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Application of Diversity Techniques for Multi User IDMA Communication System

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Abstract
In wireless communication, fading problem is mitigated with help of diversity techniques. This paper presents Maximal Ratio Combining (MRC) diversity approach to uproot the fading problem in interleave-division multiple-access (IDMA) scheme. The approach explains receiver diversity as well as transmits diversity analysis as 1:2 and 2:1 antenna system in fading environment, no. of antennas can be increased to improve diversity order. Random interleaver as well tree based interleaver has been taken for study. Significant improvements in performance of IDMA communication is observed with application of diversity techniques.
Keywords: Random Interleaver, Tree Based Interleaver, MRC diversity, IDMA

1. Introduction

The goal for the next generation mobile communications system is to seamlessly provide a wide variety of communication services to anybody, anywhere, anytime such as high voice quality, higher data rates etc. The technology needed to tackle the challenges to make these services available is popularly known as the Third Generation (3G) Cellular Systems using multiuser detection [1]. The fundamental phenomenon which makes reliable communication difficult is time varying multipath fading, which is major impairment in any wireless communication system. The performance improvement is very difficult in such situation

Theoretically, improvement in signal to noise ratio may be achieved by providing higher transmit power or additional bandwidth which are not feasible solution as they are contrary to the requirements of next generation wireless communication [2]. On the other hand, the problem of fading may be handled with suitable diversity technique without expanding communication resources easily.

In most wireless channels, antenna diversity is a practical, effective and widely used technique for reducing the effect of multipath fading. The maximal ratio combining (MRC) diversity technique, is implemented with interleave-division multiple-access (IDMA) scheme, as MRC is performed well in comparison with selection or equal gain combining.[3]-[5]. The IDMA scheme is known as advanced version of CDMA, which inherits many advantages from CDMA such as dynamic channel sharing, mitigation of cross-cell interferences, asynchronous transmission, ease of cell planning, and robustness against fading. It also allows a low complexity multiple user detection (MUD) techniques [7] (CBC detection) applicable to systems with large numbers of users in multi-path channels.

The objective of this paper is to use MRC diversity in IDMA communication system to reduce the effect of fading. The study of transmit as well as receiver diversity is taken separately, because both have their own application area [2]. The paper is organized as follows. Concept of IDMA is introduced in section 2. Section 3 deals with classical MRRC diversity approach used with IDMA. In section 4 transmit diversity is discussed with IDMA. Performance analysis is provided in section 5. Finally conclusions are presented in section 6.

2. IDMA Scheme

2.1 IDMA Mechanism

The performance of conventional code-division multiple-access (CDMA) systems [1] 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 [8]-[11].
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 [12].

2.1 Scheme Model

Here, we consider an IDMA system [1], shown in Figure 1, with K simultaneous users using a single path channel. At the transmitter, a N-length input data sequence $d_k = [d_k(1), \ldots\ldots\ldots, d_k(i), \ldots d_k(N)]^T$ of user k is encoded into chips $c_k = [c_k(1), \ldots\ldots\ldots, c_k(j), \ldots c_k(J)]^T$ based on low rate code C, where J is the Chip length.
The chips c_k is interleaved by a chip level interleaver 'Πk', 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 $r = [r_k(1), \ldots\ldots, r_k(j), \ldots r_k(J)]^T$. 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

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

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 an 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 $\{x_k\}$ defined as

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

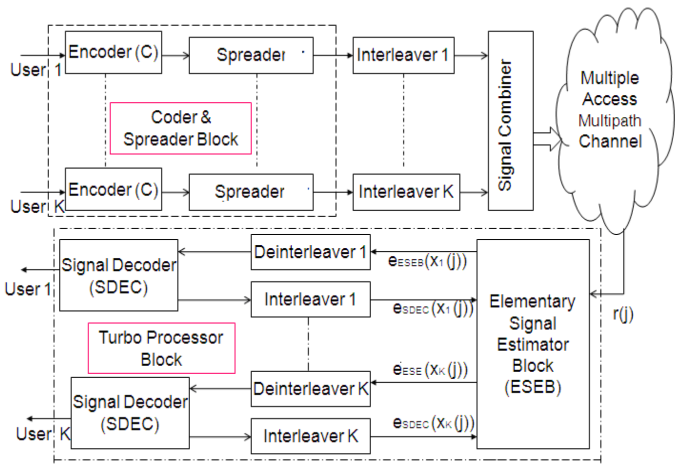

Figure 1. Transmitter and Receiver structures of IDMA scheme with K simultaneous users.

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

$$r(j) = h_k x_k(j) + \zeta_k(j) \quad (3)$$

where

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

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,

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

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. RECIEVER DIVERSITY ANALYSIS FOR IDMA

The block diagram of maximal ratio combining (MRC) diversity 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 k_{th} 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.

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,

$$h_0 = \alpha_0 e^{i\theta 0}$$
$$h_1 = \alpha_1 e^{i\theta 1} \quad (5)$$

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

$$R_0 = h_0 x_k + n_0$$
$$R_1 = h_1 x_k + n_1 \quad (6)$$

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

$$\bar{X}_K = h_0^* R_0 + h_1^* R_1 \quad (7)$$

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

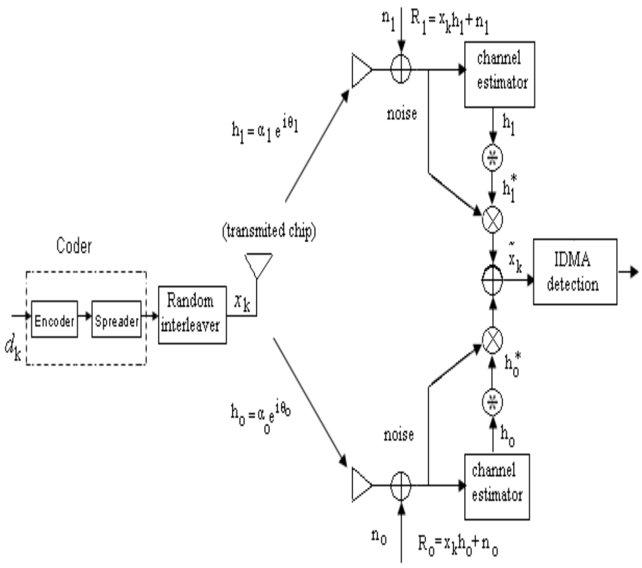

Figure 2. IDMA with proposed two branches MRRC diversity scheme for k^{th} user

4. TRANSMIT DIVERSITY ANALYSIS FOR IDMA

In this section transmit diversity is discussed with IDMA communication system; figure 3 is showing the arrangements for k_{th} user. After encoding and spreading the data is interleaved then sent by two transmit antenna.

If two transmit antenna and one receive antenna system is used, then channel between first transmit antenna (t0) and receiver antenna is h0 and between second transmit antenna (t1) is h1. So, the channel can be modeled like:

$$\boldsymbol{h_0 = \alpha_0\, exp(j\theta_0)}$$
$$\boldsymbol{h_1 = \alpha_1\, exp(j\theta_1)} \qquad (8)$$

At a given symbol period two signals are simultaneously transmitted from two antennas. The signal transmitted from antenna zero is $\mathbf{S_0}$ and antenna one is $\mathbf{S_1}$. During next symbol period conjugate of $\mathbf{(-S_1)}$ is transmitted from antenna zero and conjugate signal $\mathbf{S_0}$ is transmitted from antenna one, i.e. transmitted symbols are space time encoded. Now the received signal can be written as

$$r_0 = r(t) = h_0 s_0 + h_1 s_1 + n_0$$
$$r_1 = r(t+T) = -h_0 s_1^* + h_1 s_0^* + n_1 \qquad (9)$$

These two signals will be received by the same antenna after a delay of T (Symbol period).

$$\widetilde{s0} = h_0^* r_0 + h_1 r_1^*$$
$$\widetilde{s1} = h_1^* r_0 - h_0 r_1^* \qquad (10)$$

Solving equations (8), (9) and (10), we can write

$$\widetilde{s0} = (\alpha_0^2 + \alpha_1^2) s_0 + n_0 h_0^* + h_1 n_1^*$$

$$\widetilde{s1} = (\alpha_0^2 + \alpha_1^2) s_1 + h_0 n_1^* + n_0 h_1^* \qquad (11)$$

Now finally these two signals fed in to the CBC detection based IDMA detector.

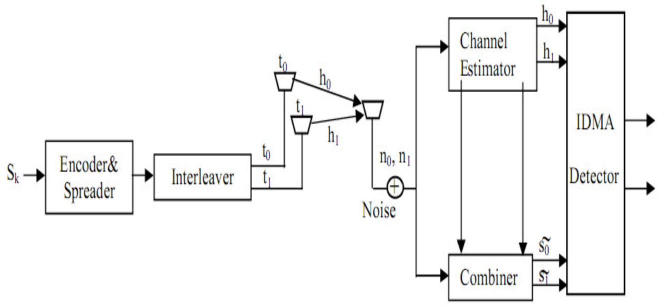

Figure 3. IDMA with proposed transmit diversity scheme for k[th] user

5. PERFORMANCE ANALYSIS

For simplicity, IDMA system with BPSK signaling is assumed with uniform repetitive coding and spread length 16, for all users along with 15 iterations.

The interleavers used in simulations are random interleaver (RI) [3] and tree based interleaver (TBI) [15].

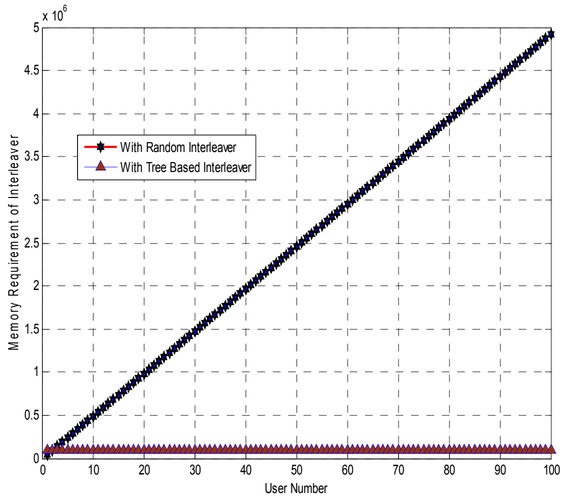

Figure 4. Memory requirement comparison of Random Interleaver and Tree Based Interleaver.

Figure 4 demonstrates the memory requirement of RI and TBI. The memory requirement of RI is dependent on user count [3] [4] while that of TBI is constant [15] due to use of only two master interleaving sequences for generating the other user specific interleaving sequences. The memory required by Tree Based Interleaver generation method is extremely less than that required for random interleaver generation method [3] and is independent of user count.

In this section, we present simulation results to demonstrate the performance of the MRC diversity scheme with IDMA systems. Here we refer the channel as slow fading Rayleigh channel. The interleavers used in simulations are random interleaver [3] and tree based interleaver [15]. The block length is 200 and frame length is 65536 bits/frame with spread length to be 16. The iterations selected for simulation in receiver is 15. The simulations have been performed for one transmitter and two receiver arrangement in the case of receiver diversity. On the other hand, in the case of transmit diversity two transmitter antennas and one receiver antenna is used for analysis. It is also assumed that transmit power from two antenna in transmit diversity is same as the power transmit by single antenna in receiver diversity.

Figure 5 demonstrates the performance of IDMA scheme with using random interleaver. Here in receiver as well as in transmit diversity two branches maximal ratio combining scheme is used for implementation of space diversity technique. In this case, the degree of complexity remains similar to that in simple IDMA systems. The BER performance with maximal ratio combining diversity is better than without using any diversity technique in fading environment.

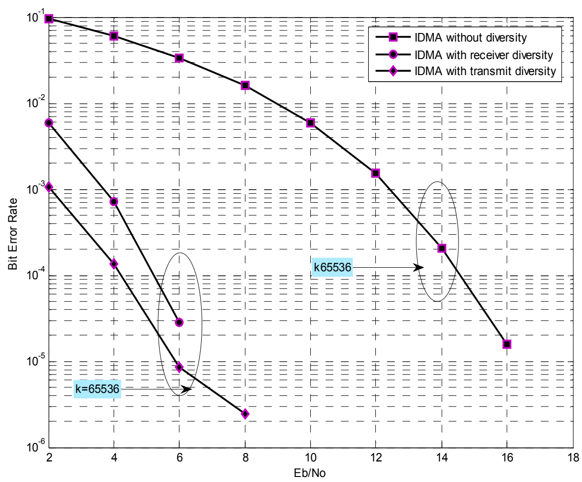

Figure 5. Performance of RI-IDMA with transmit and receive diversity

Figure 6 shows the BER performance of IDMA scheme using tree based interleaver with both diversity schemes. From this figure we can see that the performance of IDMA system with MRC diversity is far better than that without diversity also the performance of Tree based interleaver comes out to better in the case of transmit diversity.

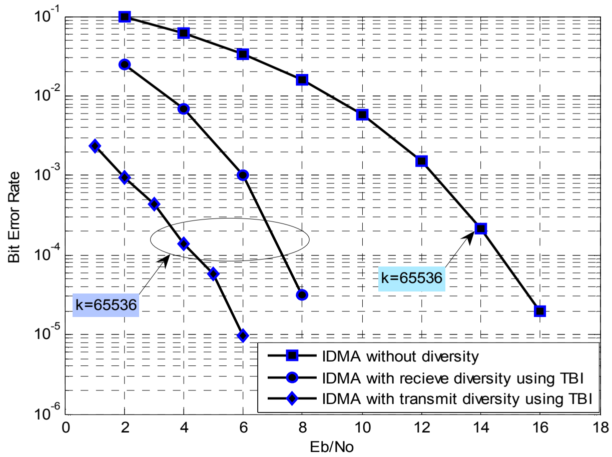

Figure 6. Performance of TBI-IDMA IDMA with transmit and receive diversity

6. CONCLUSIONS

We have employed diversity scheme for reducing the fading problem in IDMA systems. The results have taken for transmit as well as receive diversity configuration. Simulation results show that IDMA scheme performs better with both type of diversity schemes. Although it is not the intention to compare transmitter diversity to receiver diversity, because it is already stated that both the diversity schemes performs nearly [2], but having distinguish application area.

It is already explained that tree based interleaver performs good, near to random interleaver [13],but in the reference of complexity and memory requirement it takes edge on random interleaver [figure 4]. So, both the interleavers are taken for study and simulations show good BER performance.

IDMA with suitable diversity technique can generate fruitful results in the area of wireless communication. Since IDMA inherits all the merits of DS-CDMA in addition to its own advantages, existing CDMA systems may be enhanced by IDMA systems and study can also enhanced to Multiple input and multiple output (MIMO) antenna system to improve the diversity order and hence the performance of IDMA communication system.

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