BPSK and QPSK Modulation Techniques with Optimum Tree Based Interleaver in Iterative IDMA Systems

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Abstract

In Interleave-Division Multiple-Access (IDMA) scheme, user specific interleavers are employed as the only means for user separation. It is well established fact that these interleavers must have property of orthogonality amongst each other. The interleavers are, therefore, referred has the heart of IDMA system. The researchers have proposed various non-orthogonal interleavers in the literature which are easy to generate and have near-zero collision property. The Tree Based Interleaver (TBI) is one of those non-orthogonal interleavers 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 master random 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. In this paper, the performance analysis of iterative IDMA receivers have been evaluated with BPSK & QPSK modulation techniques employing tree based interleavers and random interleavers, as representative of non-orthogonal interleaver, in uncoded and rate $\frac{1}{2}$ covolutionally coded conditions with Additive White Gaussian Noise (AWGN) channel. In the simulation results, the IDMA system with QPSK modulation techniques employing TBI outperforms the Random Interleavers optimally.

Keywords

Tree Based Interleaver; Random Interleaver; Multiuser Detection; AWGN Channel; IDMA Receiver; BER; Modulation Techniques.

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I. Introduction

In[1], the researchers have demonstrated that Interleavers may be employed 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 Multi-user Detection (MUD) cost (per user) is independent of the number of users while in case of CDMA systems, the MUD cost is solely dependent on user count. On the other hand, the power consumption of CDMA systems is also user dependent.

In[1], researchers have presented an IDMA system which employs randomly and independently generated interleavers. With randomly generated interleavers, the IDMA system in[1] performs similarly and even better than a comparable CDMA system. If this is the case, the base station (BS) has to use a considerable amount of memory to store these interleavers, which may cause serious concern in case of large user count. 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 researchers have suggested solution of high memory requirement in[2]. In this paper, the user specific interleavers are generated by master random interleaver method, but the computational complexity required to generate the interleaving sequence is increased extensively, and it is user dependent in spite of adopting some special arrangements[2]. 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], M. Shukla et al proposed Tree Based Interleaver (TBI) 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.

The paper is organized as follows. Section II presents an introduction of the iterative IDMA communication system. Section III contains importance of digital modulation schemes with special focus on QPSK scheme. Section IV presents simulation results of IDMA systems with the Tree Based Interleaver (TBI) and random interleaver (RI) using BPSK and QPSK signaling. Section V concludes the paper.

II. Iterative IDMA System

An iterative IDMA system[1], is shown in Figure 1, for K simultaneous users with a single path channel. The upper part in the figure1 shows the transmitter, with N-length input data sequence from user k is $d_k = [d_k(1), \ldots, d_k(i), \ldots d_k(N)]^T$ and is encoded using low rate code C into $c_k = [c_k(1), \ldots, c_k(j), \ldots c_k(J)]^T$, where J is denoted as the Chip length and coded bits are chips following the convention of CDMA systems.

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 repetition code with spread length of 16.

Further, the chips c_k are interleaved by a chip level interleaver 'Π_k', producing a transmitted chip sequence as $x_k = [x_k(1), \dots, x_k(j), \dots x_k(J)]^T$. After transmitting through the AWGN channel, the bits are observed at the receiver side as $r = [r_k(1) \dots r_k(j) \dots r_k(J)]^T$. The Channel opted for simulation purpose may be changed depending on the environment.

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

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

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

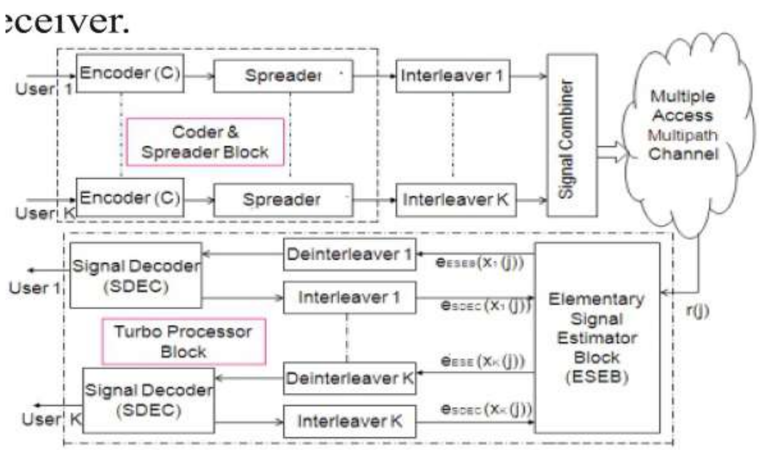

Figure 1. Transmitter and Receiver structures of IDMA scheme with K simultaneous users

The receiver 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. The outputs of the PSE and DECs are extrinsic log-likelihood ratios (LLRs) about $\{x_k\}$ defined as

$$e(x_k(j)) = \log \frac{p(y \mid x_k(j) = +1)}{p(y \mid x_k(j) = -1)}, \quad \forall k, j \tag{2}$$

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 (2) denotes the received channel output while for the DECs, y in (2) 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[1].

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

$$r(j) = h_k x_k(j) + \xi_k(j) \tag{3}$$

Where $\xi_k(j)$ is the distortion (including the 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.

III. Modulation Techniques in IDMA Systems

We define modulation scheme[4] as an operator on the baseband signal. Modulation is one of the most important signal processing operations that takes place in a communication system. It can be effectively employed 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.

In any modulation scheme, specific parameter is varied in accordance with the carrier signal. Also, 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. The researchers have gone through large variety of modulation techniques for use in mobile radio Communications systems with endless efforts.

According to norms of IMT 2000, the prime objective of 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) depending on environment.

In this paper, IDMA system with coherent BPSK & QPSK modulation schemes has been studied. In BPSK scheme, 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.

In QPSK scheme, the four symbols are generated for every couple of input bits hence it is known as bandwidth-conserving modulation scheme. Similar to BPSK scheme, the QPSK scheme also carries information in terms of the phase variations. In particular, the phase takes on one of four equally spaced values such as $\pi/4, 3\pi/4, 5\pi/4, 7\pi/4$, 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 counter clockwise direction.

If special characteristics of QPSK are to be mentioned, we quote that for the same Eb/No, a QPSK system transmits the information at twice the bit rate of BPSK for the same channel bandwidth, and 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, For the same bit rate QPSK uses only half the channel bandwidth, 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:

$$
\begin{aligned}
(1\,0) &= (1 - 1j) \\
(0\,0) &= (-1 - 1j) \\
(0\,1) &= (-1 + 1j) \\
(1\,1) &= (1 + 1j)
\end{aligned}
$$

IV. Numerical Results

During simulation, some assumptions have been made. It is assumed that every user is having same dat length and similar coding scheme. Assuming IDMA system with BPSK & QPSK signaling schemes in single path AWGN channels, with unequal power allocation scheme[7,8], we employ Random Interleaver (RI) and Tree Based Interleaver (TBI) mechanisms for user separation purpose during simulation. The reason for selection of RI mechanism lies with the fact related to better probability of orthogonality amongst user specific interleavers[9].

The TBI mechanism consumes extremely less memory for storing user-specific interleavers when compared to that pf RI mechanism, however Master Random Interleaver (MRI) mechanism[2] requires similar memory requirement. In figure 2, the memory requirement has been simulated for 100 user count with all the three interleavers and simulation results confirm the optimality of TBI mechanism[5].

At first, the uncoded IDMA has been considered employing tree based interleavers. Simulation has been performed taking parameters as data length 512, spreading as repetition code of length 16, iteration numbers 15. From figure 3, it is evident that QPSK technique has better BER performance as compared to that of BPSK technique for various number of users n=1,4,8,16,32,64. It is also observed that 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.

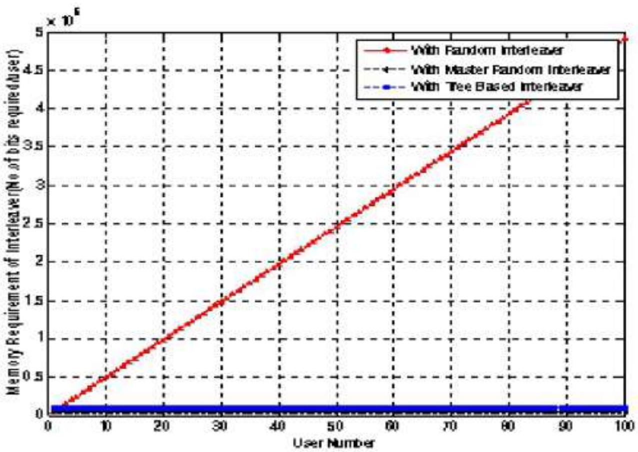

Figure 2. Comparison of RI, MRI, and TBI for memory requirement[5]

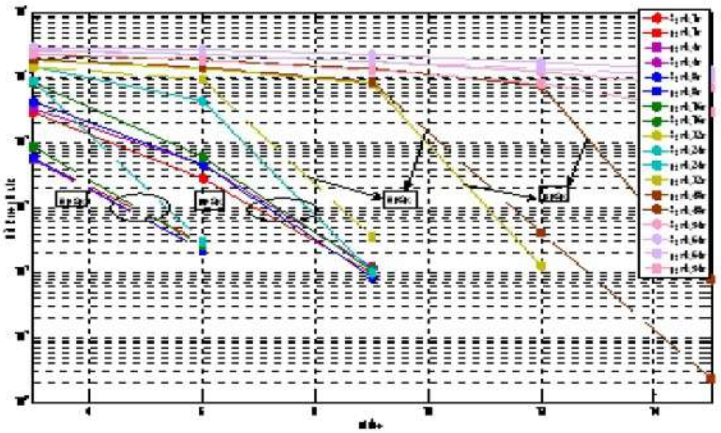

Figure 3. Simulation of uncoded IDMA using TBI with BPSK & QPSK for variation in user count.

In figure4, uncoded IDMA is simulated with variation in data length while other parameters have been opted to be similar to that in previous simulation for eight users. From the figure, it once again demonstarted that QPSK scheme has better BER performance as compared to BPSK scheme for different data lengths. On incresing data length, BER performance for both QPSK and BPSK almost remains same.

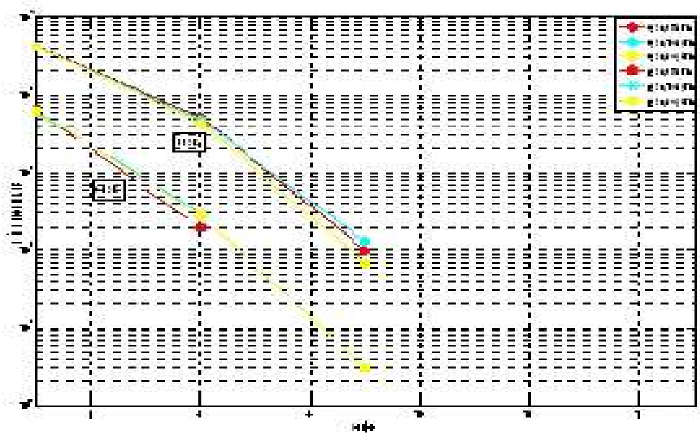

Figure 4. Simulation of uncoded IDMA using TBI with BPSK & QPSK for 8 users with variation in data length

The figure 5 presents uncoded IDMA system with tree based interleaver and random interleaver. The simulation has been performed taking parameters as data length 512, spreading as repetition code of length 16, iteration numbers 15 and Eb/No=3dB. The simulations results once again confirms the superior BER performance of QPSK when compared to BPSK for various user count. 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, it has been observed that both have almost same performance for different values of users. Thus QPSK with Tree Based interleaver can replace QPSK with random interleaver (RI) as memory requirements for Tree Based interleaver (TBI) is less as compared to random interleaver and TBI is referred to be optimum interleaver[3].

In figure 6, the coded IDMA scheme has been evaluated for Random Interleaver and Tree Based Interleaver for 16 users. The simulation results confirm that the tree based interleaver is performing at par with that of random interleaver howver on other front including bandwidth and memory requirements, the tree based interleaver outperforms the random interleavers when employed with IDMA systems.

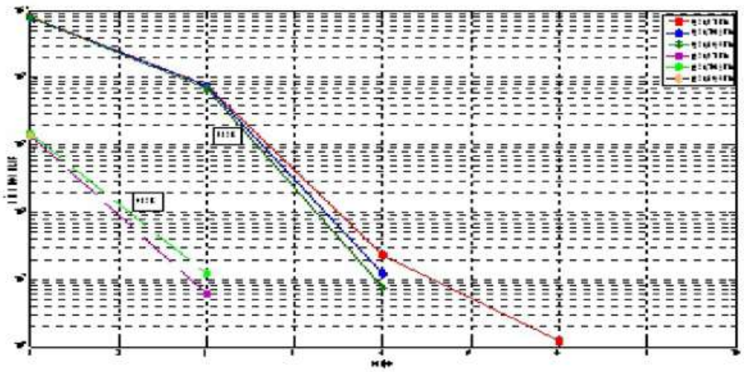

Figure 5. Simulation of coded IDMA using TBI with BPSK & QPSK for 16 users with variation in data length

In figure 7, rate $\frac{1}{2}$ convolutionally coded IDMA has been considered with tree based interleaver. Simulation has been performed with almost similar parameters taken for figure 3 and results observed repeats the conclusions drawn from figure 3.

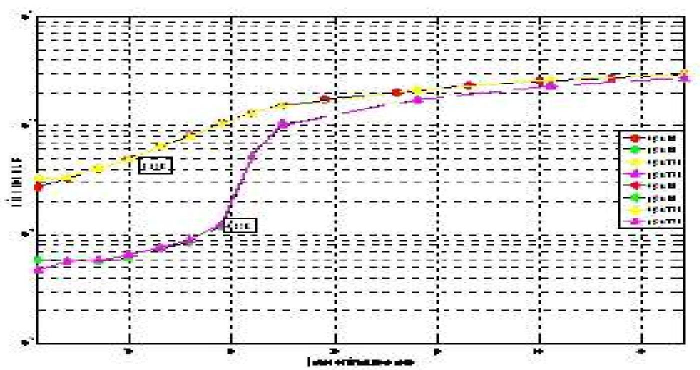

Figure 6. Uncoded IDMA comparing TBI with RI using BPSK & QPSK for variation in user count at Eb/No=3dB

For final observation, we see that, 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.

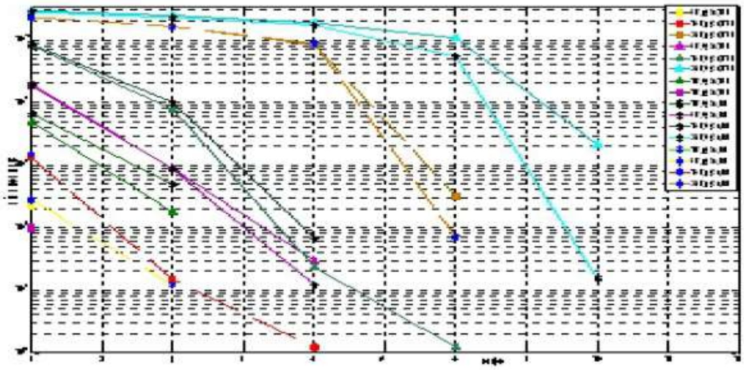

Figure 7. Coded IDMA comparing TBI with RI using BPSK & QPSK for variation in user count

V. Conclusions

In this paper, the IDMA system has been evaluated on the basis of bit error rate (BER) with BPSK & QPSK modulation techniques with random interleaver and tree based interleaver in uncoded and rate $\frac{1}{2}$ convolutionally coded environments. The simulation results have been compared with variation in user count, variation in data length and for different values of Eb/No. From the simulations, it can be concluded that uncoded and coded IDMA system with random interleaver and tree based interleaver has better BER performance with QPSK modulation in comparison to that of IDMA with BPSK modulation.

It is also demonstrated that tree based interleaver has almost similar 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 QPSK modulation can replace random interleaver using BPSK or QPSK modulation.

It has also been observed that for larger number of users (more than 40) QPSK modulation has same BER performance as that of BPSK modulation scheme however on the front of bandwidth conservation, QPSK scheme always demonstrate its upper edge on BPSK scheme regardless of the multiple access scheme employed for the purpose of communication.

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