COMPARISON OF MULTIUSER DETECTION TECHNIQUES FOR ASYNCHRONOUS MULTIRATE DS-CDMA SYSTEMS

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Abstract
This paper compares performance of various multiuser receiver structures for asynchronous multirate DS-CDMA systems over multipath Rayleigh fading channels. Bit-error-rates (BER) of the novel decorrelator based successive interference cancellation (DBSIC) detector and other commonly used suboptimum multiuser receivers such as the decorrelating, minimum mean-square-error (MMSE), SIC, parallel interference cancellation (PIC) and decorrelating decision-feedback (DF) detectors are evaluated for variable processing gain (VPG) CDMA systems with both perfect and imperfect channel side information. Simulation results show that DBSIC outperforms all other considered multiuser detection techniques in various multirate scenarios including cases with more than two rates at the expense of some additional complexity. In particular, DBSIC provides gains in the case where some physical users have increased data rates (i.e. heavier system’s load in terms of virtual users). It is also observed that, while all the receivers suffer degradation in performance in the case of imperfect channel estimates, DBSIC still outperforms the other detection schemes.

I. INTRODUCTION

With the increasing demand for system capacity and broadband multimedia services at various costs, it is desirable to develop CDMA wireless systems that operate at multiple data rates. There are several ways to design a multirate CDMA system. Higher rate users can be accommodated by assigning them several parallel communication channels (Multi-code (MC) or multi-channel), higher-order modulations (modulation-division multiplexing (MDM)), spreading sequences of smaller lengths (variable processing gain (VPG)), or spreading sequences of same length but with different chip rate (variable chip rate (VC))[1]-[3]. Noting that VC is usually more complex practically partly due to the unequal bandwidth spreading of different users VPG is considered in this work.

Receivers for asynchronous multirate CDMA systems based on classical multiuser detection techniques [4] such as multiple access interference (MAI) decorrelation [2], minimum mean-square-error (MMSE) [5], successive interference cancellation (SIC) (including possibly multistage as in [6]), parallel interference cancellation (PIC) and blind successive intracell IC [7] have been studied for one or several multirate methods, most works assuming perfect channel estimation.

The impact of channel estimation error on the signal-to-noise ratio (SNR) and bit-error-rate (BER) was investigated in [8] but only for synchronous decorrelating and MMSE receivers. Assuming perfect, imperfect or no power control, and imperfect channel side information, [9] showed that multistage SIC always performs better than single or multistage PIC.

To improve performance and possibly to reduce complexity, variations of those receivers have been proposed. For example, a truncated window asynchronous VPG CDMA decorrelator was presented in [10] where a user is decoded by employing sliding finite length observation windows that extend over a sufficient number of the user’s bits. A multistage PIC structure with hyperbolic tangent decision device designed for asynchronous MC multirate CDMA was analyzed and simulated over AWGN and flat Rayleigh fading channels in [11] assuming both total and partial IC. Using either MC or VPG multirate methods, [12] showed the decorrelating and groupwise serial IC (with either PIC or decorrelator within the group) schemes yield smaller BER than PIC. A groupwise SIC receiver was proposed in [13] for a dual-rate CDMA system where users are divided into two groups according to their data rates. After initial bit estimates obtained using adaptive MMSE detection, PIC is employed first for the high-rate users, and then for the low-rate users once the interferences from the high-rate users have been regenerated and canceled.

A new asynchronous multirate multiuser detection scheme, namely the decorrelator based SIC receiver (DBSIC) was presented in [14] but its performance was evaluated only for a dual rate system and compared only to the decorrelating and conventional SIC detectors with no complexity assessment. DBSIC is similar to the conventional SIC scheme, except that at each stage of the SIC receiver, a decorrelator on top of the conventional MF detector is employed to detect the user’s signal to be used at the next stage. By implementing this decorrelation in the early stages of DBSIC fewer decision errors are obtained yielding improved performance under perfect and imperfect channel side information due to less error propagation from one stage to the next.

This paper extends previous works such as [14] by considering multirate systems with more than two rates over multipath fading channels, comparing the performance of DBSIC to MMSE, PIC and decorrelating decision-feedback (DF) multiuser receivers in addition to the decorrelating detector and conventional SIC schemes, and assessing receiver complexity.

The paper is organized as follows. The CDMA system and channel models are presented in section II. Section III describes the various schemes considered in this work. BER simulation results are presented in section IV. Conclusions are given in section V.

II. SYSTEM AND CHANNEL MODELS

We consider an asynchronous multirate CDMA system with $C$ data rate classes and $K_c$ physical users in class $c$. VPG is
employed here where physical users with the lowest data rate have the largest processing gain and vice versa. The data rate for class \( c \) is denoted as \( R_c \), with the slowest data rate denoted as \( R(= R_1) \). Assuming that \( R_c = cR \), where \( c \) is an integer, each physical user in class \( c \) can be treated as \( c \) independent virtual users with data rate \( R \). The \( k^{th} \) physical user of class \( c \) is assigned a spreading sequence of length \( G_1 \) (regardless of its class):

\[
S_{c,k}(t) = \sum_{i=1}^{G_1} a_{c,k}[i] \frac{1}{\sqrt{G_1}} P(t - (i - 1)T_{ch})
\]

where \( T_{ch} \) is the chip interval, \( G_1 \) is the processing gain for the slowest rate users, \( P(t) \) is a pulse of duration \( T_{ch} \) (assumed for simplicity to be rectangular with unit energy) and \( a_{c,k}[i] \) \((\in \{-1, 1\})\) is the value of the \( i^{th} \) chip of the \( k^{th} \) user of class \( c \). For \( 0 \leq t \leq T_s \), \( j = 1, \ldots, c \) and \( c = 1, \ldots, C \) the signature code of the \( j^{th} \) virtual user derived from the \( k^{th} \) physical user is [12],[14]

\[
S_{c,k}^{(j)}(t) = \begin{cases} 
S_{c,k}(t), & (j - 1)T_s \leq t < jT_s \\
0, & \text{else} 
\end{cases}
\]

where \( T_s^* = 1/R_c \) is the symbol duration of users of class \( c \). For example an initial random signature sequence of length 32 is assigned to each physical user of a dual-rate system with a low-rate user processing gain of 32 and a high-rate user processing gain of 16. Each physical high rate user can be treated as two virtual users. The spreading sequence of the first virtual user can be formed by adding 16 ‘0’s after the first half of the 32 chips. The spreading sequence of the second virtual user is obtained by adding 16 ‘0’s before the second half of the same 32 chips. Since we are considering even processing gains, the spreading sequences \( S_{c,k}(t) \) are generated by adding one random chip to Gold sequences [12].

Assuming transmission of a BPSK modulated information sequence of length \( N \) (with respect to class 1 users), the received signal is [14]

\[
r(t) = \sum_{i=1}^{N} \sum_{c=1}^{C} \sum_{k=1}^{K_c} \sum_{l=1}^{L} \left\{ \sqrt{E_{c,k}^{(j)}b_{c,k}[i]}a_{c,k}[l] \right\}
S_{c,k}^{(j)}(t - \tau_{c,k}^{(j)} - (i - 1)T_{ch} - (i - 1)T_s) + n(t)
\]

(2)

where we have modeled the multipath Rayleigh fading channel as a truncated tapped delay line (TDL) with taps delay equal to \( T_{ch} \) with sufficiently slow fading such that the fading is constant over a sequence of \( N \) bits. Note that \( N \) could be as small as 5 as used in the simulations. In (2) \( T_s \) is the symbol duration for the slowest class users and \( b_{c,k}[i] \in \{-1, 1\}, E_{c,k}^{(j)}, S_{c,k}^{(j)}(t), a_{c,k}[l] \) and \( \tau_{c,k}^{(j)} \) are respectively the \( i^{th} \) bit, transmitted signal energy, signature waveform (given by (1)), 11 path gain (modeled as a zero-mean circularly complex Gaussian random variable) and delay of the \( j^{th} \) virtual user derived from the \( k^{th} \) physical user of class \( c \). All virtual users associated with the same physical user have the same delay. Each physical user’s delay is assumed to be an integer of \( T_{ch} \) (chip interval) and less than \( T_s^* \), and is uniformly randomly generated. In other words the system is assumed to be symbol-asynchronous but chip-synchronous. The noise \( n(t) \) is a complex Gaussian random process with zero mean and power spectral density \( \frac{N_0}{2} \). For simplicity of notation, let us order the virtual users for all physical users for all classes such that the \( j^{th} \) virtual user derived from the \( k^{th} \) user of class \( c \) is assigned the index \( m \in \{1, \ldots, K_c\} \) defined as \( m = \sum_{i=1}^{c-1} lK_i + c(k - 1) + j \), where \( j \in \{1, \ldots, c\}, k \in \{1, \ldots, K_c\}, c \in \{1, \ldots, C\} \).

Let \( K_c = \sum_{c=1}^{C} cK_c \) be the total number of virtual users and let \( C_m(t) = a_m^{(c)} \). \( S_m(t) \) be the effective signature sequence for the \( m^{th} \) virtual user, where \( S_m(t) = \left[ S_m(t), S_m(t - T_{ch}), \ldots, S_m(t - (L - 1)T_{ch}) \right]^T \) and \( a_m = [\alpha_m[1], \alpha_m[2], \ldots, \alpha_m[L]]^T \). The received signal (2) can be re-written as:

\[
r(t) = \sum_{i=1}^{N} \sum_{m=1}^{K_c} \sqrt{E_m} b_m[i] C_m(t - \tau_m - (i - 1)T_s) + n(t)
\]

III. MULTIUSER RECEIVER STRUCTURES

The sampled output of \( K_c \) Rake matched filters (MF) is

\[
y_m[i] = \int_{(i-1)T_s+\tau_m}^{iT_s+\tau_m} r(t) C_m^*(t - \tau_m - (i - 1)T_s) dt
\]

(3)

where \( m = 1, \ldots, K_c \) and \( i = 1, \ldots, N \). Let \( \tilde{y}_m[i] = [\tilde{y}_m[0], \ldots, \tilde{y}_m[i]]^T \). Considering the sequence of \( N \) symbols, since \( \tau_m < T_s \), from [14] the output vector \( \tilde{y}_{\{NK_c \times 1\}} = [\tilde{y}^T[1], \ldots, \tilde{y}^T[N]]^T \) is

\[
\tilde{y}_m = \tilde{R} \tilde{E} \tilde{b}_m + \tilde{n}_m
\]

where \( \tilde{R} \) is a matrix of dimension \( NK_c \times NK_c \)

\[
\tilde{R} = \begin{pmatrix}
R(0) & R(-1) & 0 & \cdots & 0 \\
R(1) & R(0) & R(-1) & \cdots & 0 \\
0 & \cdots & \cdots & \cdots & 0 \\
0 & \cdots & \cdots & \cdots & 0 \\
0 & \cdots & \cdots & \cdots & 0
\end{pmatrix}
\]

\( \tilde{E} = \text{diag}(E, \ldots, E) \), \( \tilde{E} = \text{diag}(\sqrt{E_1}, \ldots, \sqrt{E_{K_c}}) \),

\( \tilde{b}_m = [\tilde{b}_m[0], \ldots, \tilde{b}_m[N]]^T \)

\( \tilde{b}_m[i] = [b_m[i], \ldots, b_{K_c}[i]]^T \),

\( \tilde{n}_m = [\tilde{n}_m[1], \ldots, \tilde{n}_m[N]]^T \),

\( \tilde{n}_m[i] = [n_m[i], \ldots, n_{K_c}[i]]^T \)

and for \( l = -1, 0, 1 \), \( R(l) \) is a \( K_c \times K_c \) matrix with \((mn)^{th} \) element \( a_m^H \rho_l^{(0)}(m, m) a_n \)

\[
\int_{(i-1)T_s+\tau_m}^{iT_s+\tau_m} C_m(t - \tau_m - (i - 1 - l)T_s) C_n^*(t - \tau_m - (i - 1)T_s) dt
\]

The matrix \( \rho_l^{(0)}(m, m) \) has \((kj)^{th} \) element \( \rho_{kj}^{(0)}(m, m) \):

\[
\rho_{kj}^{(0)}(m, m) = \int_{(i-1)T_s+\tau_m}^{iT_s+\tau_m} \frac{S_m(t - \tau_m - (i - 1 - l)T_s - (k - 1)T_{ch})}{S_m(t - \tau_m - (i - 1)T_s - (j - 1)T_{ch})} dt
\]

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1. Conventional single-user MF detector: \( \hat{b}_{\text{MF}} = \text{sign} (\Re \{ \hat{g} \} ) \), where \( \Re \{ \cdot \} \) is real part of \( \cdot \) (elements by elements).
2. Decorrelating detector:
\[
\hat{b}_{\text{DRC}} = \text{sign} \left( \Re \left\{ \begin{bmatrix} \hat{\mathbf{R}} \hat{\mathbf{E}} \end{bmatrix}^{-1} \hat{g} \right\} \right)
\]
3. MMSE detector:
\[
\hat{b}_{\text{MMSE}} = \text{sign} \left( \Re \left\{ \begin{bmatrix} \hat{\mathbf{R}} \hat{\mathbf{E}} \end{bmatrix} + (N_0/2) \mathbf{I} \right\}^{-1} \hat{g} \right) \]
4. PIC detector: The decision statistic at stage \( g \) is:
\[
j_{k,\text{PIC}}^{(g)} = \text{sign} \left( \Re \left\{ \begin{bmatrix} \mathbf{y}^T \mathbf{F}^T \end{bmatrix} \mathbf{z} \right\} \right) \quad k = 1, \ldots, NK_v
\]
\[
b_{k,\text{PIC}}^{(0)} = 0
\]
where \( y_k^\text{MF} \) is the \( k \)th element of \( \hat{y} \) and \( z_k^\text{MF} \) is the \( k \)th element of \( \hat{\mathbf{R}} \hat{\mathbf{E}} \).
For the conventional SIC, decorrelating DF and DBSIC, for each sequence of length \( N \), the receiver signal is passed through the bank of matched filters once and the SIC cancellation/detecting order is determined based on these outputs for all the symbols of the sequence. Let \( \hat{y}_{\text{new}} \) be the vector obtained by reordering \( \hat{y} \) so that its elements \( y_i \) are listed in decreasing order. Then:
\[
\hat{y}_{\text{new}} = \hat{\mathbf{R}}_{\text{new}} \hat{\mathbf{E}}_{\text{new}} \mathbf{b}_{\text{new}} + \hat{n}_{\text{new}} = \hat{\mathbf{Z}}_{\text{new}} + \hat{n}_{\text{new}}
\]
\[
y_i = \sum_{j=1}^{NK_v} z_{ij} b_j + n_i \quad i = 1, \ldots, NK_v
\]
with \( \hat{\mathbf{Z}} = \hat{\mathbf{R}}_{\text{new}} \hat{\mathbf{E}}_{\text{new}} \) and \( b_j = j \)th element of \( \mathbf{b}_{\text{new}} \).
5. Conventional SIC detector: \( b_{1,\text{SIC}} = \text{sign}(\Re \{ y_1 \} ) \)
\[
\hat{b}_{k,\text{SIC}} = \text{sign} \left( \Re \left\{ \begin{bmatrix} y_k \end{bmatrix} - \sum_{j=1}^{k-1} z_{kj} \hat{b}_{j,\text{SIC}} \right\} \right) \quad k = 2, \ldots, NK_v
\]
6. Decorrelating DF detector: Let \( \hat{\mathbf{Z}} = \mathbf{F}^H \hat{\mathbf{F}} \), where \( \mathbf{F} \) is a lower triangular matrix (obtained using techniques similar to the classical Cholesky decomposition). Applying \( \mathbf{F}^H \) (noise whitening filter) to \( \hat{y}_{\text{new}} \) yields:
\[
\hat{y}_f = \mathbf{F}^H_{\text{new}} \hat{y} + \hat{n}_f
\]
\[
\hat{b}_{k,\text{DF}} = \text{sign} \left( \Re \left\{ \begin{bmatrix} \begin{bmatrix} y_{f,k} \end{bmatrix} - \sum_{j=1}^{k-1} f_{kj} \hat{b}_{j,\text{DF}} \end{bmatrix} \right\} \right) \quad k = 2, \ldots, NK_v
\]
7. DBSIC detector: The first symbol of the strongest user is determined using
\[
\hat{b}_{1,\text{DBSIC}} = \text{sign} \left( \Re \left\{ \begin{bmatrix} \hat{\mathbf{Z}}^{-1} \hat{y}_{\text{new}} \end{bmatrix}_{1} \right\} \right)
\]
but unlike the decorrelating detector that detects all users’ signals, only the first symbol is detected at this stage. The other \( b_i \)‘s are determined as follows. Define \( \hat{y}^{(k)}_{\text{new}} = \begin{bmatrix} y^{(k)}_k, \ldots, y^{(k)}_{NK_v} \end{bmatrix}^T, \hat{n}^{(k)}_{\text{new}} = \begin{bmatrix} n^{(k)}_1, \ldots, n^{(k)}_{NK_v} \end{bmatrix}^T, \hat{b}^{(k)}_{\text{new}} = \begin{bmatrix} b^{(k)}_1, \ldots, b^{(k)}_{NK_v} \end{bmatrix}^T \), where \( y^{(k)}_i \triangleq y_i \) and for
\[
l_i \triangleq y^{(k-1)}_i - z_{i,k-1} \hat{b}_{k-1} \quad n_i \triangleq n_i + \sum_{j=1}^{k-1} z_{ij} (b_j - \hat{b}_j)
\]
\[
\implies \hat{y}^{(k)}_{\text{new}} = \hat{\mathbf{Z}}^{(k)} \hat{\mathbf{Z}}^{(k-1)}_{\text{new}} + \hat{n}^{(k)}_{\text{new}}
\]
The matrix \( \hat{\mathbf{Z}}^{(k)}_{(NK_v-k+1) \times (NK_v-k+1)} \) is given by
\[
\begin{bmatrix}
z_{kk} & z_{k+1,k} & \cdots & z_{k,NK_v} \\
z_{k+1,k} & z_{k+1,k+1} & \cdots & z_{k+1,NK_v} \\
\vdots & \vdots & \ddots & \vdots \\
z_{NK_v,k} & z_{NK_v,k+1} & \cdots & z_{NK_v,NK_v}
\end{bmatrix}
\]
The estimate of \( b_k \) is obtained using
\[
\hat{b}_{k,\text{DBSIC}} = \text{sign} \left( \Re \left\{ \begin{bmatrix} \hat{y}^{(k)}_{\text{new}} \end{bmatrix}^{-1} \hat{y}^{(k)}_{\text{new}} \right\} \right)
\]
In the evaluation of the receivers complexity, we count only the operations after the matched filters’ outputs (i.e. starting from (3)), and we define the computational complexity as the total number of multiplications and additions [15].
For the decorrelating detector, starting from (3), the required operations are the inversion of \( \hat{\mathbf{R}} \hat{\mathbf{E}} \) and the multiplication of \( \hat{\mathbf{E}}^{-1} \), and \( \hat{y} \) yielding the computational complexity \( \sim O \left( (NK_v)^3 \right) \). Implemented directly MMSE is more complex than the decorrelator, but its complexity can be reduced by using the LMS algorithm [15].
Excluding the first stage, the number of operations to compute \( \hat{b}^{(g)}_{\text{SIC}} \) is \( 2(NK_v - 1) \). Hence the total complexity for PIC with \( g \) IC stages and the first (non IC) stage is \( 2g(NK_v - 1)NK_v \).
The number of operations for the computation of \( \hat{b}_{k,\text{SIC}} \) starting from (4) is \( 2(k-1) \). Hence the total complexity for SIC is \( \sum_{k=2}^{NK_v} 2(k-1) + NK_v \log_2(NK_v) = (NK_v - 1)NK_v + NK_v \log_2(NK_v) \sim O \left( (NK_v)^2 \right) \), where \( NK_v \log_2(NK_v) \) represents the reordering of \( \hat{y} \) to get \( \hat{y}_{\text{new}} \).
The number of operations of the decorrelating DF detector can be decomposed as:
- Decomposition of \( \hat{\mathbf{Z}} \) into \( \mathbf{F}^H \mathbf{F} \) and inversion of \( \mathbf{F}^H \)
  (upper triangular matrix) : \( \sim O \left( (NK_v)^3 \right) \)
- Multiplication of \( \mathbf{F}^H \) to \( \hat{y}_{\text{new}} \) (taking into consideration that \( \mathbf{F}^H \) is an upper triangular matrix):
\[
\sum_{p=1}^{NK_v} \sum_{p=1}^{NK_v-1} p = 2 \frac{(NK_v - 1)(NK_v)}{2} + NK_v = (NK_v)^2
\]
- Computation of \( \hat{b}_{k,\text{DF}} \) : \( 2(k-1) \rightarrow \sum_{k=2}^{NK_v} 2(k-1) \) (all \( \hat{b}_{k,\text{DF}} \))
Therefore the total number of operations for the decorrelating DF detector is \( O \left( (NK_v)^3 \right) + (NK_v)^2 + (NK_v - 1)(NK_v + NK_v \log_2(NK_v) \sim O \left( (NK_v)^3 \right) \).
Starting from (4), the number of operations needed to compute \( \hat{b}_{k,\text{DBSIC}} \) (including the input for the next cancellation stage) is composed of three parts:
- Inversion of \( \hat{\mathbf{Z}}^{(k)} \):
\[
O \left( (NK_v - k + 1)^3 \right) \quad \text{(following [15])}
\]
- Multiplication of \( \hat{\mathbf{Z}}^{(k)} \) and \( \hat{y}^{(k)}_{\text{new}} \) (considering that only the first element of the result is needed):
\[
(NK_v - k + 1) + (NK_v - k + 1 - 1) = 2(NK_v - k + 1)
\]
- Generation of \( \hat{y}^{(k+1)}_{\text{new}} \) : \( 2(NK_v - k) \)
yielding a total complexity for DBSIC (N-bit sequence) of

\[ N K_e \sum_{k=1}^{N} \left[ 1 + 4(NK_e - k) + O(NK_e - k + 1)^3 \right] \]

\[ = NK_e + 2(NK_e - 1)NK_e + O \left[ (NK_e)^2(NK_e + 1)^2/4 \right] \]

Hence the complexity for DBSIC is \( O \left[ (NK_e)^4 \right] \) + \( NK_e \log_2(NK_e) \sim O \left[ (NK_e)^4 \right] \). It is seen that DBSIC has a more complex structure than the other receivers due to the implementation of the decorrelator at each stage which translates into a repeated matrix inversion of decreasing dimension at each stage. However, with the implementation of iterative algorithms such as steepest descent (SD), conjugate gradient (CG), and preconditioned conjugate gradient (PCG) [16], the complexity and processing delay of DBSIC can be reduced.

IV. PERFORMANCE

An asynchronous multirate DS/CDMA system with the same number of physical users (ten) is modeled in the simulations according to the cases outlined in Table I. The processing gain of the lowest-rate users is 32. We assume that all virtual users of all classes have the same energy, normalized to unity. The code sequences assigned to each virtual user are kept constant for the whole simulation set once generated. A two-path Rayleigh slow fading channel model is considered. The fading gains of all physical users are assumed to be mutually independent, constant over a sequence of 5 consecutive bits and are implemented based on Clarke’s model. We also assume that the receiver for each user has perfect knowledge of the signature waveforms, delays, and amplitudes of all users in the system (except for the imperfect channel estimation scenario). Hard bit decisions are used in the simulations with no coding.

<table>
<thead>
<tr>
<th>case</th>
<th>Class1</th>
<th>Class2</th>
<th>Class3</th>
<th>Class4</th>
<th>virtual users</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>tot. # = 10</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>tot. # = 13</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>tot. # = 17</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>tot. # = 20</td>
</tr>
</tbody>
</table>

Monte Carlo simulations are used in this work assuming the widely used approximation that for a large number of trials the independent errors will result in a 95% confidence interval. We run simulations such that at least 15 errors would occur for the lowest BER desired and at least 1000 trials where each user transmits 5 symbols continuously are run. The BER averaged over all users is plotted against the SNR per bit \( E_b/N_0 \), where each point is averaged over at least 1000 trials.

Figs. 1-4 present performance of the conventional MF, decorrelating, MMSE, conventional SIC, PIC, decorrelating DF and DBSIC detectors over 2-path equal strength Rayleigh fading channels under perfect channel side information with various data rate classes as specified in Table I. It is seen that among all detectors, DBSIC achieves the best BER performance for both single and multirate systems, yielding for example compared to the decorrelating DF detector, a gain of 4.8dB at a 10^{-5} BER in a single-rate system (Fig. 1), 2.8dB at a 2 \cdot 10^{-5} BER in a 2-rate system (Fig. 2), 3dB at a 2 \cdot 10^{-5} BER in a 3-rate system (Fig. 3) and 2.2dB at a 4 \cdot 10^{-5} BER in a 4-rate system (Fig. 4). Higher gains are obtained compared to the decorrelating detector (6.2dB at a 2 \cdot 10^{-5} BER in a single-rate system, 4.8dB at a 3 \cdot 10^{-5} BER in a 2-rate system), or the MMSE detector (4.5dB at a 4 \cdot 10^{-5} BER in a 3-rate system and 4.7dB at a 8 \cdot 10^{-5} BER in a 4-rate system). DBSIC also outperforms greatly the conventional SIC. This can be explained by the fact that SIC makes decisions based on the MF outputs which are then used for the next user detection and the decision estimate accuracy might be poor in the presence of MAI. DBSIC has more accurate decision estimate due to its decorrelating operation at each interference cancellation stage.

Fig. 1. Performance over 2-path Rayleigh fading channel with RAKE, perfect channel estimate. \( K_1 = 10 \). \( G_1 = 32 \)

Fig. 2. Performance over 2-path Rayleigh fading channel with RAKE, perfect channel estimate. \( K_1 = 7 \), \( K_2 = 3 \), \( G_1 = 32 \)

As more and more users demand higher data rate such as from case 1 to case 4, the number of virtual users increases accordingly and yields performance loss for all receivers as expected (heavier loaded system case). However, Fig. 4 shows that DBSIC’s performance degradation is smaller. For example, Fig. 4 shows a penalty of 2.2dB for DBSIC at a 2 \cdot 10^{-5} BER when some physical users rates double from the original single-rate system. The performance degrades by an additional 3.4dB in the 3-rate case where the data rate triples.
In practical wireless systems, the channel coefficients are unknown to the receiver and the corresponding channel estimates are imperfect due to the existence of noise and interference. As a non-perfect channel estimation example, we assume that the estimated channel fading coefficient of each path is equal to the true channel coefficient multiplied by a random variable uniformly distributed between $-6.25\%$ and $6.25\%$, which is referred in this paper as 12.5% channel estimation error and is illustrated in Fig. 5. While all receivers considered in this work including DBSIC undergo performance loss under imperfect channel estimation, DBSIC still outperforms the other receivers and achieves for example a 1.5 dB gain over the decorrelating DF scheme at a BER of $5 \cdot 10^{-3}$ in a 4-rate system with up to 12.5% channel estimation error.

This paper compares the performance of various multiuser receiver structures such as the novel DBSIC scheme for asynchronous VPG multirate CDMA systems. It is shown that DBSIC outperforms the decorrelating, MMSE, SIC, PIC and decorrelating DF detectors over multipath Rayleigh fading channels with both perfect and imperfect channel side information in various multiuser scenarios including cases with more than two rates at the expense of some additional complexity. In particular, it is seen that gains are obtained even in the case where some physical users have increased data rates (i.e., heavier system’s load in terms of virtual users). It is also observed that, while all the receivers suffer degradation in performance in the case of imperfect channel estimates, DBSIC still outperforms the other detection schemes.

REFERENCES