Abstract—This paper presents an effective multiuser detector (MUD) for the uplink of dual-signaling multiple-input multiple-output (MIMO) code division multiple access (CDMA) systems over multipath fading channels, where the data are transmitted using either the spatially multiplexing (SM) or the space-time block code (STBC) scheme. The new MUD first separates users into two groups according to their transmission signaling schemes and then alternatively detects the users in each group with the removal of iteratively refined soft information-assisted multiple access interferences (MAI) to enhance the interference cancellation capability. Moreover, for practical low-complexity implementations, the users in each group are further partitioned into smaller subgroups to reduce the computational load. Conducted simulations show that the proposed MUD can render superior performance compared with previous approaches, especially in highly loaded scenarios.

I. INTRODUCTION

With the assistance of spatial diversity and array gain, the MIMO systems which deploy multiple antennas at both transmitters and receivers, can enhance the communication quality without extra power or bandwidth resources [1]. Two most common transmit diversity schemes have been developed to take the advantages of the MIMO systems including the SM for high transmission rate and the STBC for transmit diversity. Besides, the CDMA, possessing the merits of spectral efficiency and the robustness against multipath fading [2], has been a promise for future wireless communications. Therefore, it is of importance to consider the MIMO CDMA for emerging wireless communication systems, where such as users employ either the SM or STBC transmission scheme, referred to as dual-signaling systems.

The impairment caused by the MAI is a big impediment to the communication quality of the MIMO CDMA systems, especially for dual-signaling scenarios. One effective approach to mitigate the MAI is the MUDs. The optimum MUD, however, requires prohibitively high complexity and thus suboptimal MUDs such as the zero forcing (ZF) and the minimum mean-squared error (MMSE) MUD are more feasible in practice [2]. For the MIMO systems, Foschini et al. [3] proposed the renowned vertical Bell Laboratories layered space-time (V-BLAST). However, this symbol-wise recursive detector needs high computations and the successive interference cancellation (SIC) structure suffers the setback of error propagation. Ho et al. [4] extended the V-BLAST to multiuser dual-signaling environments by ingeniously utilizing the algebraic structure of the orthogonal codes to reduce the error propagation effect as well as the computational complexity. However, [4] is not applicable to practical multipath MIMO channels as the presumed algebraic structure is no longer hold. Moreover, the aforementioned detectors will deteriorate substantially in the highly loaded scenarios.

In this paper, we consider an MUD for multiuser, dual-signaling MIMO CDMA systems over multipath channels. The new MUD first separates users into two groups according to their transmission schemes. The users in each group are then detected alternatively with the removal of the MAI, which are incurred from the users in both groups and refined iteratively with the assistance of the soft-decision outputs in either the previous or present iteration to enhance the interference cancellation capability. Note that the proposed scheme is different from the conventional SIC or the group-wise SIC in [5], [6], as the interferences removed in each group are iteratively refined and include the soft estimates from both groups to render more thorough interference mitigation. Moreover, for practical implementations, the users in each group are partitioned into smaller subgroups based on their effective channel correlations and then detected in parallel by a bank of MMSE filters to further reduce the computational load. Conducted simulations show that the proposed MUD can provide superior performance compared with previous works especially in highly loaded scenarios.

II. SYSTEM MODEL

Consider an uplink of synchronous MIMO CDMA systems with each user being equipped with $N_T = 2$ transmit antennas and $N_R$ receive antennas, in which symbols are first BPSK modulated, spread by their respective spreading codes, and
then transmitted by either the SM or the Alamouti STBC schemes [7], as shown in Fig. 1. For simplicity on the algorithm development, all transmitted symbols are assumed to have the same power, and the transmission signaling scheme is decided by their effective channel strength [4], [8]. The numbers of users in the SM group and the STBC group are $K_1$ and $K_2$, which implies that there are in total $4 \times K_1$ and $2 \times K_2$ transmitted symbols, respectively, over two consecutive symbol periods. Also, assume that the length of the spreading codes and the number of fading channel paths for all users are $N$ and $L$, respectively. The numbers of users in the SM group and the STBC groups are denoted by their effective channel strength [4], [8]. The numbers of users are omitted for the rest of this paper.

Over two consecutive symbol periods, the sequence of symbols are transmitted and multiplexed, and the output of the receiver in the $t^{th}$ symbol duration, $r$, can be represented as

$$r = H_1 b_1 + H_2 b_2 + n = H b + n$$  \hspace{1cm} (1)$$

where $H = [H_1 \ H_2]$, in which $K = 4K_1 + 2K_2$, and $H_1 = \sum_{i=1}^{L} H_{1i}$ and $H_2 = \sum_{i=1}^{K_2} H_{2i}$ are the effective SM and STBC channel matrices, respectively. $H_{1i} = \begin{bmatrix} H_{11i} & \vdots & H_{1Ni} \end{bmatrix}$ and $H_{2i} = \begin{bmatrix} H_{21i} & \vdots & H_{2Ni} \end{bmatrix}$, where

$$H_{1i}^\dagger = \begin{bmatrix} 0_{(L-1)\times4} & \cdots & 0_{(L-1)\times4} \\ \vdots & \ddots & \vdots \\ 0_{L\times4} & \cdots & 0_{L\times4} \end{bmatrix}$$ and $H_{2i}^\dagger = \begin{bmatrix} 0_{(L-1)\times2} & \cdots & 0_{(L-1)\times2} \\ \vdots & \ddots & \vdots \\ 0_{L\times2} & \cdots & 0_{L\times2} \end{bmatrix}, 1 \leq \mu \leq N_R$, with $H_{1i}^\perp = \begin{bmatrix} h_{1i1}^\mu \ h_{1i2}^\mu \\ h_{1i3}^\mu \ h_{1i4}^\mu \end{bmatrix}$ and $H_{2i}^\perp = \begin{bmatrix} h_{2i1}^\mu \ h_{2i2}^\mu \\ -h_{2i3}^\mu \ -h_{2i4}^\mu \end{bmatrix}$, $1 \leq i \leq K$, $H_{1i}^\perp = \begin{bmatrix} h_{1i1}^\mu \ h_{1i2}^\mu \\ h_{1i3}^\mu \ h_{1i4}^\mu \end{bmatrix}$ and $H_{2i}^\perp = \begin{bmatrix} h_{2i1}^\mu \ h_{2i2}^\mu \\ -h_{2i3}^\mu \ -h_{2i4}^\mu \end{bmatrix}$.

III. ALTERNATING MUD AND LOW-COMPLEXITY IMPLEMENTATIONS

This section addresses a soft information-assisted alternating MUD. A low-complexity variant is also considered to alleviate the computational load.

A. Proposed Soft Information Assisted MUD

For the proposed MUD, users are first classified into two groups according to their transmission signaling schemes. The detection is then conducted alternatively between the SM and the STBC groups with the interferences being refined iteratively and removed with the assistance of the soft-decision outputs.

For brevity on the description of the algorithm, we only consider the detection for the users in the SM group. First, we obtain a rough symbol estimate by employing a set of matched filters given by

$$y_1 = H^H r$$  \hspace{1cm} (2)$$

where $(\cdot)^H$ denotes the Hermitian operation. Thereafter, to precisely estimate the symbol for the $i^{th}$ user, we remove the MAI arising from users in both of the SM and the STBC groups. Consequently, the residue for the $q^{th}$ symbol of the $i^{th}$ user in the SM group at the $j^{th}$ iteration, $\hat{y}_{1i,q}(j)$, is determined by

$$\hat{y}_{1i,q}(j) = y_1 - H_1^H (H_1 b_{1i,q}(j) + H_2 \tilde{b}_2(j-1))$$  \hspace{1cm} (3)$$

for $1 \leq i \leq K_1, 1 \leq q \leq 4$, where $\hat{b}_{1i,q}(j) = [\hat{b}_{1i,q}(1), \cdots, \hat{b}_{1i,q}(4)]$, $\hat{b}_{1i,q}(1), \cdots, \hat{b}_{1i,q}(4)$ are the transmitted symbols in the SM group at the $j^{th}$ iteration, and the time index $t$ are omitted for the rest of this paper.
users in the STBC group at the $j$th iteration. Also, $\mathbf{b}_2(j - 1)$ is the soft-decision outputs for the transmitted symbols of the users from the STBC group at the $(j - 1)^{th}$ iteration.

It is noteworthy that in (3), $\mathbf{b}_{2,j}^T(j)$ forms the MAI from users in the SM group while $\mathbf{b}_{2,j}(j)$ accounts for the MAI from users in the STBC group. Also note that since the detection is conducted alternatively between the SM and the STBC groups, we have to use the soft decision outputs for the users from the STBC group in the previous iteration.

Next, to estimate the $q^{th}$ symbol of the $i^{th}$ user, we invoke an MMSE filter given by [2]

$$w_{i1,q}(j) = R_{i1,q}(j)^{-1}p_{i1,q}(j)$$

where $R_{i1,q}(j) = E\{\mathbf{y}_{i1,q}(j)\mathbf{y}_{i1,q}^H(j)\}$ and $p_{i1,q}(j) = E\{\mathbf{y}_{i1,q}(j)\mathbf{b}_{1i,q}(j)\}$. Thereafter, the output of the MMSE filters for the $q^{th}$ symbol of the $i^{th}$ user is given by

$$\tilde{z}_{i1,q}(j) = w_{i1,q}^H(j)\mathbf{y}_{i1,q}(j)$$

If we assume that the output of the MMSE filter $\tilde{z}_{i1,q}(j)$, in (5) is approximately Gaussian [6], then $\tilde{z}_{i1,q}(j) = \tilde{m}_{i1,q}(j) + n_{i1,q}(j)$, where $\tilde{m}_{i1,q}(j)$ is the equivalent strength and $n_{i1,q}(j)$ is the noise with variance $\tilde{\sigma}_{i1,q}^2(j)$, which, after some manipulations, can be expressed, respectively, as

$$\tilde{m}_{i1,q}(j) = E\{\tilde{z}_{i1,q}(j)\mathbf{b}_{1i,q}(j)\} = w_{i1,q}^H(j)\mathbf{H}_1\mathbf{H}_1^H\mathbf{e}_{i1,q}$$

where $\mathbf{e}_{i1,q}$ is a $4K_1 \times 1$ elementary vector whose $(4(i - 1) + q)^{th}$ entry is one and the remaining entries are zero, and

$$\tilde{\sigma}_{i1,q}^2(j) = \text{Var}\{\tilde{z}_{i1,q}(j)\}$$

$$= w_{i1,q}^H(j)\mathbf{R}_{i1,q}(j)w_{i1,q}(j) - \tilde{m}_{i1,q}^2(j)$$

The soft-decision output after the MMSE filter and the MAP criterion can then be expressed as [6]

$$\tilde{\lambda}(\tilde{b}_{1i,q}(j)) = \frac{\log p(\tilde{z}_{i1,q}(j)|b_{1i,q}(j) = +1)}{\log p(\tilde{z}_{i1,q}(j)|b_{1i,q}(j) = -1)}$$

$$= \frac{2\tilde{z}_{i1,q}(j)\tilde{m}_{i1,q}(j)}{\tilde{\sigma}_{i1,q}^2(j)}$$

Then, the soft estimated symbol $\tilde{b}_{1i,q}(j) = \text{tanh}(\frac{1}{2}\tilde{\lambda}(\tilde{b}_{1i,q}(j)))$, $1 \leq i \leq K_1$, $1 \leq q \leq 4$, can be used to construct a new soft estimate of the $q^{th}$ symbol of the $i^{th}$ user. Finally, taking the sigmoid function of the soft estimated symbol $\tilde{b}_{1i,q}(j)$ yields the estimate of the $q^{th}$ symbol of the $i^{th}$ user at the $j^{th}$ iteration.

The updates of the STBC group follow the same steps as those of the SM group with $\mathbf{H}_1$ being replaced by $\mathbf{H}_2$. As a whole, the procedures of the proposed alternating MUD can be summarized as follows:

**Step 1** (Initialization): Separate the users into the SM and the STBC groups and carry out the matched filter for each signaling group by (2). Set the appropriate initial soft-decision outputs of $\mathbf{b}_1(0)$ and $\mathbf{b}_2(0)$.

**Step 2**: For the SM group, remove the MAI by (3). For the $q^{th}$ symbol of the $i^{th}$ user, invoke the group detector to estimate the weights of the detector $w_{i1,q}(j)$ by (4). Thereafter, estimate the soft-decision output of each symbol, $\tilde{\lambda}(\cdot)$, by (5)-(8), which will be employed to refine the estimate of the MAI in the next iteration.

**Step 3**: Repeat Step 2 alternatively between the SM and the STBC groups until convergence.

**B. Reduced-Complexity Implementations**

To further reduce the complexity, in this subsection we partition the users in each group into smaller subgroups. Since the data matrices become smaller, the computations required to determine the MMSE filters, which dictate the computational load, can thus be alleviated. Again, for brevity we only consider the detection for the users in the SM group. For this, users in the SM group are first ordered according to their effective channel correlations given by $C_1 = \mathbf{H}_1^H\mathbf{H}_1$, where the entry $[C_1]_{i,p}$ denotes the correlation between the $i^{th}$ user and the $p^{th}$ user. Users are then partitioned into a prescribed number, say $M_1$, of subgroups according to their correlations with users having close correlations in the same subgroups so as to alleviate the interference from the different subgroups [9].

First, we obtain a rough estimate of the users in the $m^{th}$ subgroup by

$$y_1^m = (\mathbf{H}_1^m)^H\mathbf{r}, \quad m = 1, \cdots, M_1$$

where $\mathbf{H}_1^m = \mathbf{H}_1(4(m - 1)K_1^m + 1 : 4mK_1^m)$ in which $\mathbf{H}_1(i : j)$ denotes the $j^{th}$ to $j^{th}$ column submatrix of $\mathbf{H}_1$ and $K_1^m$ denotes the number of users in the $m^{th}$ subgroup. Similar as the above, after removing the MAI, the residue for the $q^{th}$ symbol of the $i^{th}$ user in the $m^{th}$ subgroup at the $j^{th}$ iteration, $\tilde{y}_{i1,q}^m(j)$, is given by

$$\tilde{y}_{i1,q}^m(j) = y_1^m - (\mathbf{H}_1^m)^H(\mathbf{H}_1(\tilde{b}_{1i,q}^m)\downarrow(j) + \mathbf{H}_2\tilde{b}_2(j - 1))$$

for $1 \leq q \leq 4$, $1 \leq i \leq K_1^m$, $m = 1, \cdots, M_1$, where $(\tilde{b}_{1i,q}^m(j))\downarrow = [(\tilde{b}_{1i,q}^m(j))^T, \cdots, (\tilde{b}_{1i,m}^m(j))^T]^T$ denotes the soft-decision outputs for the transmitted symbols of the users in the SM group at the $j^{th}$ iteration, in which $\tilde{b}_{1i,q}^m(j) = [(\tilde{b}_{1i,q}^m(j))^T, \cdots, (\tilde{b}_{1i,(i-1)}^m(j))^T, (\tilde{b}_{1i,i}^m(j))^T, \cdots, (\tilde{b}_{1i,K_1^m}^m(j))^T]^T$. $\tilde{b}_{1i,q}^m(j) = [(\tilde{b}_{1i,1}^m(j))^T, \cdots, (\tilde{b}_{1i,K_1^m}^m(j))^T]^T$, $k \neq i$, $\tilde{b}_{1i,q}^m(j)$ is replaced the $q^{th}$ element of $\tilde{b}_{1i}^m(j)$ by zero, and $\tilde{b}_{1i,q}^m(j)$ is $E\{\tilde{b}_{1i,q}^m(j)\}$ denotes the mean of the $q^{th}$ symbol of the $k^{th}$ user in the $m^{th}$ subgroup of the SM group at the $j^{th}$ iteration.

Note that in (10), $(\tilde{b}_{1i,q}^m(j))\downarrow$ accounts for the MAI from the users in the SM group while $\tilde{b}_2(j - 1)$ denotes the MAI in the STBC group. Again, to estimate the $q^{th}$ symbol of the $i^{th}$ user in the $m^{th}$ subgroup, we invoke the MMSE filter by [2]

$$w_{i1,q}^m(j) = (\mathbf{R}_{i1,q}^m(j))^{-1}p_{i1,q}^m(j)$$

(11)
where $\mathbf{R}_{1i,q}^m(j) = E\{\tilde{\mathbf{y}}_{1i,q}^m(j)(\tilde{\mathbf{y}}_{1i,q}^m(j))^H\}$ and $\mathbf{p}_{1i,q}^m(j) = E\{\tilde{\mathbf{y}}_{1i,q}^m(j)\tilde{\mathbf{h}}_{1i,q}^m(j)^H\}$. Thereafter, the output of the MMSE filter for the $q^{th}$ symbol of the $i^{th}$ user in the $m^{th}$ subgroup is given by $z_{1i,q}^m(j) = (\mathbf{w}_{1i,q}^m(j))^H(j)\tilde{\mathbf{y}}_{1i,q}^m(j)$. Again, by assuming the output of each MMSE filter in the subgroup is approximately Gaussian [6], then $z_{1i,q}^m(j) = \tilde{m}_{1i,q}^m(j) + n_{1i,q}^m(j)$, where $\tilde{m}_{1i,q}^m(j)$ is the equivalent strength and $n_{1i,q}^m(j)$ is the noise with variance ($\tilde{\sigma}_{1i,q}^m(j)^2$), which, following the derivations in (6)-(8), can be expressed, respectively, as

$$\tilde{m}_{1i,q}^m(j) = (\mathbf{w}_{1i,q}^m(j))^H(j)(\mathbf{H}(j))\tilde{\mathbf{e}}_{1i,q}^m(j)$$

and

$$\tilde{\sigma}_{1i,q}^m(j)^2 = (\mathbf{w}_{1i,q}^m(j))^H(j)\mathbf{R}_{1i,q}^m(j)\mathbf{w}_{1i,q}^m(j) - (\tilde{m}_{1i,q}^m(j))^2.$$  

The soft decision output for the $q^{th}$ symbol of the $i^{th}$ user in the $m^{th}$ subgroup, after the MMSE filter and the MAP decision, is then given by [6]

$$\tilde{\lambda}(b_{1i,q}^m(j)) = \frac{2z_{1i,q}^m(j)\tilde{m}_{1i,q}^m(j)}{(\tilde{\sigma}_{1i,q}^m(j)^2)} \quad (12)$$

The soft estimated symbol $\tilde{b}_{1i,q}^m(j) = \tanh(\frac{1}{2}\tilde{\lambda}(b_{1i,q}^m(j)))$ [6], can then be used to construct the new soft estimate for the $q^{th}$ symbol of the $i^{th}$ user in the $m^{th}$ subgroup.

The update for the users in the STBC group follow similarly and are not repeated here. The overall procedures of this low-complexity implementation are outlined as follows:

**Step 1n** (Initialization): Partition the users in the SM and the STBC groups into prescribed $M_1$ and $M_2$ subgroups, respectively, based on the correlation matrix $\mathbf{C}_1 = \mathbf{H}_1^H\mathbf{H}_1$ and $\mathbf{C}_2 = \mathbf{H}_2^H\mathbf{H}_2$. For each subgroup, carry out the matched filter by (9). Set the appropriate initial soft-decision outputs.

**Step 2n**: For the SM group, in parallel proceed the following operations for each of the $M_1$ subgroups: Remove the MAI by (10). For the $q^{th}$ symbol of the $i^{th}$ user in the $m^{th}$ subgroup, determine the MMSE detector, $\mathbf{w}_{1i,q}^m(j)$, by (11). Thereafter, estimate the soft-decision output of each symbol by (12).

**Step 3n**: Alternatively proceed the detection between the SM and the STBC groups until convergence.

**C. Computational Complexity**

Next, we evaluate the proposed detectors in terms of the computational complexity based on the number of complex multiplications and additions (CMAs) required.

Note that for the V-BLAST, after ordering the effective channels, the symbols are recursively detected by the ZF detector which roughly requires $K_3 + 2K_2N_R(2N + L - 1)$ CMAs for the pseudo-inverse of the $N_R(2N + L - 1) \times K$ matrix $\mathbf{H}$, so the overall computational load is around $K(K_3 + 2K_2N_R(2N + L - 1))$ CMAs.

For the proposed alternating MUD, referred to as the AMUD, the computations are also mainly dictated by Step 2. For the SM group, the MAI removal in (3) requires $4N_R(2N + L - 1)K_1$ and $16K_1(K_1)^2 + 4N_R(2N + L - 1)K_1$ CMAs for the computations of $\mathbf{H}_1^H\mathbf{H}$. Also, the determination of the MMSE filter in (4) requires $64(K_1)^3$ CMAs for the inverse of $4K_1 \times 4K_1$ auto-covariance matrix. By including similar manipulations for the STBC group, the number of the CMAs adds to $4K_1(64(K_1)^3 + 16(K_1)^2 + 8K_1) + 2K_2(8(K_2)^3 + 4(K_2)^2 + 4K_2)$. For the low-complexity implementation, referred to as the AMUD-p, users are partitioned into $M_1$ and $M_2$ subgroups for the SM group and the STBC group and hence the size of the correlation matrix required to be inverted is further reduced to $4K_1^m \times 4K_1^m$ and $2K_2^m \times 2K_2^m$, respectively. Therefore, the determination of the corresponding MMSE filters only calls for $(4K_1^m)^3$ and $(2K_2^m)^3$ CMAs, which in general are less than $N_R(2N + L - 1)$, so the complexity can be dramatically reduced. For reference, Table I shows the analytic expressions for the total numbers of CMAs required by the aforementioned detectors, where $N$ is the length of the spreading codes, $K_1$ and $K_2$ denote the number of users in the SM group and the STBC group, respectively; $K = K_1 + K_2$ is the total number of transmitted symbols over two consecutive symbol intervals, $M_1$ and $M_2$ denote the number of subgroups in the SM group and STBC group, respectively, $S_1 \equiv N_R(2N + L - 1)$, and $J$ is the number of iterations required by the proposed AMUD and AMUD-p.

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Complex multiplications/additions</th>
</tr>
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<tbody>
<tr>
<td>VBLAST</td>
<td>$K(K_3^m + 2S_1K_1^m + 2S_1)$</td>
</tr>
<tr>
<td>AMUD</td>
<td>$S_1K + J((4K_1^m)^4 + (2K_2^m)^4) + 2((4K_1^m)^3$</td>
</tr>
<tr>
<td></td>
<td>$+(2K_2^m)^3) + 2 + K)(((4K_1^m)^2 + (2K_2^m)^2) + S_1K_1^m)$</td>
</tr>
<tr>
<td>AMUD-p</td>
<td>$S_1K + J(S_1K_1^m + 4K_1^m)((4K_1^m)^2 + 4K_1^m$</td>
</tr>
<tr>
<td></td>
<td>$+K + 2) + 2K_2(2K_2^m)((2K_2^m)^2 + 2K_2^m + K)$</td>
</tr>
</tbody>
</table>

**IV. Simulations and Discussions**

Some simulations are conducted to verify the proposed MUDs. Consider a dual-signaling MIMO CDMA system as depicted in Sec. 2, where there are $N_R = 3$ receive antennas and the length of the spreading codes, $N$, is 32. Assume that the channels are frequency selective Rayleigh fading and the number of fading channel paths for each user, $L$, is 2. Also, according to the channel strength, all users have properly decided their transmission signaling schemes [8]. Assume the users in the SM and the STBC groups are $K_1=8$ and $K_2=8$, respectively, which amounts to half loading rate, i.e. $\rho = 0.5$, where $\rho = K/N_RN$. All users’ information, such as channel responses and spreading codes, is assumed to be available at the base station. Three detectors: the V-BLAST [3], the proposed AMUD, and its reduced-complexity version, AMUD-p, are conducted for comparison in terms of the BER performance and the computational load. For the AMUD-p, we assume that the users in both of the SM and the STBC groups are further equally partitioned into 2 subgroups. As a benchmark, the BER performance for users which are all transmitted using the STBC scheme is also provided.

First, we compare the BER performance versus the number of iterations at signal to noise ratio (SNR)=10 dB and 14 dB for the AMUD and AMUD-p, as shown in Fig. 2. We can observe that both MUDs can converge in 3 iteration, so the number of iteration will be chosen as 3 in the following simulations.
Next, we compare the BER performance versus the SNR. We can observe from Fig. 3 that although the V-BLAST employs the ordered SIC to remove the MAI stage by stage before conducting the symbol detection, it still does not provide satisfactory performance as the propagation errors become more pronounced in such dual-signaling environments. The proposed AMUD yields the most superior performance, as it, unlike the SIC, employs the estimated interferences from both signaling groups. Furthermore, the soft information aided MAI are iteratively refined so as to attain more thorough interference cancellation. The AMUD-p is slightly inferior to the AMUD, as now the users in each subgroup also suffer the MAI from the other subgroups in the same group, but its performance is still better than the V-BLAST. As for complexity, based on the analytic expressions given in Table 1, the numbers of the CMAs required by the V-BLAST, AMUD, and AMUD-p are 49121856, 3351849, and 1282848, respectively. Therefore, the computational complexity of the AMUD is lower than the V-BLAST, as the dimension of the auto-covariance matrices to be inverted is smaller. The AMUD-p, despite with slight performance degradation, can drastically alleviate the computational load by further reducing the size of the auto-covariance matrices.

To assess the loaded problem, we also compare the BER performance with different loading rate at SNR = 14 dB, as shown in Fig. 4. We can observe from Fig. 4 that the performance deteriorates as the loading rate increases and that the new MUDs still exhibit superior performance even for high-loaded scenarios.

V. CONCLUSIONS

This paper addresses an alternating MUD for the dual-signaling MIMO CDMA systems. The MUD first groups users according to their transmission signalings and then proceeds the detection alternatively with the removal of the iteratively refined soft interferences in between. To reduce the computational load, users in each group are further partitioned into subgroups based on their effective channel correlations. Conducted simulations verify the effectiveness of the new MUD especially in highly loaded scenarios.

Acknowledgement

This work was supported by National Science Council of R.O.C. under contracts NSC 98-2221-E-011-086 and NSC 98-2221-E-211-011.

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