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Analysis of User Specific Interleavers for Iterative Multi-User Detection System

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Abstract—Interleave division multiple access (IDMA) and orthogonal frequency division multiplexing – interleave division multiple access (OFDM-IDMA) have been proposed for beyond third generation (B3G) and fourth generation (4G) communication systems. These system are based on iterative multiuser detection (MUD) techniques. The efficiency of these systems is dependent on the generation of efficient user specific interleavers on the basis of which the users are differentiated as compared to signature code sequences in code division multiple access (CDMA). In this paper we discuss the impact of interleaver design on the efficiency of IDMA system.

***Index Terms*— Chip by chip detection, IDMA, Iterative MUD, User specific Interleavers**

I. Introduction

Significant amount of work has been done in the field of iterative multi user detection (MUD) techniques for suppressing multiple access interference(MAI) [1-2]. Interleave division multiple access (IDMA) and orthogonal frequency division multiplexing – interleave division multiple access (OFDM-IDMA) are the two multiple access (MA) schemes that make use of the iterative MUD efficiently, [3-5]. IDMA has already been proposed for fourth generation (4G) communication [6].

IDMA is basically the evolution of code division multiple access(CDMA), in which the user specific spreading codes should be replaced by user specific random interleavers as the spreader provides no coding gain [3]. Instead all the spreading can be devoted to forward error correction (FEC) coding. With these interleavers, the IDMA system performs similarly and even better than a comparable CDMA system. IDMA also inherits the advantages of CDMA such as asynchronous transmission, diversity against fading and cross cell interference mitigation at a reduced cost of complexity [3]. This chip by chip turbo type detection technique in IDMA also reduces the complexity of receiver multi use detector (MUD) as compared to that used in CDMA system [2-3].

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As IDMA relies on interleaving as the only means for user separation, the efficiency of this system is dependent on the generation of different pseudo random interleaving patterns for each user. The system performance seriously degrades when the interleaving patterns are not properly generated i.e. the collision among the interleaving patterns is not minimum. These interleavers disperse the coded sequences so that the adjacent chips are approximately uncorrelated, which facilitates the simple chip-by-chip detection.

Due to the randomness of interleaver pattern the simplicity of generation of these patterns and the transmission of these patterns is also an issue. The greater the size of interleaver the more it consumes the memory and extra bandwidth for transmission, this becomes a greater problem when the number of users increase. An efficient technique for interleaver generation in IDMA has been proposed in [7].

The first section provides an overview of the working of IDMA; the second section highlights the importance of interleaver design in IDMA and the third section explains the effect of different parameters of interleaver

II. IDMA Principles

The IDMA scheme is an evolution of CDMA scheme suggested in [2] in which instead of using different spreading codes for different users, we use different interleaving pattern for different users. So the orthogonal spreaders in case of CDMA are removed which paves the way for bandwidth expansion to be completely devoted to FEC coding using low rate codes. This in return provides coding gain. Most importantly the IDMA MUD structure [3] reduces the complexity per user from K*L in CDMA [2] to just L.

A. *Transmitter Structure*

The IDMA scheme for K users in a Multipath channel with L-taps is shown in the fig. 1. Here we have assumed that the transmitter and receiver are fully synchronized, the channel information is known at the receiver, and BPSK signaling is used. All considerations are made for uplink though it can readily be applied to downlink also.

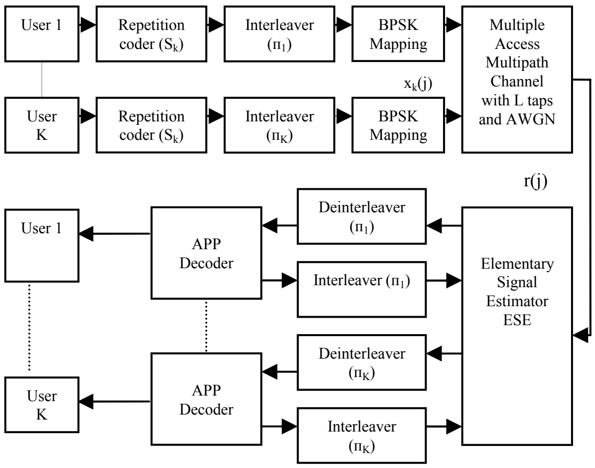

Figure 1: Illustration of IDMA in multipath channel

Here we have assumed that the transmitter and receiver are fully synchronized, the channel information is known at the receiver, and BPSK signaling is used. All considerations are made for uplink though it can readily be applied to downlink also. Let the data from K-users be {dk (i), where i=1…N; k is the user index and N is the data length for the frame}. It is first encoded by low rate code like repetition code having code rate of e.g. 1/16 and then in case of coded IDMA it is encoded by convolutional code of rate e.g. ½. Hence the net coding rate can be 1/32 as suggested in [3]. We assume same FEC codes are used for each user as this doesn't affect the system performance. The output of FEC code is fed into the user specific random interleavers {∏k, k=1…K} to get {xk (j), where j=1….J; J is the frame length given by J=N/Code Rate}. The signal then passes through multipath channel with L-taps and additive white Gaussian noise (AWGN). Let the channel coefficients be {hk,l; k=1….K; l=1…..L}. The signal at receiver r(j) is given by[3]:

$$r(j)= \Sigma_{k=1}^{K} \Sigma_{l=0}^{L-1} h_{k,l} * x(j-l) + n(j) \tag{1}$$

$$r(j+l) = h_{k,l} x_k(j) + \zeta_{k,l}(j) \tag{2}$$

Here h_k is a coefficient for user-k representing the combined effect of power control and path loss, and $\{n(j)\}$ are samples of an additive white Gaussian noise (AWGN) process with variance σ2 = N0/2. We assume that $\{h_k\}$ are known *a priori* at the receiver. Where $\zeta_{k,l}$ is the distortion contained in $r(j)$ with respect to user-k. From the central limit theorem, $\zeta_{k,l}$ is approximately Gaussian, so x_k can be estimated provided that the mean and variance of $\zeta k(j)$ are available [8].

B. Receiver Structure

At the receiver which is a chip by chip turbo type receiver [9] based on central limit theorem, there is an Elementary Signal Estimator (ESE) which processes the combined signal r(j) to generate the estimate (LLR) for chips of each user [3]. In addition to this there is a bank of K a posteriori (APP) decoders which process the LLR of each user chip to generate estimate for each user data bit called Log Logarithmic Ratio (LLR) [8]. The extrinsic information is shared between ESE and decoders, which is used to generate statistics for each user data bit which is then used in the next iteration for the signal estimation in ESE. The output of ESE is given by [3]:

$$e_{ESE} (x_k (j))_l = 2h_{k,l} .[r(j+l) - E(\zeta_{k,l}(j))]/Var(\zeta_{k,l}(j)) \tag{3}$$

$$e_{ESE} (x_k (j)) = \Sigma_{l=0}^{L-1} e_{ESE} (x_k (j))_l \tag{4}$$

As each x_k(j) is observed on L successive received samples $\{r(j) \ldots r(j+L-1)\}$, the information of $x_k(j)$ from all these samples should be combined to generate $e_{ESE}(x_k(j))$, and an LLR combining (LLRC) technique is adopted for this purpose.

The net complexity of IDMA MUD then becomes K*l. So the multipaths increase the complexity of IDMA which becomes more evident as the channel taps increase. So the IDMA provide joint MAI and ISI cancellation but at increased receiver complexity in Multipath environment.

III. Interleaver design in IDMA

The interleaver design has an important role in the efficiency of IDMA system. Not only does it provide uncorrelation between adjacent bit sequences as in the case of orthodox turbo coding and decoding, it also provides a mean to uncorrelate different users [3]. The correlation between interleavers should measure how strongly signals from other users affect the decoding process of a specific user. The better the interleaver uncorrelation, the lesser the iterations required for detection in IDMA MUD. The uncorrelation among the interleavers provides a mean to reduce the MAI from other users thus helping in the convergence of detection process.

In case of IDMA the transmitter need to transmit the interleaver matrix consisting of interleaving pattern of the users to the receiver, so the greater the size of the interleaver, the more bandwidth and resources are used [10].

A. Design Criteria for Random Interleavers

Random interleavers for IDMA need to satisfy two design criteria [7]:

1) They are easy to specify and generate, i.e., the transmitter and receiver can send a small number of bits between each other in order to agree upon an interleaver, and then generate it.
2) The interleavers do not "collide".

The collision among interleavers is interpreted in the form of the uncorrelation among the interleavers.

If the interleavers are not randomly generated, the system performance degrades considerably and the MUD is unable to resolve MAI problem at the receiver resulting in higher values of Bit Error Ratio (BER).

On the other hand if the interleaving patterns are generated more and more random, the MUD resolves the MAI problem more quickly and better values of BER are obtained for the same parameters.

IV. Simulation Results

For all the simulations in this paper, the IDMA decoding algorithm described above was used and all the simulations were implemented in MATLAB. Fig. 2 explains the effect of interleaver length on the BER performance of the system

It is seen from the fig. 2that the increase of the length of interleaver allows more randomness to be introduced in the interleaver design resulting in more uncorrelation between users thus resulting in better BER performance. The more uncorrelation among the interleaver pattern of different users causes the MUD to efficiency resolve MAI from different users thus increasing the BER of the system. But the increase of interleaver length also increases the amount of resources used to transmit the interleaver matrix to the receiver, so interleaver length should be chosen for optimum performance and resource utilization.

Fig. 3 highlights the effect of randomness of interleaver pattern on IDMA system for fixed interleaver length. The more we increase the randomness the better performance we get. But a given interleaver length puts a limit on the amount of randomness that could be introduced among the interleavers.

On the other hand we require more complex methods for interleaver pattern generation to introduce more randomness which increases the complexity of the system. So a given system complexity also the amounts of randomness introduced in the system.

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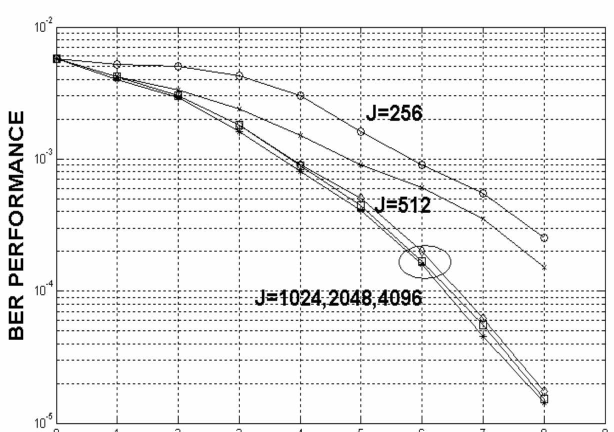

Figure 2: Performance of uncoded IDMA system for different interleaver length. Spreading Length=16, K=4, It_no=15

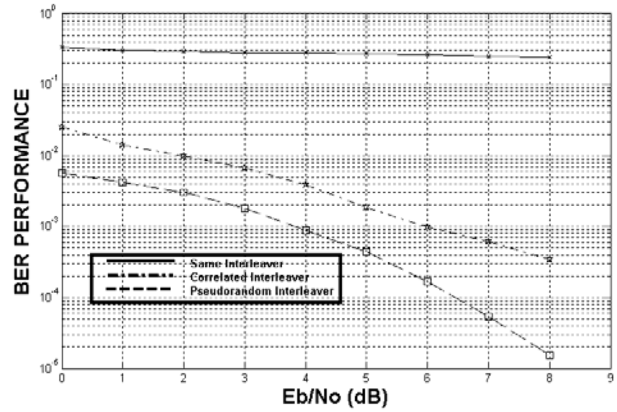

Figure 3: Performance of uncoded IDMA system for different type of interleaver. Frame Length=2048, Spreading Length=16, K=4, It_no=15

I. Conclusion

In this paper we have outlined the role of interleaver design in IDMA system. We have also emphasized on the randomness of interleaver in a sense that it uncorrelates the user data among themselves and among each other. The best performance is obtained if we choose the optimum interleaver length, which minimizes resource utilization for its transmission to the receiver, and the interleaver pattern which generates maximum randomness among the interleaver such that the system complexity remains under check.

Without proper interleaving patterns, the IDMA system will not perform to its full efficiency. Much research can be done on the orthogonality of interleavers and uncorrelation between them. Further research is suggested on the effect of interleaver design on the convergence of detection in IDMA MUD.

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