Performance Evaluation of Maximal Ratio Receiver Combining Diversity with Prime Interleaver for Iterative IDMA Receiver

M. Shukla[1*] Akanksha Gupta[2] Rinkoo Bhatia [3]

6. Department of Electronics Engineering, Harcourt Butler Technological Institute, Kanpur, India

7. Department of Electronics & Communication Engineering, I.T.M. University, Gwalior, India

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

Abstract

The antenna diversity mechanism is established as the well known mechanism for reduction of probability of occurrence of communication failures (outages) caused by fades. In receiver diversity, multiple antennas are employed at the receiver side in case of transmitter diversity, multiple antennas are the integral part of transmitter section.. In this paper, Maximal Ratio Receiver Combining (MRRC) diversity technique is evaluated to mitigate the effect of fading in IDMA scheme employing random interleaver and prime interleaver with single transmit two receiving antennas in low rate coded environment**.** For the performance evaluation, channel is assumed to be Rayleigh multipath channel with BPSK modulation. Simulation results demonstrate the significant improvement in BER performance of IDMA with maximal ratio receiver combining (MRRC) diversity along with prime interleaver and random interleaver and it has also been observed that BER performance of prime interleaver is similar to that of random interleaver with reduced bandwidth and memory requirement at transmitter and receiver side.

Keywords: Multipath Fading, MRRC diversity, Multi user detection, Interleave-Division Multiple Access (IDMA) Scheme, Random Interleaver, Prime Interleaver

1. Introduction

Based on the developing trends of mobile communication, the goal of next generation is to attain broader bandwidth, higher data rate, and smoother and quicker handoff. Researchers are required to focus on ensuring seamless service across a multitude of wireless systems and networks The Next generation mobile communication system will be able to provide a complete solution where voice, data and streamed multimedia can be given to users on an "Anytime, Anywhere" basis, and at higher data rates than previous generations. It will be a major move toward ever-present communications systems and seamless high-quality communication services. The technology required to allow a very simple chip-by-chip (CBC) iterative multiuser detection strategy to deal with challenges to make these services available is commonly known as the Third generation (3G) Cellular Systems using multiuser detection [Shukla 2006]. Wireless communication systems performance is limited by much impairment such as the thermal noise, the path loss in power as the radio signal propagates the shadowing due to the presence of fixed obstacles in the radio path, and the fading which combines the effect of multiple propagation paths, and the rapid movement of mobile units' reflectors [Wang 2006]. Leading the signal transmission, different signal copies undergo different attenuation, distortion, delays and phase shifts. Due to this problem overall system performance severely degraded.

So, this is necessary to reduce the problem of multi- path fading, but not at the cost of extra power or additional bandwidth. One effective solution is the proposed named space diversity (based on orthogonal design) to combat the effect of multi path fading and improve coverage, capacity and reliability, without the requirement of power or extra bandwidth. The most commonly used Space diversity method used with IDMA is the maximal ratio receiver combining (MRRC) diversity technique, with one transmits and two

received antennas[Shukla 2009], where several uncorrelated replicas of the signals are combined at the receiver in order to improve the signal reconstruction. Ref. [Ping 2006] Studied a chip interleaved CDMA scheme and a maximal-ratio-combining (MRC) technique for multiple access channels (MACs) with inter symbol interference (ISI). It clearly demonstrated the advantages of introducing chip-level interleaver In IDMA scheme, a chip level interleaver is followed by spreading process inherits many advantages from conventional CDMA scheme, as it allows a low complexity multiple user detection (MUD) techniques [Ping 2006] applicable to systems with large numbers of users in multi-path channels and robustness against fading. The MRRC diversity technique, with one transmits and two receive antennas, is implemented with interleave-division multiple access.

This paper demonstrates the analysis of IDMA scheme with MRRC diversity at the receiver end to overcome the effect of fading. During the performance analysis of MRC diversity technique, the enhancement in the bit error rate (BER) performance of IDMA scheme has been observed and the performance of IDMA systems with Prime interleaver is found to be similar to that with random interleavers. The paper is structured as follows. Section II introduces the system model of IDMA scheme and introduction about random and proposed prime interleaver. maximal ratio receiver combining (MMRC) is presented in Section III. Section IV shows the performance analysis of proposed interleaver scheme. Finally, Section V presents the conclusion.

2. Interleave-Division Multiple-Access (IDMA) Scheme

It is well investigated by researchers that the performance of conventional Code-Division Multiple-Access (CDMA) systems [Liu 2006] is mainly limited by multiple access interference (MAI), as well as intersymbol interference (ISI). Also, the complexity of CDMA multi-user detection has always been a serious problem for researchers all over the world. The problem can be visualized from the angle of computational cost as well complexity of multi-user detection algorithms in CDMA systems. The use of user-specific signature sequences is a characteristic feature for a conventional CDMA system. The possibility of employing interleaving for user separation in CDMA systems is briefly inducted in [1] but the receiver complexity is considered as a main problem. In interleave-division multiple-access (IDMA) scheme, users are distinguished by user specific chip-level interleavers instead of signatures as in a conventional CDMA system. The scheme considered is a special case of CDMA in which bandwidth expansion is entirely performed by low-rate coding. This scheme allows a low complexity multiple user detection techniques applicable to systems with large numbers of users in multipath channels in addition to other advantages.

In CDMA scheme, signature sequences are used for user separation while in IDMA scheme, every user is separated with user-specific interleavers, which are orthogonal in nature. The block diagram of IDMA scheme is shown in figure 1 for K users. The principle of iterative multi user detection (MUD) which is a promising technique for multiple access problems (MAI) is also illustrated in the lower part of Fig. 1. The turbo processor involves elementary signal estimator block (ESEB) and a bank of K decoders (SDECs). The ESEB partially resolves MAI without considering FEC coding. The outputs of the ESEB are then passed to the SDECs for further refinement using the FEC coding constraint through de-interleaving block. The SDECs outputs are fed back to the ESEB to improve its estimates in the next iteration with proper user specific interleaving. This iterative procedure is repeated a preset number of times (or terminated if a certain stopping criterion is fulfilled). After the final iteration, the SDECs produce hard decisions on the information bits [Ping 2006, Wu 2006].

The complexity involved (mainly for solving a size KxK correlation matrix) is $O(K^2)$ per user by the well-known iterative minimum mean square error (MMSE) technique in CDMA, while in IDMA, it is independent of user. This can be a major benefit when K is large [Shukla 2009].

2.1 IDMA Scheme Model

Here, we consider an IDMA system [Ping 2006], 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 chips $c_k = [c_k(1), \ldots, c_k(j), \ldots c_k(J)]^T$ based on low rate code C, where J is the Chip length.

The chips 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

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

where h_k is the channel coefficient for k^{th} user and $\{n(j)\}$ are the samples of an additive white Gaussian noise (AWGN) process with mean as zero and variance $\sigma^2 = N_0/2$. An assumption is made that $\{h_k\}$ are known priori at the receiver.

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

$$e(x_k(j)) = \log\left(\frac{p(y/x_k(j) = +1)}{p(y/x_k(j) = -1)}\right), \forall k, j. \tag{2}$$

2.2 LLR Generation

These LLRs are further distinguished by the subscripts i.e., $e_{ESEB}(x_k(j))$ and $e_{SDEC}(x_k(j))$, depending upon whether they are generated by ESEB or SDECs. Due to the use random interleavers $\{\Pi_k\}$, the ESEB operation can be carried out in a chip-by-chip manner, with only one sample r(j) used at a time. So, rewriting (2) as

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

where

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

is the distortion in *r(j)* with respect to user-k. $\xi_k(j)$ is the distortion (including interference-plus-noise) in received signal with respect to user-k.

A brief description of CBC algorithm [1] used in IDMA, has been presented in [3]. The operations of ESEB and APP decoding are carried out user-by-user.

The outputs of the ESEB as extrinsic log-likelihood ratios (LLRs) is given as,

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

The LLR output of SDEC is given as,

$$e_{SDEC}(x_k(\pi(j))) = \sum_{j=1}^{S} e_{ESEB}(x_k(\pi(j))) \qquad j = 1, \ldots, S$$

Now, these steps are repeated depending on no. of iterations and users.

3. Various Interleavers for IDMA Scheme

Interleaving is a process of rearranging the ordering of a data sequence in a one to one deterministic format. Interleaving is a practical technique to enhance the error correcting capability of coding. In turbo coding, interleaving is used before the information data is encoded by the second component encoder. The basic role of an interleaver is to construct a long block code from small memory convolutional codes, as long codes can approach the Shannon capacity limit. Secondly, it spreads out burst errors [Ping 2004, Ping 2004]. The interleaver provides scrambled information data to the second component encoder and decorrelates inputs to the two component decoders so that an iterative suboptimum-decoding algorithm based on uncorrelated information exchange between the two component decoders can be applied. The final role of the interleaver is to break low weight input sequences, and hence increase the code free Hamming distance or reduce the number of codewords with small distances in the code distance spectrum. The size and structure of interleavers play a major role in the performance of turbo codes. There are a number of interleavers, which can be implemented.

a) Random Interleavers:
The user specific Random Interleaver rearranges the elements of its input vector using a random permutation [Ping 2006]. The incoming data is rearranged using a series of generated permuter indices. A permuter is essentially a device that generates pseudo-random permutation of given memory addresses. The data is arranged according to the pseudo-random order of memory addresses. If random interleavers are employed for the purpose of user separation, then lot of memory space will be required at the transmitter and receiver ends for the purpose of their storage. Also, considerable amount of bandwidth will be consumed for transmission of all these interleaver as well as computational complexity will be increase at receiver ends.

b) Prime Interleavers:
Prime interleaver is based on prime number which gives a novel user-specific interleaver generation mechanism with lesser time to get it generated and along with minimal consumption of bandwidth required during transmission well similar performance in terms of BER to that of random interleaver. In generation of prime interleaver we have used the prime numbers as seed of interleaver. Here, user-specific seeds are assigned to different users. For understanding the mechanism of prime interleaver, let us consider a case of interleaving n bits with seed p. First, we consider a Galois field GF (n). Now, the bits are interleaved with a distance of seed over GF (n) [Shukla 2010].
In case, if {1, 2, 3, 5, 6, 7, 8… n} are consecutive bits to be interleaved with seed p then location of bits after interleaving will be as follows:
In generation of prime interleaver we have used the prime numbers as seed of interleaver. Different seeds are assigned to different users. Consider a case of interleaving n bits with seed p.
First consider a gallois field GF(n), now interleave bits with a distance of seed over the GF(n). That is
If{1,2,3,5,6,7,8,………….,n} are consecutive bits these are to be interleaved with seed p
Then
Location of bits after interleaving will be as fallows
1===> 1
2===> (1+p) mod n
3===> (1+2p) mod n
4===> (1+3p) mod n
.   .
.   .
.   .
n===> (1+(n-1)p) mod n
for Example if we have to interleave 8 bits such that {1,2,3,4,5,6,7,8} and we wish to interleave these bits with seed 3 then the new location of bit will be as fallows

1===> 1
2===> (1+1*3) mod 3===>4
3===> (1+2*3) mod 3===>7
4===> (1+3*3) mod 3===>2
5===> (1+4*3) mod 3===>5
6===> (1+5*3) mod 3===>8
7===> (1+6*3) mod 3===>3
8===> (1+7*3) mod 3===>6
So new order of bits will be{1,4,7,2,5,8,3,6}.
The memory required by the Prime Interleaver is smaller then other available interleavers as now only seed is to be transmitted. The prime interleaving scheme reduces the bandwidth requirement that occurs in other available interleaving scheme. It is shown by the help of a comparison table 1.

The bandwidth required by the Prime Interleaver (PI) is smaller than other available interleavers as now only seed is to be transmitted, in addition to very small amount of memory required at the transmitter and receiver side as well this scheme reduces the computational complexity that occurs in random interleaving scheme.

3. Maximal Ratio Receiver Combining (MRRC) Technique

The block diagram of maximal ratio combining (MRC) diversity also referred as Maximal Ratio Receiver Combining (MRRC) diversity technique with IDMA scheme is shown in figure 2. In this method, the diversity branches are weighted for maximum SNR. As shown in block diagram in figure 2, d_k is data of kth user, after encoding and spreading the data is randomly interleaved and termed as 'chips'. Now this chip Signal x_k is sent from the transmit antenna, which will propagate from both the channel [Shukla 2009].

If we consider 1 transmit and 2 receive antenna, then channel between transmit antenna and the first received antenna is h_0 and between the transmit antenna and second receive antenna one is denoted by h_1. The channel can be modeled having magnitude and phase response. So,

$$h_0 = \alpha_0 e^{i\theta 0}$$

$$h_1 = \alpha_1 e^{i\theta 1} \tag{5}$$

Noise can be added at both the receiver. The resulting received signals are

$$R_0 = h_0 x_k + n_0$$

$$R_1 = h_1 x_k + n_1 \tag{6}$$

where n_0 and n_1 represents the noise and interference at both the receiver separately.

Now the Receiver combining scheme for two branches MRRC can be written as

$$\overline{X}_K = h_0^* R_0 + h_1^* R_1 \tag{7}$$

Now this output of maximal ratio combiner can fed to the detector for the proper estimation of transmitted signal x_k.

4. PERFORMANCE ANALYSIS OF PROPOSED SCHEME

For performance evaluation of IDMA scheme with MRRC diversity, 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.

Figure 3 and Table-1 demonstrates the bandwidth requirement of random, tree based and prime interleaver. The bandwidth required by the Prime Interleaver (PI) is smaller than other available interleavers as now only seed is to be transmitted, in addition to very small amount of memory required at the transmitter and receiver side. In Figure3.for the simulation purpose, the data length is opted to be 512 bits while 16. The

iteration at the receiver is chosen to be 15. The simulation has been performed for 100 users.

Now, we present simulation results to demonstrate the performance of the MRRC diversity scheme with IDMA systems along with random and prime interleavers. Here we refer, that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK. The simulations are performed for one transmitter and two receiver arrangement.

Figure 4 demonstrates the performance of IDMA scheme with rate ½ FEC convolutional coding using prime interleaver. Here two branches maximal ratio combining scheme is used for implementation of diversity technique. The performance with MRRC diversity along with FEC coding outperforms the other simulations. The block length is 2000, data length is 1024 bit/user with spread length to be 16 and number of iterations used are 15.

Figure. 5 shows the BER performance of IDMA scheme with both random interleaver [3] and prime interleaver with MRRC diversity with rate ½ FEC convolutional coding. From this figure we can see that the performance with coding MRRC diversity is far better than that without coding MRRC diversity also the BER performance of prime interleaver with MRRC diversity comes out similar to that of BER performance of random interleaver with MRRC diversity.

5. Conclusion

This paper demonstrates the analysis of IDMA scheme with maximal ratio receiver combining (MRRC) diversity at receiver end to overcome the effect of fading. During the performance analysis of MRRC diversity technique, the enhancement in the BER performance of IDMA scheme with coding MRRC diversity has been observed better than that of without coding MRRC diversity and the performance of IDMA systems with MRRC diversity along with Prime interleavers is found similar to that of random interleavers. Due to the advantages of same BER performance, smaller bandwidth and memory requirement, the prime interleaver can take place of the random interleaver without performance loss.

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Akanksha Gupta is engaged in studies of M. Tech. in I.T.M. University, Gwalior, India and is working in the area Ad-Hoc Neworks, Multiple Access Scheme and Modulation Schemes.

Rinkoo Bhatia is associated with I.T.M. University, Gwalior, India as Associate Professor in Electronics & Communication Engineering Department. At present she is working in the area of Cooperative Communication, Ad-Hoc Networks, routing algorithms, and Mobile Computing mechanisms. She has published several papers in national and international conferences of repute apart from various journal publications. She is also member of various professional bodies and is active in research areas.

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.

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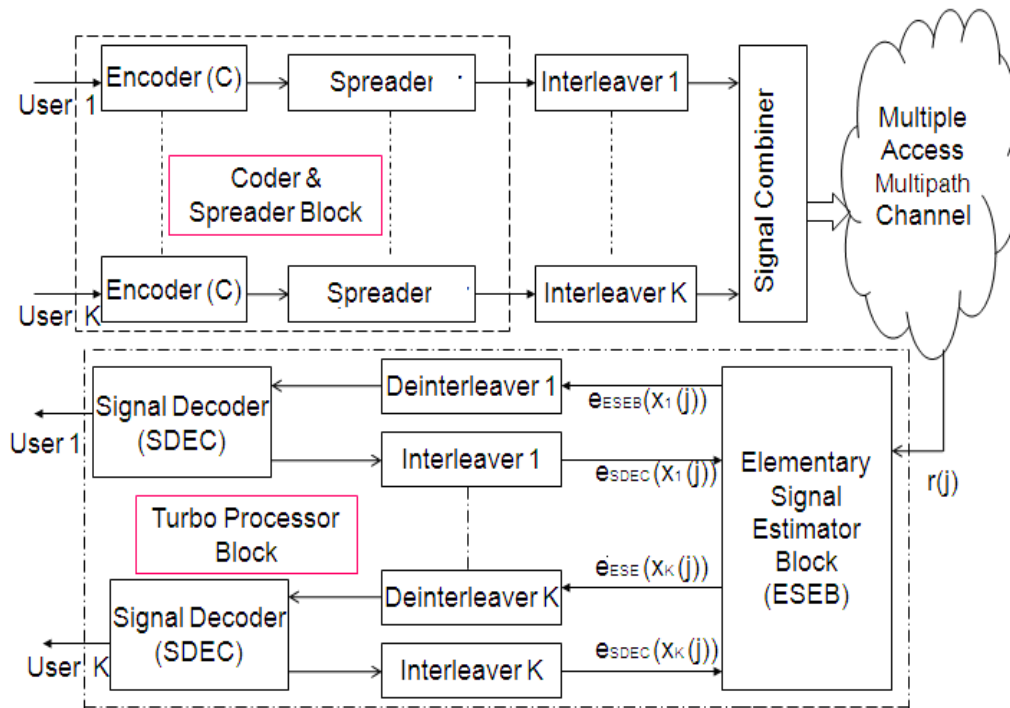Vol 1, No.3, 2011

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Figure 1. Transmitter and Receiver structures of IDMA scheme with *K* simultaneous users.
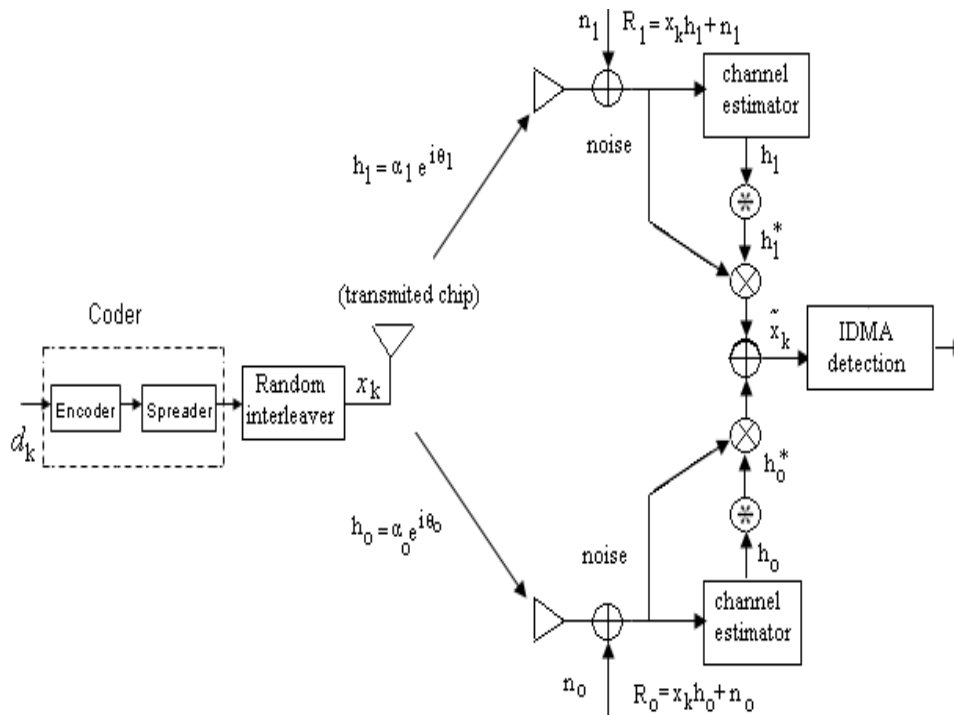
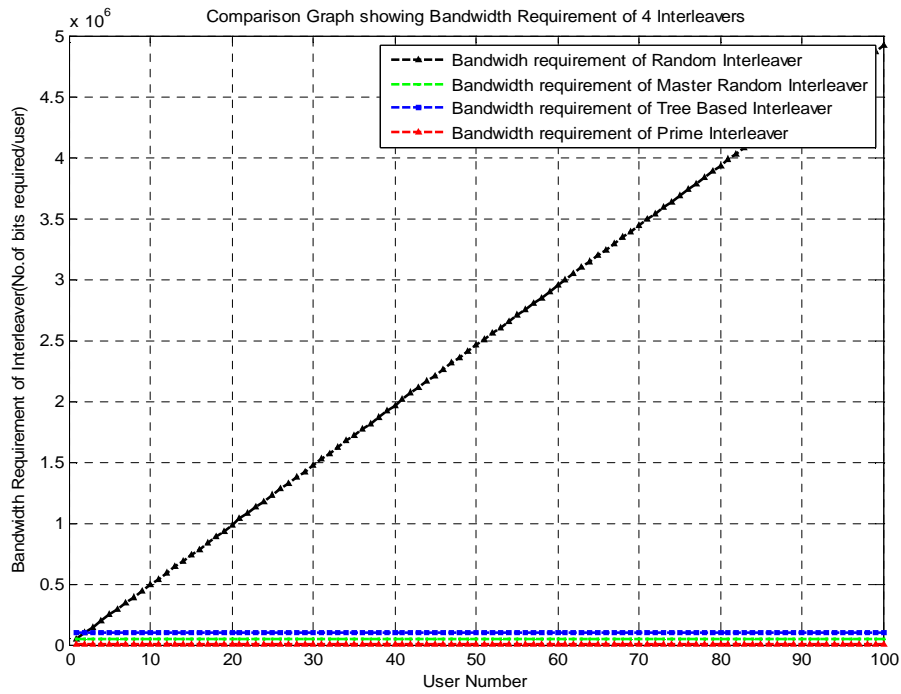Figure 2.   IDMA with proposed two branches MRRC diversity scheme for k^{th} user

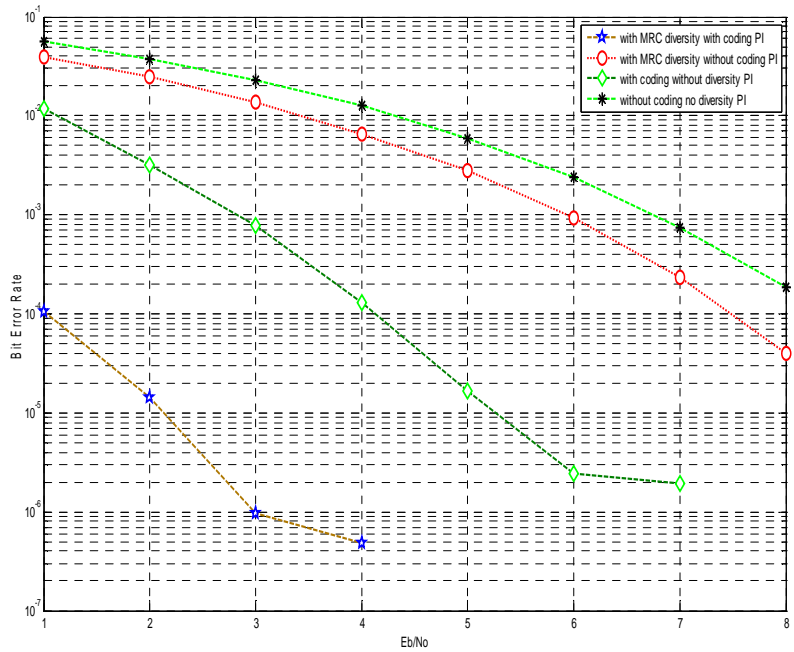Figure3. Comparison of Bandwidth requirement of various interleavers

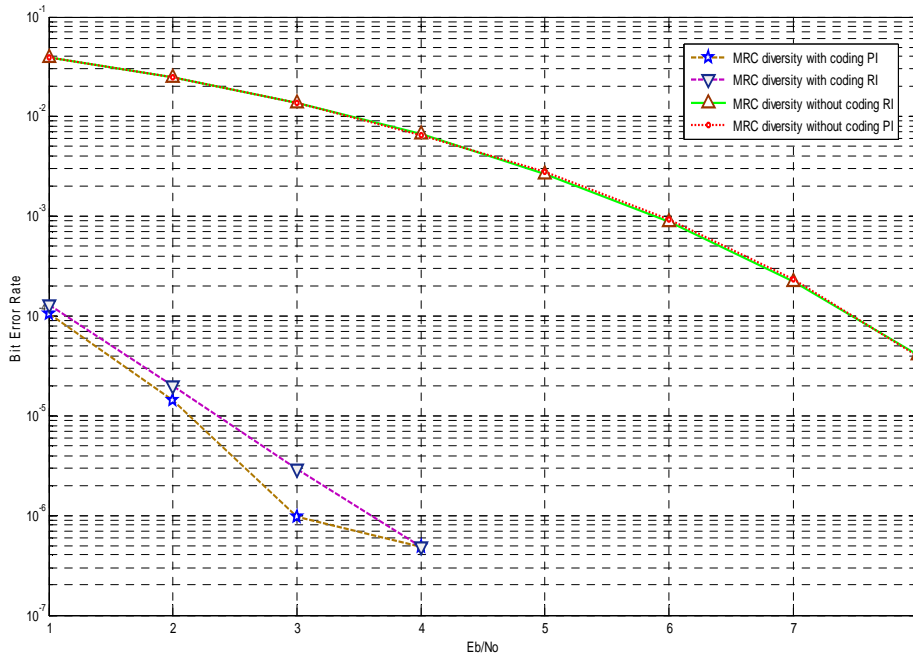Figure 4. Performance comparison of uncoded and coded IDMA with Prime Interleaver with MRRC diversity

Figure 5. Performance comparison random interleaver and Prime Interleaver in uncoded/ coded IDMA with MRRC diversity

Table1.Comparision of bandwidth requirement for transmission of interleaving mask

User Count	Random Interleaver	Tree Based Interleaver	Prime Interleaver
2	2	0	1
6	6	1	1
14	14	2	1
30	30	3	1
62	62	4	1
126	126	5	1