Performance Analysis of Various Modulation Techniques in Multipath Ad-Hoc Network using Tree Based Interleaver for Iterative IDMA Systems

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ABSTRACT
In recent years, the Interleave-Division Multiple-Access (IDMA) scheme has attracted the attention of researchers to be a promising candidate for next generation networks. And Since then numerous technical papers about IDMA have been published in the literature. In this paper, we have simulated the IDMA scheme with various interleavers and modulation mechanism to establish the fact that tree based interleaver along with QPSK modulation mechanism performs better than other mechanisms. It has also been shown that the tree based interleaver is the optimum interleaver for IDMA receivers because it is the best solution to fading at low cost and without requirement of extra bandwidth.

Keywords
Modulation mechanism, Channel Model, Multiple Access Scheme, Tree Based Interleaver.

1. INTRODUCTION
A modulation method can be thought of as an operator on the baseband signal. Modulation is one of the most important signal processing operations that takes place in a communication system. In most media for communication, only a fixed range of frequencies is available for transmission. One way to communicate a message signal whose frequency spectrum does not fall within that fixed frequency range, or one that is otherwise unsuitable for the channel, is to alter a transmittable signal according to the information in your message signal. This alteration is called *modulation*, and it is the modulated signal that you transmit. The receiver then recovers the original signal through a process called *demodulation*.

It can be effectively used to match a signal with the channel characteristics, to minimize the effects of channel noise, and to provide the capability to multiplex many signals, practicability of antennas.

The basic idea of modulation is to vary some characteristics property of a RF signal such as its amplitude, frequency or phase by the information signal to be transmitted. The selection of the particular modulation method used is determined by the application intended as well as by the channel characteristics such as available bandwidth and susceptibility of channel to fading. A large variety of modulation techniques have been studied for use in mobile radio Communications systems and research is ongoing.

In following section II, the factor influencing the choice of modulation mechanism has been explained. Section III highlights the IDMA scheme with single path communication system. In section IV, Tree Based Interleaver (TBI) has been presented in brief. Further, numerical results have been presented in section V while in section VI, the conclusions have been drawn.

2. FACTORS INFLUENCING CHOISE OF MODULATION MECHENISM
Several factors influence the choice of a digital modulation scheme [1]. A desirable modulation scheme provides low bit error rates at low received signal-to-noise ratios, performs well in multipath and fading conditions, occupies a minimum of bandwidth and is easy and cost effective to implement. Existing modulation schemes do not simultaneously satisfy all of these requirements. Some modulation schemes are better in terms of bit error rate performance, while others are better in terms of bandwidth efficiency. Depending on the demands of the particular application, tradeoffs are made when selecting a digital modulation.

The performance of a modulation scheme is often measured in terms of its power efficiency and bandwidth efficiency [1]. Power efficiency describes the ability of a modulation technique to preserve the fidelity of the digital message at low power levels. In digital communication system, in order to increase noise immunity, it is necessary to increase the signal power. However, the amount by which the signal power should be increased to obtain a certain level of fidelity (i.e., an acceptable bit error probability) depends on the particular type of modulation employed.

The power efficiency, η_p (sometimes called energy efficiency) of a digital modulation scheme is a measure of how favorably this tradeoff between fidelity and signal power is made, and is often expressed as the ratio of the signal energy per bit to noise power spectral density (E_b/N_o) required at the receiver input for a certain probability of error.

Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth. In general, increasing the data rate implies decreasing the pulse-width of a digital symbol, which increases the bandwidth of the signal. Thus there is unavoidable relationship between data rate and bandwidth occupancy. However, some modulation schemes perform better than the others in making this tradeoff. Bandwidth efficiency reflects how efficiently the allocated bandwidth is utilized and is defined as the ratio of the throughput data rate per Hertz in a given bandwidth.

The system capacity of a digital mobile communication is directly related to the bandwidth efficiency of the modulation scheme, since a modulation with a greater value of η_B will transmit more data in a given spectrum allocation.

There is fundamental upper bound on achievable bandwidth efficiency. Shannon's channel coding theorem states that for an arbitrarily small probability of error, the maximum possible bandwidth efficiency is limited by the noise in the channel, and is given by the channel capacity formula. Shannon's bound applies for AWGN non fading channels.

There is a tradeoff between bandwidth efficiency and power efficiency. Other than these, other choices of a digital modulation are the cost and complexity of the subscriber receiver must be minimized, simple to detect, modulation performance under various types of channel impairments such as Rayleigh and Ricean fading and multipath time dispersion, in an interference environment, sensitivity to detection of timing jitter caused by time varying channels.

3. IDMA SCHEME

Here, we consider an IDMA system [2], shown in Fig.1, K simultaneous users using a single path channel. The upper part in the figure is the transmitter, a N-length input data sequence from user k is $d_k = [d_k(1), \ldots\ldots\ldots, d_k(i), \ldots d_k(N)]^T$ and is encoded using low rate code *C* into $c_k = [c_k(1), \ldots\ldots\ldots, c_k(j), \ldots c_k(J)]^T$, where J is the Chip length and coded bits are chips following the convention of CDMA.

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 and repition code of 16 in length. However, in this paper, the uncoded IDMA system has been considered for simulation purpose.

Then c_k is interleaved by a chip level interleaver 'Π_k', producing a transmitted chip sequence as $x_k = [x_k(1), \ldots\ldots, x_k(j), \ldots x_k(J)]^T$. 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

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

Where h_k is the channel coefficient for user-k and {n (j)} are samples of an AWGN process with zero mean and variance, $\sigma^2 = N_0/2$. Assuming that the channel coefficient $\{h_k\}$ are known a priori at the receiver.

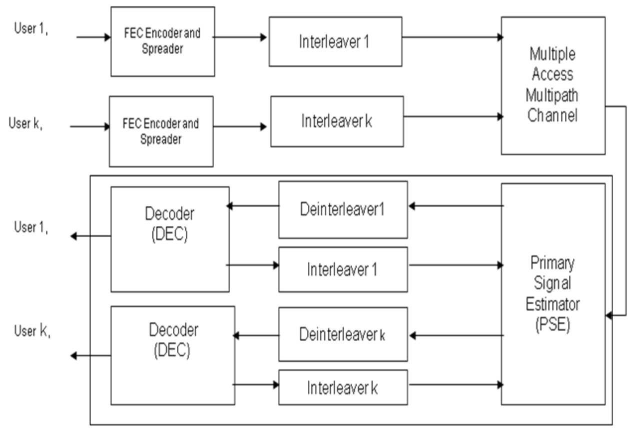

Fig.1: IDMA transmitter and receiver structure [2]

Due to the use of random interleaver $\{\pi_k\}$, the PSE operation can be carried out in a chip-by-chip manner, with only one sample $r(j)$ used at a time

$$r(j) = h_k x_k(j) + \xi_k(j) \text{ ---------------------------- (2)}$$

where

$$\xi_k(j) = r(j) - h_k x_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j) \text{ ---(3)}$$

$\xi_k(j)$ 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;

$$p(r(j)/x_k(j) = \pm 1) = \frac{1}{\sqrt{2\pi Var(\xi_k(j))}} \exp\left(-\frac{\left(r(j) - (\pm h_k + E(\xi_k(j)))\right)^2}{2Var(\xi_k(j))}\right) \text{---(4)}$$

where E (.) and Var (.) are the mean and variance functions, respectively. Adopting an iterative sub-optimal receiver structure, as demonstrated in fig.1, consisting of the primary signal estimator (PSE) and K single user a posteriori probability (APP) decoders (DECs), the data is iterated for pre-decided number iterations before finally taking hard decision on it.

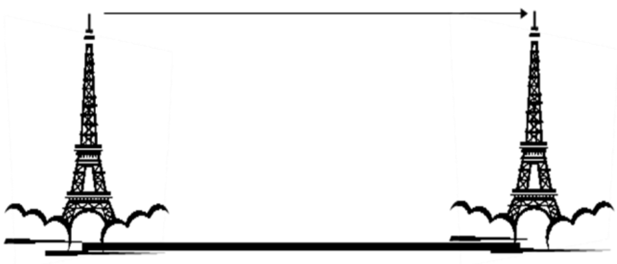

Fig.2: Single Path Propagation

For single path propagation, as shown in fig.2, there is only one path for the transmission. The multiple access and coding constraints are considered separately in the PSE and DECs. The outputs of the PSE and DECs are extrinsic log-likelihood ratios (LLRs) about$\{x_k(j)\}$ defined below as;

$$e\left(x_k(j)\right) = \log\left(\frac{p(y \mid x_k(j)) = +1}{p(y \mid x_k(j)) = -1}\right), \quad \forall K, j \text{ -------------- (5)}$$

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

For the PSE section, *y* in Equation (5) denotes the received channel output while for the DECs, *y* in Equation (5) is formed by the deinterleaved version of the outputs of the primary signal estimator (PSE) block. A global turbo type iterative process is then applied to process the LLRs generated by the PSE and DECs blocks [2].

3.1 Descriptions of the ESE

The ESE generates coarse estimates of { $x_K(j)$, j = 1,…, J, K = 1,..k,.., K}. We ignore the constraint of *Coder* to maintain low complexity. Consider the *j*th chip of the *k*th user with $x_K(j) \in \{+1, \ -1\}$ under BPSK modulation. We treat $x_K(j)$ as a random variable and use $e_{DEC}(x_K(j))$ (initialized to zero) to approximate the *a priori* LLR of $x_K(j)$,

$$\{e_{DEC}(x_K(j))\} \approx \log\left[\frac{p_r(x_K(j) = +1}{p_r(x_K(j) = -1}\right] \text{----------- (6)}$$

Based on (2.14), we have

$$E(x_K(j))) = \frac{\exp(e_{DEC}(x_K(j)))-1}{\exp(e_{DEC}(x_K(j)))+1} = \tanh((e_{DEC}(x_K(j)))/2) \text{---}$$

(7)

$$\mathrm{Var}(x_K(j)))\text{=}1\text{-}E(x_K(j)))^2 \text{ ------------------------(8)}$$

The following is a list of the PSE detection algorithm [2], assuming that the a priori statistics $\left\{E\left(x_k\left(j\right)\right)\right\}$ and $\left\{Var\left(x_k\left(j\right)\right)\right\}$ are available. Based on [2], the algorithm for chip-by-chip detection will now be presented in next sub-section.

3.2 Algorithm for Chip-by Chip Detection in a single path Channel

Step (i): Estimation of Interference Mean and Variance Set

Then

$$e_{DEC}(x_k(j)) = 0 \qquad \text{--------------------------(9)}$$

$$E(r(j)) \Leftarrow \sum_k h_k E(x_k(j)) \qquad \text{----------------(10)}$$

$$Var(x_k(j)) \Leftarrow 1-(E(x_k(j))/2) \text{ -------------(11)} \quad \forall k, j$$

$$\xi_k(j) \quad E(\xi_{k,l}(j)) = E(r(j)) - h_k E(x_k(j))$$

$$Var(\xi_k(j)) = Var(r(j)) - |h_k|^2 Var(x_k(j))$$

is the distortion (including interference-plus-noise) in received signal with respect to user-k.

Step (ii): LLR Generation

$$e_{ESE}(x_k(j)) = 2h_k . \frac{r(j) - E(r(j)) + h_k E(x_k(j))}{Var(r_j) - |h_k|^2 Var(x_k(j))}$$

3.3 DEC Function

The DECs in fig.1 carry out APP decoding using the output of the PSE as the input. With binary phase shift keying (BPSK) signaling, their output is the extrinsic log-likelihood ratios (LLRs){$e_{DEC}(x_k(j))$ of x_k (j) defined in Equation (5), which are used to generate the following statistics,

$$E(x_K(j))) = \frac{\exp(e_{DEC}(x_K(j)))-1}{\exp(e_{DEC}(x_K(j)))+1} = \tanh((e_{DEC}(x_K(j)))/2)$$

--(12)

$$\mathrm{Var}(x_K(j)))\text{=}1\text{-}E(x_K(j)))^2 \qquad \text{------------------(13)}$$

$$e_{DEC}(x_k(\pi(j))) = \sum_{j=1}^{S} e_{ESE}(x_k(\pi(j))) \quad j = 1,\ldots,S$$

In the iterative process, PSE and DEC-*k* exchange the extrinsic information about $x_k(j)$. The CBC detection for IDMA scheme can be concluded as follows, (1) Primary signal estimator generates $e_{PSE}(x_k(j))$ by equation (2.18) for decoder DEC-*k*. (2) DEC-*k* generates, e_{DEC} $(x_k(j))$ which are used to update mean and variance of $x_k(j)$. For IDMA scheme, nterestingly, the cost per information bit per user is independent of the number of users K. This is considerably lower than that of other alternatives.

3.4 Flowchart for iterative decoder

The basic flowchart for decoder which operates in iterative manner is given below. The flowchart used for detection mechanism is presented in fig.2. The data is iterated in the receiver section for the pre-decided number of iterations. After final iteration in the receiver, the data is decoded with respective mechanism.

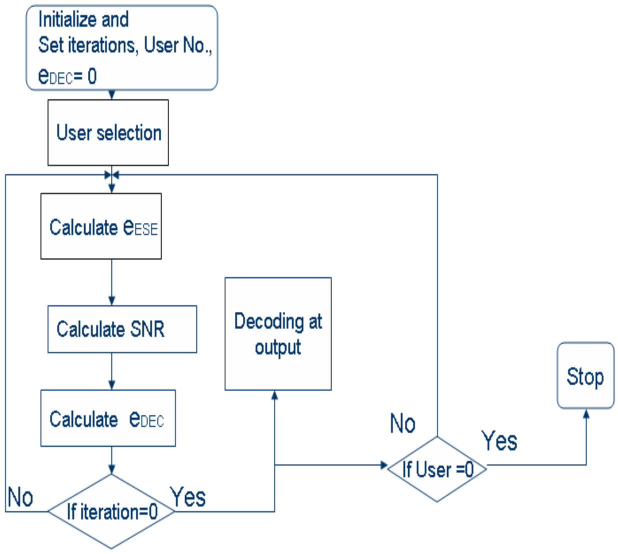

Fig. 3: Flowchart for decoding mechanism in the receiver of IDMA scheme

4. IMPORTANCE OF OPTIMUM MODULATION IN IDMA SCHEME

One of the future requirements of wireless communication is to provide high data rate and high spectral efficiency with optimum BER at those channels which are subjected to Multipath Rayleigh Fading and Additive White Gaussian Noise (AWGN). Modulation schemes that will be studied includes BPSK and QPSK schemes under Additive White

Gaussian Noise (AWGN) channels. The AWGN channel has two characteristics:

1. The channel is linear, with a bandwidth that is wide enough to accommodate the transmission of signal with negligible or no distortion (white noise)

2. The channel noise is the sample function of a zero-mean white Gaussian noise process and power spectral density No/2.

Coherent M-ary PSK, which includes BPSK & QPSK as special case with M=2 and M=4 respectively.

In BPSK, the binary symbols 1&0 differ only in a relative phase shift of 180 degrees. Coherent BPSK system is therefore characterized by having a signal space that is one Dimensional, with a signal constellation consisting of two message points.

QPSK is bandwidth-conserving modulation scheme. In QPSK as with BPSK, Information carried by the transmitted signal is carried in the phase. It transmits 2 bits per symbol. In particular, the phase takes on one of four equally spaced values such as π/4, 3π/4, 5π/4, 7π/4, where each value of phase corresponds to a unique pair of message bits. Accordingly, a QPSK signal, has two-dimensional signal constellation and four message points, M=4, whose phase angles increase in counterclockwise direction.

The basis signal

S(BPSK)= $\pm\sqrt{Eb}\,\phi 1(t)$ ………………………………….(14)

S(QPSK)= $\{\sqrt{Es}$ Cos[(2i-1)π/4] $\phi 1(t)$ - $\sqrt{Es}$ Sin[(2i-1)π/4] $\phi 2(t)$ }i=1,2,3,4……...……(15)

Special characteristics of QPSK:

1-For the same Eb/No, a QPSK system transmits the information at twice the bit rate of BPSK for the same channel bandwidth.

2-QPSK provides twice the spectral efficiency, compared to that of BPSK with the same energy efficiency. In other words for a prescribed performance, QPSK uses channel bandwidth better than BPSK.

3-For the same bit rate QPSK uses only half the channel bandwidth.

4-For the same bit rate, Eb/No and channel bandwidth, the performance is based on Bit Error Rate of QPSK& BPSK system using MATLAB 7.8 simulation under AWGN channel.

The mapping rule for QPSK used in the simulations is given as follows:

(1 0) = (1-1j)
(0 0) = (-1-1j)
(0 1) = (-1+1j)
(1 1) = (1+1j)

5. TREE BASED INTERLEAVER

The Tree Based Interleaver is basically aimed to optimize the problems of the computational complexity and memory requirement that occurs in power interleaver [4] and random interleaver [2] respectively. The mechanism of Tree Based user-specific interleaver generation [3] is based on two master interleavers, which are randomly selected. User specific interleaver is designed using a combination of these randomly selected master interleavers. Here Π1 and Π2 two master interleavers which are randomly selected. The interleaver Π1 is opted for upper branch while Π2 is reserved for initiation for lower branch. Upper branch is selected in case of odd user count while lower branch is selected if user count is even. For the sake of understanding, from figure 3, for first user interleaver will be Π1 while for second user, the interleaver will be Π2. In case of third user it will be Π1 (Π1) and for fourth user, the interleaving sequence will be Π2 (Π1). For 14th user the interleaving sequence will be minimized to Π 14 = Π 2 (Π 2 (Π 2)). The memory required by the Tree Based Interleaver generation method is only slightly more than that required for master random interleaver generation method [4] due to requirement of two orthogonal interleavers in place of one interleaver. The IDMA scheme, inbuilt with random interleaver, imposes the problem of extra bandwidth consumption in the channel, along with high memory requirement at the transmitter and receiver ends. The result demonstrates that the memory required for storing the user-specific interleavers is user dependent for random interleavers in case of its deployment in IDMA scheme, while it is found to be at minimum level, in case of deployment of master random interleaver [4]. For tree based interleaver, the requirement of memory is observed to be little bit high in comparison to that required in case of master random interleaver, however, it is extremely less when compared with requirement in case of random interleaver.Figure 4 is demonstrating the similar bit error rate (BER) performance of tree based interleaver (TBI) to random interleaver (RI) and master random interleaver (MRI). The stated problems of extra channel bandwidth consumption and high memory requirement were solved by master random interleaver in [4]. However, the problem of computational complexity was raised with master random interleaver. In [3], the TBI is examined on the ground of computational complexity with that of master random interleaver [2] at transmitter end.

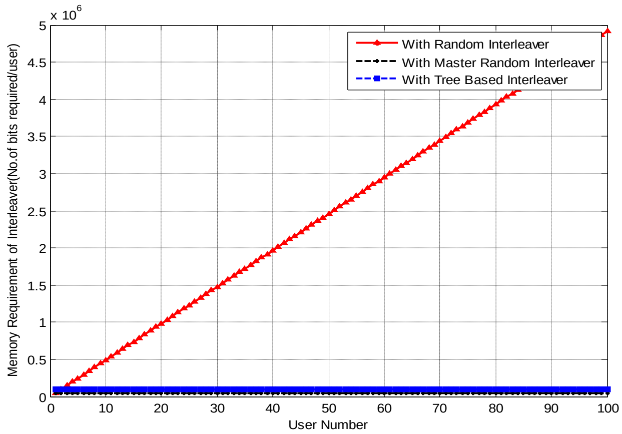

Fig. 5: Comparison of RI, MRI, and TBI for memory requirement

6. SIMULATION RESULTS

For performance evaluation of IDMA scheme with various modulation mechanisms along with variation in interleavers for no FEC (Forward Error Correction) coding , it is assumed that there is no adjacent-channel and co-channel interference i.e. the simulation is performed in single cell architecture. Also, the mobility of the user in the cell is assumed to be negligible.

In this paper, the simulation of IDMA scheme is based on B.E.R (Bit Error Rate) performance with respect to Eb/No, B.E.R performance with variation in data lengths, B.E.R performance with variation in number of users for random and tree based interleaver using repition spreading in both uncoded and coded IDMA environment with BPSK and QPSK modulation.

In fig.6 uncoded IDMA is considered using random interleaver, simulation is done taking parameters as data length 512, spreading as repition code of length 16, iteration numbers 15 .From this plot QPSK has better BER performance as compared to BPSK for different number of users n=1,4,8,16,32,64. But above 32 number of users QPSK and BPSK has almost same BER performance, with difference that QPSK improves its BER performance at lower Eb/No.

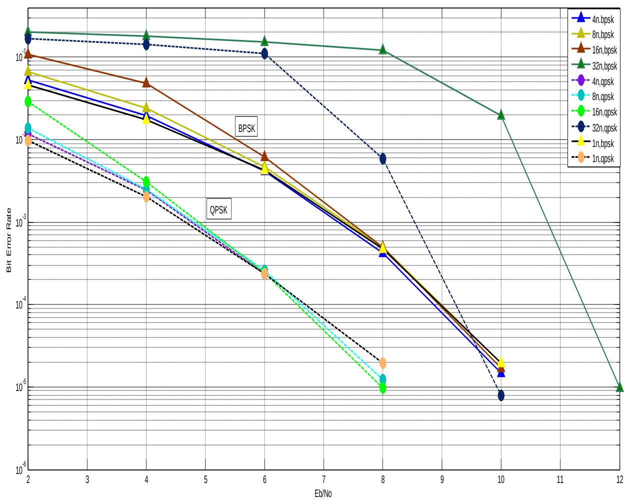

Fig. 6: Simulation of uncoded IDMA using RI with BPSK & QPSK for variation in user count

In fig. 7, uncoded IDMA is considered using random interleaver, simulation is done taking parameters as data length 512,1024,2048, spreading as repition code of length 16, iteration numbers 15 for n=32. .From this plot,QPSK and BPSK has almost same BER performance for lower values of Eb/No. But QPSK has better BER performance as compared to BPSK for different data lengths for higher values of Eb/No. On incresing data length, BER performance for both QPSK and BPSK almost remains same.

In fig. 8, uncoded IDMA is considered using random interleaver, simulation is done taking parameters as data length 512, spreading as repition code of length 16, iteration numbers 15and Eb/No=3dB .From this plot QPSK has better BER performance as compared to BPSK for different number of users n=1,4,7,10,13,16,19,22,25,27,38,51,64. But above 32 number of users QPSK and BPSK has almost same BER performance .

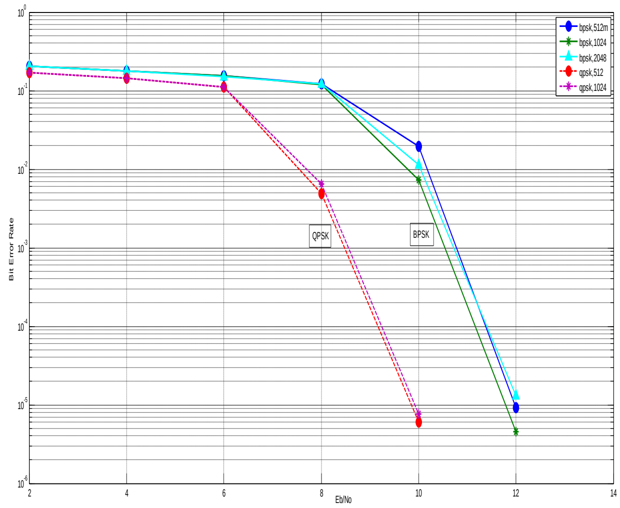

Fig. 7: Simulation of uncoded IDMA using RI with BPSK & QPSK for 32 users with variation in data length

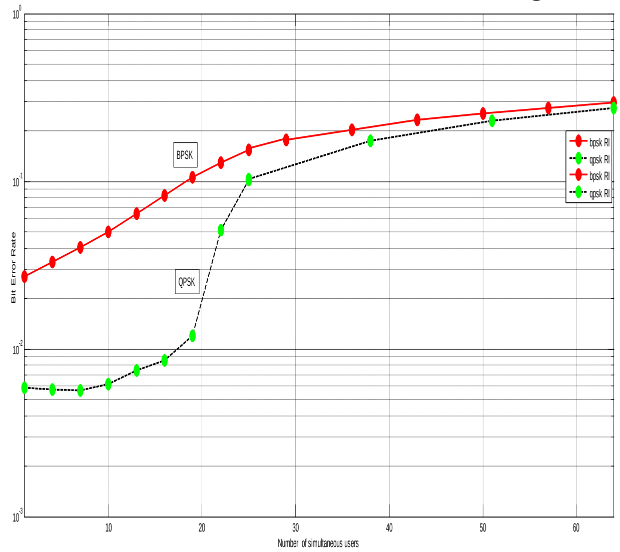

Fig. 8. Uncoded IDMA with RI using BPSK & QPSK for variation in user count at Eb/No=3dB

In fig. 9, uncoded IDMA is considered using tree based interleaver, simulation is done taking parameters as data length 512, spreading as repition code of length 16, iteration numbers 15and Eb/No=3dB .From this plot QPSK has better BER performance as compared to BPSK for different number of users n=1,4,7,10,13,16,19,22,25,27,38,51,64. But above 32 number of users QPSK and BPSK has almost same BER performance .In fig. 10, uncoded IDMA is considered using tree based interleaver, random interleaver simulation is done taking parameters as data length 512, spreading as repition code of length 16, iteration numbers 15 .From this plot QPSK has better BER performance as compared to BPSK for different number of users,n=1,4,8,16.On comparing BER performance of Tree Based interleaver and random interleaver, both have almost same performance. Thus QPSK with Tree Based interleaver can replace QPSK with random interleaver as memory requirements for Tree Based interleaver is less as compared to random interleaver.

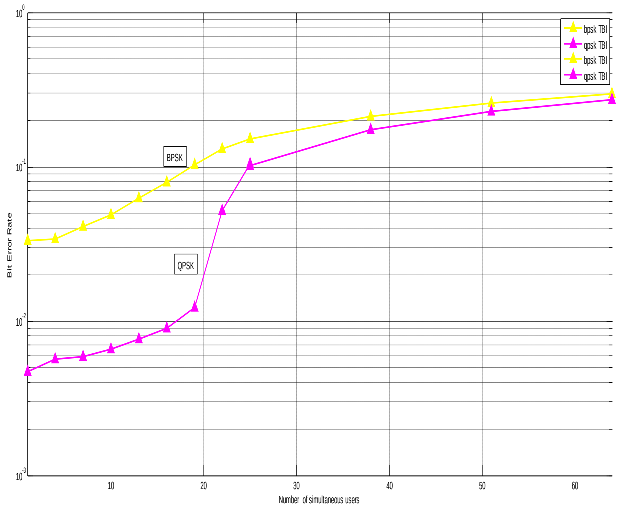

Fig. 9: Uncoded IDMA with TBI using BPSK & QPSK for variation in user count at Eb/No=3dB

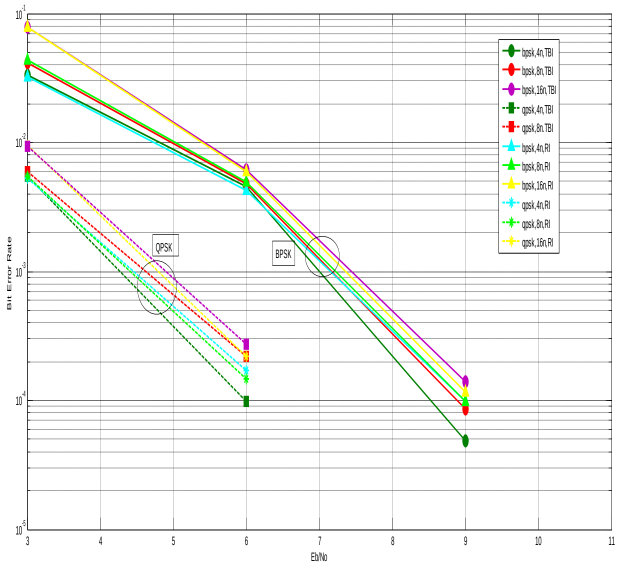

Fig. 10: Uncoded IDMA comparing performance of TBI with RI using BPSK &QPSK for variation in user count

In fig. 11, 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 .From this plot QPSK has better BER performance as compared to BPSK for various count of users availabel in same cell in communication environment for n=1,4,7,10,13,16,19,22,25,27,38,51,64. But above 32 number of users QPSK and BPSK has almost same BER performance . On comparing BER performance of Tree Based interleaver and random interleaver, both have almost same performance for different values of users. Thus QPSK with Tree Based interleaver can replace QPSK with random interleaver as memory requirements for Tree Based interleaver is less as compared to random interleaver.

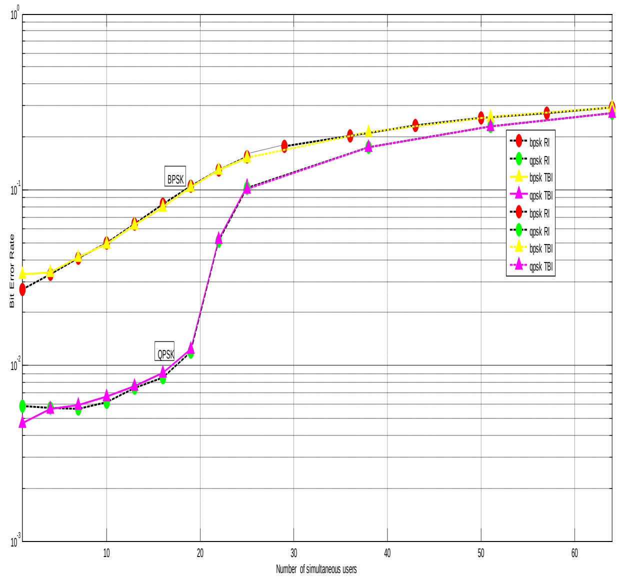

Fig. 11: Uncoded IDMA comparing TBI with RI using BPSK & QPSK for variation in user count at Eb/No=3dB

7. CONCLUSIONS

It is well established that optimum modulation scheme is the solution of high error problems without the increment in complexity and extra requirement of bandwidth in the system. In this paper, BPSK and QPSK modulation mechanism has been considered with variation in interleavers. The interleavers opted for the purpose were random interleavers and tree based interleavers. The performance of tree based interleaver with QPSK modulation mechenism has been observed under IDMA environment. The BER performance comparison has also carried out with MRI, RI, and TBI mechanisms. The performance of tree based interleaver has been found to be optimum in nature with iterative IDMA receivers when implemented with QPSK modulation mechenism. Various simulations presented confirm the superior performance of IDMA scheme with TBI and QPSK scheme.

8. REFERENCES

[1] T. S. Rappaport, “Wireless Communications: Principles and Practice,” 2nd Englewood Cliffs, NJ: Prentice-Hall, 2002.

[2] Li ping, Lihai Liu, Keying Wu and W. K. Leung, “Interleave-Division Multiple-Access,” in IEEE Transaction of Wireless Communication, Vol. 5(4), pp. 938-947, 2006.

[3] M. Shukla, V.K. Srivastava, S. Tiwari, “Analysis and Design of Optimum Interleaver for Iterative Receivers in IDMA Scheme”, Wiley Journal of Wireless Communication and Mobile Computing, Vol. 9 (10), pp. 1312-1317, 2009.

[4] H. Wu, L.Ping and A. Perotti, “User-specific chip-level interleaver design for IDMA System,” IEEE Electronics Letters, Vol.42, Feb 2006.