A Novel Approach for Random Interleavers in IDMA System

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Abstract: - Interleave Division Multiple Access (IDMA) is a multiuser scheme which enables user separation on the basis of interleavers. Interleaver design can allow the IDMA system to approach near Shannon limits of channel capacity. Interleaver combats against Intersymbol Interference (ISI), channel fading and all sorts of noises. In addition, interleavers provide security to the system users. Designing the random interleaver provides a solution for all impairments but they are generally considered computationally heavy. In this paper, an efficient approach has been developed for design of user specific random block interleavers. This design approach reduces the complexity for developing interleaving patterns and is computationally economical.

Key-Words: - Interleavers, Random Interleavers, Multiuser Detection, ISI, MAI, IDMA.

1 Introduction

Multiple access interference (MAI) and intersymbol interference (ISI) are two main performance limiting factors in cellular mobile systems such as code-division multiple-access (CDMA) [1]-[3]. Iterative multiuser detection (MUD) has been widely investigated as a potential approach to enhance the performance of CDMA systems and significant progress has been made recently [2]-[5]. However, increase in number of users rapidly increases the complexity and computational cost in CDMA-MUD, a major concern for practical applications [4].

A new multiuser scheme and a special case of random waveform CDMA is named Interleave-division multiple-access (IDMA)[6]-[10]. It uses a simple chip-by-chip (CBC) estimation algorithm, which is essentially a low-cost iterative soft-cancellation technique [8], [9] [11]. The normalized cost (per user) of this algorithm is independent of the number of users [11]. IDMA enables user separation on basis of interleavers [8],[9]. With these interleavers, the IDMA system in [8] 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 reduced complexity [8][9].

As IDMA relies on interleaving as the only mean for user separation, the system efficiency is dependent on the generation of random interleaving pattern for each user. However, randomly generated interleavers have two major drawbacks: bandwidth inefficiency [12] and lack of compact representation that leads to a simple implementation [13].

In this paper, a new interleaving strategy for IDMA is proposed. This design approach reduces the complexity for developing the random patterns and is computationally economical.

2 Interleavers in IDMA

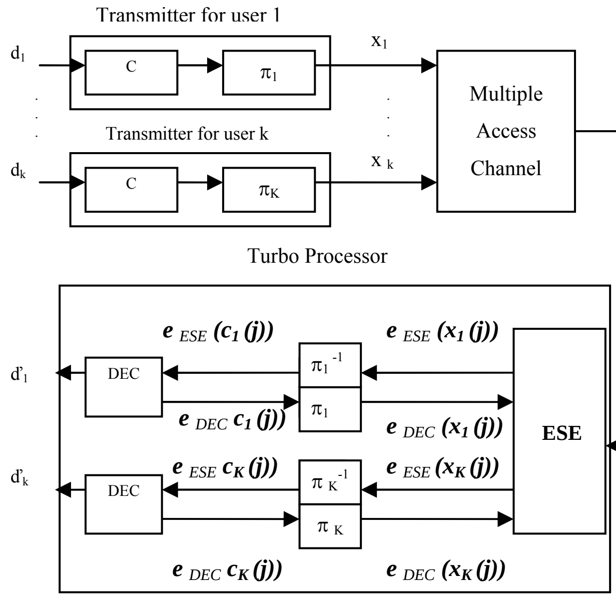

Fig.1: Transmitter and (iterative) receiver structures of an IDMA scheme with K simultaneous users [8], [9], [11]

The transmitter and receiver of an IDMA system with K simultaneous users is shown in figure 1.

The performance of an IDMA system is strongly dependent on the interleavers. Random interleavers are considered computationally heavy [13], [14] and require the transmission of entire interleaving patterns between the base station (BS) and Mobile stations (MSs) making them bandwidth inefficient. In addition, the base station (BS) has to use a considerable amount of memory to store these interleavers, which may cause serious concern when the number of users is large [12], [15].

2.1 Transceiver structure

The input data sequence of each user is first encoded by a low rate code C. The user specific random interleavers take the output of FEC encoder as input and produce the interleaved data $x_k(j)$ where j=1: J, J is the frame length. The elements in x_k are called chips. The signal then passes through multipath channel. The received signal given by [8], [9], [11]:

$$r(j) = \sum_{k=1}^{K} \sum_{l=0}^{L-1} h_{k,l} x_k(j-l) + n(j) \qquad (1)$$

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

Where,

$$\zeta_{k,l}(j) = r(j+l) - h_{k,l} x_k(j) \qquad (3)$$

The receiver consists of an Elementary Signal Estimator (ESE) which performs a coarse chip by chip estimation. It generates the extrinsic LLR about $x_k(j)$ based on the channel observation and the a priori information of the other chips. In addition, there are K single-user a posteriori probability (APP) decoders (DECs). The output of ESE is given by [8], [9], [11]:

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

The ESE outputs are deinterleaved and sent to DECs. DECs deal with coding constraints and perform a soft-in soft-out(SISO). The extrinsic LLRs from the DECs are interleaved and fed back to ESE to improve the estimates [8]. The iterative process is repeated a number of times and DEC produces hard decision in the final iteration.

2.2 Importance of Interleavers in IDMA

In IDMA, user specific interleavers disperse the coded sequences so that the adjacent chips are approximately uncorrelated, which facilitates the simple chip-by-chip detection scheme discussed in [8], [9]. Interleaver design allows IDMA system to approach near shannon limits of channel capacity [9], [11]. Interleaver combats against Inter Symbol Interference (ISI), channel fading and all sorts of noises [9]. In addition, it provides security to the system users.

Interleaving the coded messages before transmission results in energy of users to be spread out in time. The greater the randomness in the interleaving patterns, lesser is the probability of correlated patterns. The non randomness of interleavers degrades the system performance and MUD is unable to resolve the MAI problem resulting in higher values of Bit error rate (BER) [8], [16], [17].

3 Efficient Interleaver Design

As mentioned earlier, K user specific interleavers of length J are used in an IDMA system. The interleaver at the transmitter end scatters the energy of the given signal within the block of the frame. K user specific interleavers allow K number of users, all with different interleaving patterns. Difference in interleaving patterns does not allow the correlation between the energies of different user's message signals. At the receiver deinterleaver reconfigures the bit sequence of each user to assemble the decorrelated energy of the desired signal while dispersing the energy of other user's information and any signal that had been added in by the media, which is then treated as uncorrelated noise [12].

3.1 Algorithm

An efficient interleaving technique, comprising of transposition, Rows shifting, Mixrows, Mixcolumns and user model equation, is proposed. The process is demonstrated by considering alphabets A to P as input to the interleaver:

3.1.1 Transposition

Data of each user is fed into a two dimensional matrix row wise. Interchange rows and columns. The process of transposition is used to decorrelate the energy of adjacent bits.

A	B	C	D
E	F	G	H
I	J	K	L
M	N	O	P

→

A	E	I	M
B	F	J	N
C	G	K	O
D	H	L	P

3.1.2 Rows Shifting

To further disperse the coded bits, each row of the user matrix is shifted by an appropriate amount.

A	E	I	M		A	E	I	M
B	F	J	N	→	N	B	F	J
C	G	K	O		K	O	C	G
D	H	L	P		H	L	P	D

3.1.3 Mixrows

Decorrelation of bits is further increased by interchanging rows of every user matrix. The shifting process is carried according to a predefined sequence.

A	E	I	M		H	L	P	D
N	B	F	J		N	B	F	J
K	O	C	G	→	K	O	C	G
H	L	P	D		A	E	I	M

3.1.4 Mixcolumns

Randomness of data is further enhanced by mixing the columns of every user matrix. The interchanging is again done using a predecided pattern.

H	L	P	D		P	L	H	D
N	B	F	J		F	B	N	J
K	O	C	G	→	C	O	K	G
A	E	I	M		I	E	A	M

The above steps are performed on coded data of every user to introduce randomness.

3.1.5 User Model Equation

Interleavers in IDMA not only need to decorrelate the individual bit sequences but they also have to ensure seperate decorrelated sequences for each user.

To differentiate interleaving patterns of different users, a user model equation has been developed. The base station assigns a specific value to each user based on this equation. The output of the equation is an integer value. For the solution of this equation, user number is considered as the variable and modulo addition is carried out to obtain the final value for each bit location. Bit sequence randomization of every user is varied with the help of this integer value, which is added to the position of all elements to get the new locations, finally producing the interleaved data. Since this value is different for every user, this ensures non repetition of interleaving patterns.

For a specific user, the output of the interleaver after performing these five steps is:

NJCOKGIEAMPLHDFB

4 Advantages and Results

Conventional random interleavers pose many disadvantages for real time implementation.

The proposed interleaver is more bandwidth efficient as compared to a conventional random interleaver. The designed interleaver needs to transmit only channel number information whereas the whole interleaving pattern needs to be transmitted between the Base station and Mobile stations for the latter

The proposed interleaver not only reduces the BW cost but also secures the system. In conventional random interleaver, the security is compromised in case interleaving pattern is intercepted by a third party. To detect the interleaving pattern in case of proposed algorithm, knowledge of both the channel number information and algorithm is required. Thus, making the system more reliable and secure.

The designed algorithm also offers reduced memory cost since there is no requirement of storing the interleaving patterns as is the case for random interleavers.

The algorithm is very fast and computationally efficient. The strength of the algorithm is dependent on the length of interleaving pattern. In IDMA, blocks of length 256, 512, 1024, and 4096 chips are used [8], [9], and [18]. The designed algorithm is efficient for all block lengths but optimum performance is achieved on a block of 4096 bits. Moreover, security strength also improves as pattern length increases.

A comparative analysis between the designed and conventional random interleaver proofs that the execution for the former is less, thus making it more efficient. This provides the basis to a more convenient designed approach. The execution time for both the interleavers is shown below:

Num of Bits	Designed Interleaver sec	Random Interleaver sec
256	0.0750	0.0940
1024	0.1156	0.2190
4096	0.1936	0.3244

The cost of an IDMA receiver for K users is less than the total cost of K single-user receivers for an IDMA system assuming iterative decoders are involved in both cases. An IDMA receiver for K users consists of K single-user a posteriori probability (APP) decoders, K interleavers and deinterleavers and a single ESE for all users. However, for an IDMA system with K single-user receivers, K number of ESEs are also required in addition to K single-user APP decoders, K interleavers and deinterleavers, making it more costly.

5 Conclusion

In this paper, we have discussed the role of interleavers in IDMA system. Keeping in mind, the complexity and memory storage problem, an efficient approach has been developed for design of user specific random interleavers. This design approach reduces the computational complexity for developing the pattern and is BW efficient. Moreover, the proposed interleaver is very secure.

References:

[1] R.H. Mahadevappa and J.G. Proakis, "Mitigating multiple access interference and intersymbol interference in uncoded CDMA Systems with chip-level interleaving," *IEEE Trans. Wireless Commun.*, Vol.1, Oct. 2002, pp. 781–792.

[2] L. Liu, W. K. Leung, and Li Ping, "Simple chip-by-chip multi-user detection for CDMA systems," in *Proc. IEEE VTC-Spring*, Korea, Apr.2003, pp. 2157-2161.

[3]M. Moher, "An iterative multiuser decoder for near-capacity communications," *IEEE Trans. Commun.*, Vol. 46, No.7, Jul. 1998, pp. 870–880.

[4] M. C. Reed, C. B. Schlegel, P. D. Alexander, and J. A. Asenstorfer, "Iterative multiuser detection for CDMA with FEC: Near-single-user performance," *IEEE Trans. Commun.*, Vol. 46, No.12, Dec. 1998, pp. 1693–1699.

[5] X.Wang and H. V. Poor, "Iterative (turbo) soft interference cancellation and decoding for coded CDMA," *IEEE Trans. Commun*., Vol. 47, Jul. 1999, pp. 1046–1061. *Digital Commun*., Jan. 2004, pp. 98–101.

[6] L. Liu, J. Tong, and Li Ping, "Analysis and Optimization of CDMA Systems with chip-level Interleavers," *IEEE J. Select. Areas Commun.,* Vol.24, Jan. 2006, pp. 141-150.

[7] Li Ping, L. Liu, K. Y. Wu, and W. K. Leung, "Approaching the capacity of multiple access channels using interleaved low-rate codes," *IEEE Comm.Lett*., Vol. 8, Jan. 2004, pp. 4–6.

[8]Li Ping, L. Liu, K. Y, Wu, and W. K. Leung, "On interleave-division multiple-Access," in *Proc ICC'2004.* Paris, France, 2004, pp.2869-73

[9] Li Ping, Lihai Liu, K. Y. Wu, and W. K. Leung, "Interleave-Division Multiple-Access," *IEEE Trans. Wireless Commun.,* Vol. 5, No. 4, Apr. 2006, pp. 938-947.

[10] Omer, I.A. Khokhar, Zia, Waqas, "A novel approach 4G Communication system: Multi- Carrier Interleave Division Multiple Access" in *7th IASTED International conference* WOC at Montreal, Canada, 2007.

[11] L. Ping, L. Liu, and W. K. Leung, "A Simple Approach to Near Optimal Multiuser Detection: Interleave-Division Multiple-Access," Proc. *IEEE WCNC 2003-Wireless Communications and Networking Conf.*, New Orleans, LA, USA, 2003, pp. 391–396.

[12] H. Wu, L. Ping and A. Perotti, "User-Specific chip-Level Interleaver design for IDMA Systems", *IEEE Electronics Letters*, Vol.42, No.4, Feb. 2006, pp.233-234.

[13] O. Y. Takeshita, and D. J. Costello, Jr., "New Deterministic Interleaver Designs for Turbo Codes," *IEEE Trans. Inf. Theory*, Vol.46, No.6, Sept. 2000, pp. 1988-2006.

[14] Kai Xie, Wenbo Wang, and Jing Li, "On the analysis and design of good algebraic interleavers."

[15] Omer, I.A. Khokhar, Zia, Waqas, "Analysis of user specific interleavers for iterative Multiuser detection system" in *ICIE, WEC* at London. UK, 2007.

[16] Kai Li, Xiaodong Wang, Guosen Yue, and Li Ping, "A Low-Rate Code-Spread and Chip-Interleaved Time-Hopping UWB System," *IEEE J. Select. Areas Commun.* Vol. 24, No. 4, Apr. 2006, pp. 864 – 870.

[17] M. Moher, "An iterative multiuser decoder for near-capacity communications," *IEEE Trans. Commun.*, Vol. 46, July 1998, pp. 870–880.

[18] W. K. Leung, Lihai Liu, and Li Ping "Interleaving-Based Multiple Access and Iterative Chip-by-Chip Multiuser Detection," *IEICE Trans. on Commun.*, Vol. E86-B, Dec. 2003,pp. 3634-3637.