interleaver, however tree based interleaver outperforms the random interleavers in terms of memory and bandwidth requirement problems [3]. The tree based interleaver is also reported to perform better than master random interleaver in terms of computational complexity [3]. Therefore it can be concluded that tree based interleaver using repition spreading can replace random interleaver using repition spreading.

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