Pre-Decorrelation for Coded DS-CDMA System with Space-Time Block Coding

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Abstract

This paper proposes an improved pre-decorrelating approach for the coded direct sequence code division multiple access (DS-CDMA) multiuser detection (MUD) with space time coding (STBC). The main contribution of this work is the simplification of the mobile station by performing the decorrelation process at the base station. This is achieved by using the pre-decorrelation matrix at the base station them using a simple matched filter at the mobile station. The performance of the model is evaluated against the conventional decorrelating detector. It is found that the proposed model is superior due to the simplicity of the mobile station with better performance than the conventional one. The drawback of our method is increase in the transmitting energy by a factor to keep the transmitted power constant as the system without using pre-decorrelation detection.

Keywords - *Decorrelating Detector, Pre-Decorrelation, MIMO STBC, Alamouti, Turbo coding.*

I. INTRODUCTION

The new generations of mobile communications systems aim to provide enhanced voice, text and data services to the user. These demands give rise to the complexity and power consumption of the user terminal (UT) while the objective is smaller, lighter and power efficient mobiles. This thesis aims to introduce advanced signal processing techniques to examine ways of reducing the UT receiver's computational cost while maintaining a good performance.

Under severe channel conditions (i.e. multipath), the multiple access interference (MAI) becomes the major source of performance degradation for direct sequence CDMA (DS-CDMA) systems. This is because of the loss of orthogonality between the spreading codes used by each user due to the multipath channel effects. To overcome this problem, many receiver-based MUD techniques have been proposed [1,2]. These techniques demand high computational complexity, power and knowledge of spreading codes of all users. As a result, in the downlink of a CDMA system it is not feasible to employ such methods at the UT. Alternatively, transmitter-based techniques were proposed to shift computational complexity and power consumption to the base station (BS), where they can be afforded. It was shown that these methods are very effective in removing the MAI. We propose a multiuser transmitter based (multiuser pre-processing) low complex method with similar performance improvements as the receiver-based methods. In the proposed method, functions of multipath combining and MAI cancellation are presented. The MAI cancellation matrix in the proposed method is simple and does not depend on the time-varying fading channel coefficients. Multiuser pre-processing can be combined to further improve the performance. Multiuser pre-processing preserves the multipath diversity while removing the MAI [3-5].

Extending multiuser pre-processing to multiple antennas results in space diversity in addition to multipath diversity which improves the system performance[6,7].

On the other hand, parallel and serial concatenated codes, the so-called Turbo codes, are considered the most important breakthrough in the coding community in the 1990's. These powerful codes can achieve near-Shannon-limit error correction performance with relatively low complexity [8-10]. We gain high performance improvement by applying turbo codes to the system. Performance comparison is made between our proposed system with turbo codes and convolutional codes. The paper is organised as follows: Section II represents the STBC using the simple Alamouti's scheme. The MUD using decorrelating detector is introduced in section II. The proposed scheme using the pre-decorrelating detector is presented in section IV and the simulation results are shown in section V.

II. ALAMOUTI SPACE-TIME BLOCK CODING

Space-time coding is a simple yet ingenious transmit diversity technique in MIMO technology [11]. We first examine the Alamouti code [8], which started it all. Basically,Alamouti proposed a simple scheme for a 2 × 2 system that achieves a full diversity gain with a simple maximum likelihood decoding algorithm.

In order to illustrate how OSTBCs work, a simple example introduced by Alamouti is used. Originally, it employs MT = 2 transmit antennas and MR = 1 receive antenna. However, it can be easily extended to more receive antennas.

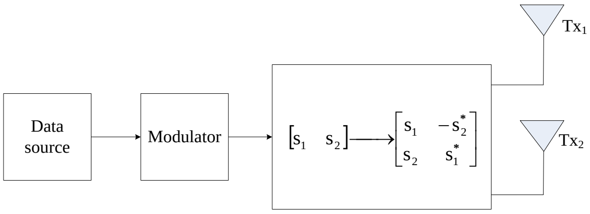

Fig. 1 Block diagram of the Alamouti space-time encoder.

The approach as outlined by Alamouti is shown in Fig. 1. The information bits are first modulated using an M-ary modulation scheme. The encoder then takes a block of two modulated symbols s1 and s2 in each encoding operation and gives it to the transmit antennas according to the code matrix,

$$S = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} (1)$$

In eq.(1), the first column represents the first transmission period and the second column the second transmission period. The first row corresponds to the symbols transmitted from the first antenna and the second row corresponds to the symbols transmitted from the second antenna. Elaborating further, during the first symbol period, the first antenna transmits s1 and the second antenna transmits s2. During the second symbol period, the first antenna transmits –s2* and the second antenna transmits s1* being the complex conjugate of s1.

This implies that we are transmitting in space (across two antennas) and time (two transmission intervals).

$$s^1 = [s_1, \quad -s_2^*]$$
$$s^2 = [s_2, \quad s_1^*] (2)$$

where the information s1 is from the first antenna and the information s2 is the second antenna output.

III. DS-CDMA DECORRELATING DETECTOR FOR STBC SYSTEM

Fig.2 shows the base station transmitter. The number of transmit antennas is MT=2 and the STBC is achieved using Alamouti's scheme where the data symbols are transmitted in two consecutive time intervals.

Let y_j^i be the transmitted vector in time interval j from antenna i. According to the code matrix in eq.(1), the transmitted signals in the first time interval are

$$\boldsymbol{y_1^i} = \sum_{k=1}^{K} \boldsymbol{A_k b_{i,k} S_k}$$

$b_{i,k}$ is the kth user transmitted turbo coded data from the ith antenna, and the signals transmitted at the second time interval are

$$\boldsymbol{y_2^1} = -\sum_{k=1}^{K} \boldsymbol{A_k b_{2,k}^* S_k}$$
$$\boldsymbol{y_2^2} = \sum_{k=1}^{K} \boldsymbol{A_k b_{1,k}^* S_k} \qquad (5.\ 1)$$

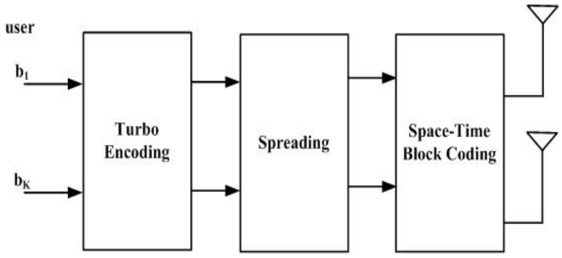

Fig. 2 The transmitter using Turbo coding and STBC

Fig. 3 shows the mobile station receiver, the kth user received signal at time j is

$$\boldsymbol{r_{j,k}} = \boldsymbol{h_k^1 y_j^1} + \boldsymbol{h_k^2 y_j^2} + \boldsymbol{n_{j,k}} (4)$$

where $n_{j,k}$is the k[th] mobile station noise vector in the time interval jth. The matched filter bank output at time j is given by $\mathbf{z_j}$=[$z_{j,1}$, $z_{j,2}$, ……… $z_{j,K}$]^T, or

$$\boldsymbol{z_i} = \boldsymbol{h_k^1 S y_i^1} + \boldsymbol{h_k^2 S y_i^2} + \boldsymbol{w_i}$$

where w_i = [$\mathbf{Sn}_{j,k}$]$_{1xK}$. Substituting into eq.(5) we get

$$\boldsymbol{z_1} = \boldsymbol{h_k^1 R A b_1} + \boldsymbol{h_k^2 R A b_2} + \boldsymbol{w_1}$$
$$\boldsymbol{z_2} = -\boldsymbol{h_k^1 R A b_2^*} + \boldsymbol{h_k^2 R A b_1^*} + \boldsymbol{w_2}$$

where **A**=diag(**A**$_k$)$_{KxK}$ is the diagonal matrix of the amplitude.

The matched filters output is passed through the decorrelating detector which is [$\mathbf{R}^{-1}$]$_{KxK}$, which eliminates the multiuser interference

$$\boldsymbol{z_1'} = \boldsymbol{h_k^1 A b_1} + \boldsymbol{h_k^2 A b_2} + \boldsymbol{w_1'}$$
$$\boldsymbol{z_2'} = -\boldsymbol{h_k^1 A b_2^*} + \boldsymbol{h_k^2 A b_1^*} + \boldsymbol{w_2'}$$

where $w_j' = R^{-1} w_j$, j=1,2.

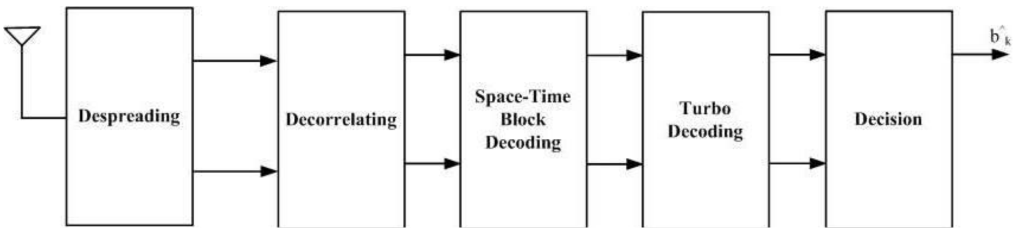

Fig. 3 The mobile receiver with turbo decoded MUD STBC.

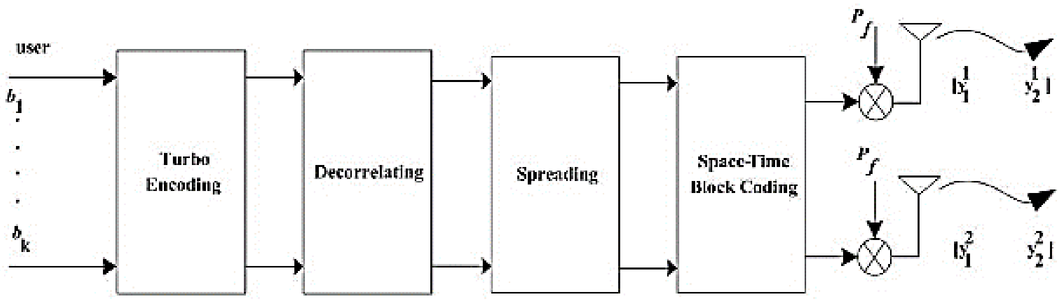

Fig. 4 The base station transmitter with pre-decorrelation, turbo coding and STBC.

The noise enhanced by the factor $\mathbf{R}^{-1}$ which is the main drawback of this detector. The decorrelating detector's output is combined by STBC decoding algorithm [8] where the decision variables for the data in two time intervals are

$$t_1 = h_k^{1*} z_1' + h_k^2 z_2'^*$$

$$t_2 = h_k^{2*} z_1' - h_k^1 z_2'^*$$

Substituting from eq.(7) into eq.(8) and doing some manipulations we have

$$\mathbf{t_1} = \left(\|\mathbf{h}_k^1\|^2 + \|\mathbf{h}_k^2\|^2\right)\mathbf{Ab_1} + \boldsymbol{\eta}_1$$

$$\mathbf{t_2} = \left(\|\mathbf{h}_k^1\|^2 + \|\mathbf{h}_k^2\|^2\right)\mathbf{Ab_2} + \boldsymbol{\eta}_2$$

Where

$$\eta_1 = \hbar_k^{1*} R^{-1} w_1 + \hbar_k^2 R^{-1} w_2^* \qquad and$$

$$\eta_2 = \hbar_k^{2*} R^{-1} w_1 - \hbar_k^1 R^{-1} w_2^*$$

IV. CODED DS-CDMA STBC SYSTEM USING PRE-DECORRELATION

The proposed system is presented in this section where the turbo-coded users' data [9-10] can be pre-decorrelated before transmission at the base station. Fig.4 shows the transmitter of the base station. The vector d is the turbo-coded data of all users. This vector passes through a pre-decorrelating filter and the output is:

$$\boldsymbol{d}' = \boldsymbol{R}^{-1}\boldsymbol{Ad} \qquad (10)$$

where $d' = [d_1', d_2', \ldots\ldots . d_K']$ and d_k' is the pre-decorrelated data for user k. We note from eq.(10) that the user's data is boosted by R^{-1} so the transmitted power is changed. We limit the power in the transmitter by a scaling factor $\boldsymbol{P_f}$ which maintains the transmitted power with using the pre-decorrelating is equal to the case without pre-decorrelating.

$$\mathbf{y}_1^i = \boldsymbol{P_f} \textstyle\sum_{k=1}^{K} \boldsymbol{S_k d_{i,k}'} (11)$$

is the transmitted vector in time interval j from antenna i. The transmitted signals in the second time interval are

$$\mathbf{r}_{j,k} = \mathrm{h}_k^1 \mathbf{y}_j^1 + \mathrm{h}_k^2 \mathbf{y}_j^2 + \mathbf{n}_{j,k}$$

$$\mathbf{y}_2^1 = -\boldsymbol{P_f} \sum_{k=1}^{K} \boldsymbol{S_k d_{2,k}'}$$

$$\mathbf{y}_2^2 = \boldsymbol{P_f} \textstyle\sum_{k=1}^{K} \boldsymbol{S_k d_{1,k}'^*} (12)$$

Consider the mobile receiver shown in Fig. 4, the k^{th} user received signal at time j is written as (8)

$$\mathbf{r_{j,k}} = \mathbf{h}_k^1 \mathbf{y}_j^1 + \mathbf{h}_k^2 \mathbf{y}_j^2 + \mathbf{n_{j,k}} \ (13)$$

where the noise vector in the j^{th} time interval in the kth mobile station is $\mathrm{n}_{i,k}$. The received signal is passed through a single user matched filter matched (9) to the corresponding spreading sequence. The output in the j^{th} time interval of the k^{th} user's matched filter is given by

$$\boldsymbol{Z}_{j,k} = \boldsymbol{S}_k (h_k^1 y_k^1 + h_k^2 y_k^2 + \boldsymbol{n}_{j,k}) \quad (14)$$

The output of all users' receivers at time j is given by the $\mathrm{z_j}$=[$\mathrm{z_{j,1}}$, $\mathrm{z_{j,2}}$, ……… $\mathrm{z_{j,K}}]^{\mathrm{T}}$, which can be written as

$$\boldsymbol{Z_j} = \boldsymbol{H}^1 \boldsymbol{S} \boldsymbol{y}_j^1 + \boldsymbol{H}^2 \boldsymbol{S} \boldsymbol{y}_j^2 + \boldsymbol{w}_j (15)$$

where $\mathrm{w_j} = [\mathbf{Sn}_j]_{1\mathrm{x}K}$. Substituting from eq.(11) and eq.(12) into (15) we get

$$\mathbf{v_1} \ = \boldsymbol{P_f}\mathbf{H}^1\,\mathbf{Ad_1} + \boldsymbol{P_f}\mathbf{H}^2\,\mathbf{Ad_2} + \mathbf{w_1} \ (16)$$

$$\mathbf{v_2} \ = -\boldsymbol{P_f}\mathbf{H}^1\,\mathbf{Ad}_2^* \ + \boldsymbol{P_f}\mathbf{H}^2\,\mathbf{Ad}_1^* + \mathbf{w_2}$$

Combining the despreaded data by the STBC decoding algorithm where the decision variables for the turbo-coded data in two time intervals are

$$\mathbf{t_1} = \mathbf{H}^{1*}\mathbf{v_1} + \mathbf{H}^2\mathbf{v}_2^*$$

$$\mathbf{t_2} = \mathbf{H}^{2*}\mathbf{v_1} - \mathbf{H}^1\mathbf{v}_2^* (17)$$

Substituting from eq.(16) into eq.(17) and after some manipulations we have

$$\mathbf{t_1} = \boldsymbol{P_f}\left(\|\mathbf{H}^1\|^2 + \|\mathbf{H}^2\|^2\right)\mathbf{Ad_1} + \boldsymbol{\eta}_1$$

$$\mathbf{t_2} = \boldsymbol{P_f}\left(\|\mathbf{H}^1\|^2 + \|\mathbf{H}^2\|^2\right)\mathbf{Ad_2} + \boldsymbol{\eta}_2 (18)$$

where

$$\boldsymbol{\eta}_1 = \mathbf{H}^{1*}\mathbf{w_1} \ + \mathbf{H}^2\,\mathbf{w}_2^* \ \textit{and}\ \mathbf{H}^{2*}\mathbf{w_1} \ - \mathbf{H}^1\,\mathbf{w}_2^*$$

We note that, From eq.(18) the MUI is eliminated and the system is converted into a singe user detection system. This result is obtained with the trade off increasing the transmission energy. The power scaling factor $\boldsymbol{P_f}$ is chosen to keep the transmitted power constant as the system without using pre-decorrelation detection. Assuming $\boldsymbol{P_f}$ is the constant for two successive intervals for the two transmitting antennas we can rewrite the transmitted signal with pre-decorrelation in eq.(3) for the first antenna at the first time interval in matrix form as

$$\bar{\mathbf{y}} = \boldsymbol{P_f}\mathbf{SR^{-1}Ad} \quad (19)$$

The average energy of this signal is given by:

$$\mathbf{E}_{av} = \boldsymbol{E}\left[\int |\bar{y}(t)|^2\, dt\right]$$

$$\mathbf{E}_{av} = \boldsymbol{P_f^2 E}\left[\int \left((\mathbf{SR^{-1}Ad})^T(\mathbf{SR^{-1}Ad})\right) dt\right]$$

$$\mathbf{E}_{av} = \boldsymbol{P_f^2 E}[(\mathbf{Ad})^T\mathbf{R}^{-T}(\textstyle\int \mathbf{SS}^T\, dt)\mathbf{R}^{-1}\mathbf{Ad}] \quad (20)$$

$$\mathbf{E}_{av} = \boldsymbol{P_f^2\, tr}(\boldsymbol{E}[\mathbf{R}^{-T}(\mathbf{Ad})(\mathbf{Ad})^T])$$

$$\mathbf{E}_{av} = \boldsymbol{P_f^2\, tr}(\mathbf{R}^{-T}\mathbf{A}\mathbf{E}[\mathbf{dd}^T]\mathbf{A}^T)$$

Using $E(\mathbf{dd}^T)=I_k$, since $E(d_i d_k)=0$, $k \neq i$, and $R^{-1}=R^{-T}$ we get

$$\mathbf{E}_{av} = \boldsymbol{P_f^2}\sum_{k=1}^{K}\mathbf{A}_k^2\mathbf{R}_{k,k}^{-1} \quad (21)$$

where $\mathbf{R}_{k,k}^{-1}$ is the k^{th} diagonal element of the matrix R^{-1}.

The energy of the transmitted signal without pre-decorrelation is given by:

$$\mathbf{E}_{av} = \sum_{k=1}^{K}\mathbf{A}_k^2/2 \quad (22)$$

Equating eq.(21) and eq.(22) we can write the power scaling factor as

$$\boldsymbol{P_f} = \frac{\sum_{k=1}^{K} A_k^2/2}{\sum_{k=1}^{K} A_k^2 R_{k,k}^{-1}} \quad (23)$$

We can use the same power scaling factor for the two antennas according to eq.(3) and eq.(4).

V. SIMULATION AND NUMERICAL RESULTS

In this section, we show simulation results representing the performance of STBC and coded STBC for pre-processed multiuser DS-CDMA system in Rayleigh fading channels. The assumptions for the Monte Carlo simulations that are carried out are listed below.

- The spreading codes for the users are random codes to allow for the worst case.
- The receiver has perfect channel state information and that the fading between transmit and receive antennas is mutually independent.
- Space-Time block coding method in this paper passed on Alamouti's scheme with two antennas in the base station and one antenna in the mobile terminal.
- Rate-half turbo code with memory-length m = 2, and soft-in-soft-out modified Log-MAP decoding algorithm [9-10] have been used.
- Soft-decision convolutional codes with m = 5, and 16 quantization levels are considered.

Fig. 5 shows the performance improvement obtained by using multiuser detection in an uncoded system with K=10 users and random spreading with PG=32. The curve of the conventional detector is flattened and does not affected by increasing the SNR; this because of the MAI has the dominant effect. Using the multiuser decorrelating detector improves the performance by removing the MAI but the curve is parallel to the single user bound because of the noise enhancement by the factor R^{-1}.

Using the multiuser pre-decorrelator gives the same performance as the decorrelating detector with transforming of the complexity from the MT to the BS.

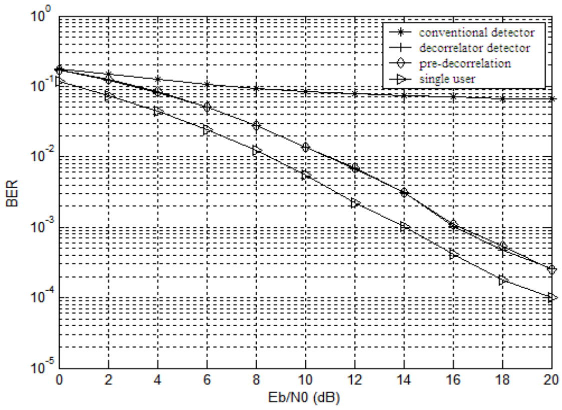

Fig. 5 Bit error rate for uncoded STBC with decorrelating detector and multiuser pre-decorrelating for K=10, and PG=32.

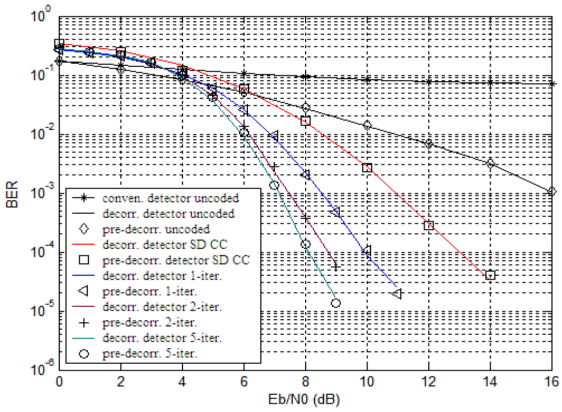

Fig. 6 Bit error rate for turbo-coded STBC with multiuser decorrelating and pre-decorrelating for K=10, and PG=32.

Fig. 6 represents the STBC multiuser pre-processed system using pre-decorrelation with the application of turbo coding. The results for the pre-decorrelator are the same as that for the decorrelator. We compare the performance of the system when using turbo-codes and convolutional codes using soft-decision Viterbi decoding algorithm. A coding gain of 5 dB is obtained by using SD-VA at BER=10^{-3}. Using iterative turbo codes of 1, 2 and 5 iterations will exceed the coding gain over that of the SD-VA by 2 dB, 1 dB and 0.5 dB respectively. As shown, increasing the number of iterations improves the performance. Increasing the number of iterations over 5 will not improve the performance by a note sable manner because, the extrinsic soft-output information becomes the same and this will give the same performance.

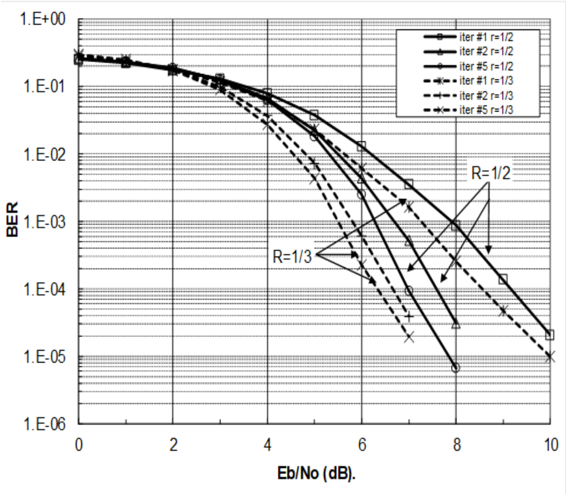

Fig. 7 Bit error rate for turbo-coded STBC with multiuser decorrelating for different Turbo-Code rates, K=10, and PG=32.

In Fig. 7 we simulate the STBC system using multiuser pre-decorrelator with rate 1/2 and 1/3 turbo codes. Power gain of 1 dB is obtained by using rate 1/3 turbo code. Also increasing the number of iterations improves the performance.

VI. CONCLUSIONS

Transmitter-based techniques were proposed to shift computational complexity and power consumption to the BS, where it can be afforded. Transmitter diversity in the downlink using multiple transmitter antennas provides similar performance gains as for the mobile terminal (UT) receiver diversity without the complexity of a second UT receiver antenna. Transmitter based methods enable to shift signal processing to the transmitter where power and computational complexity are more abundant, thus simplifying receiver units.

We propose a low complex transmitter-based method with similar performance improvements as the receiver-based method. In the proposed method, the functions of multipath combining and MAI cancellation are explained separated. Thus, the MAI cancellation matrix does not depend on rapidly time-varying fading coefficients. Multiuser pre-processing preserves the multipath diversity while removing the MAI.

STBC provides significant performance gain using modest number of antennas. The complexity of the used Alamouti STBC is the lowest since it not requires CSI. Alamouti STBC can be easily combined with pre-decorrelator.

It was shown that these techniques, though very effective in removing the MAI, demand high computational complexity, power and knowledge of spreading codes of all users. As a result, in the downlink of a CDMA system it is not feasible to employ such methods at the UT. Using the multiuser pre-decorrelator gives the same performance as the decorrelating detector with transforming of the complexity from the UT to the BS.

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