BLIND INTERFERENCE SUPPRESSION FOR DS-CDMA

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Abstract: The use of a blind scheme for suppressing interference in direct-sequence code-division multiple-access (DS/CDMA) communication systems is investigated. In particular, we use a blind version of the partial-bit DS/CDMA receiver to successfully suppress narrow-band and near-far multiple-access interference without requiring knowledge of other users' spreading codes, timing or phase information. Performance results for a 23 user/100 chip BPSK DS/CDMA system indicate that the blind partial-bit DS/CDMA receiver using as little as 33 taps can suppress narrow-band and near-far multiple-access interference, either at the beginning of a transmission or during transmission as interferers gain access to the system.

I. INTRODUCTION

Direct-sequence CDMA techniques are being proposed around the globe for use in multi-user communication systems. For secure communications, direct-sequence spread-spectrum signals are hard to detect by unauthorized users and have good resistance against intentional jamming. Direct-sequence spread-spectrum signals are increasingly being used for multiple-access communications, as they allow users to be asynchronous, thus reducing complexity. For example, there is little coordination between users. Users are allowed to occupy the same frequency spectrum at the same time. Users can enter or leave the system as they please, and furthermore, new users entering the system result in a graceful degradation of system performance. Direct-sequence spread-spectrum signals are also excellent candidates for multipath fading channels. However, with a conventional receiver, if the received power from an interferer is larger than the received power from the user of interest, communication can become unreliable. This is why some sort of power control is required with direct-sequence spread-spectrum multi-user communications.

In this paper, we show that the blind partial-bit direct-sequence spread-spectrum receiver of [1,2] can alleviate the need for strict power control techniques by suppressing strong interferers including narrow-band interferers. In contrast to the receiver considered in [7-8], the partial-bit DS/CDMA receiver was designed to suppress interference in CDMA systems employing arbitrary large processing gains, but without requiring an absurd number of taps or computation. In other words, we can use a 25 tap partial-bit DS/CDMA receiver in system using a processing gain of 25 or 400. This is because the receiver of [1,2] does not use the adaptive filter for both respreading the desired user and suppressing the interference as done in [7-8]; it will be difficult, if not impossible in the near future to use the N tap receiver considered in [7-8] for processing gains, N, larger than 30 or 40.

In this paper, we restrict the narrow-band interference to a binary phase-shift keying (BPSK) user which uses no spreading.

The remainder of the paper is organized as follows. DS/CDMA signal models are described in section II. In Section III, the blind partial-bit DS/CDMA receiver is discussed in detail. Performance results for 23 user/100 chip system employing a 33 tap partial-bit DS/CDMA receiver are provided in Section IV. Finally, Section V contains conclusions obtained from the study.
II. DS/CDMA SIGNAL MODELS

Signal models for an asynchronous DS/CDMA system presented in [1] are briefly reviewed here. It is assumed that there are K users assigned to the binary phase-shift keyed DS/CDMA system and that the kth user’s transmitted signal is given by

\[ S_k(t) = (2P_k^R)^{1/2}a_k(t)b_k(t)\cos(\omega_ct + \theta_k), \]

where \( \omega_c \) is the common carrier frequency, \( P_k^R \) is the transmitted power of the kth user and \( \theta_k \) is the phase angle introduced by the kth modulator. The kth user’s data signal, \( b_k(t) \), is given by

\[ b_k(t) = \sum_{l=-\infty}^{\infty} b_l^{(k)}P_T(t - lT), \]

where \( b_l^{(k)} \) is the data sequence of the kth user and \( P_T(\cdot) \) is a unit rectangular pulse of duration T. The kth user’s data sequence can take on values +1 or -1, with probability 1/2 each. The kth user’s spreading signal, \( a_k(t) \), is given by

\[ a_k(t) = \sum_{j=-\infty}^{\infty} a_j^{(k)}P_T(t - jT_c), \]

where \( a_j^{(k)} \in \{-1, +1\} \) and \( T_c \) is the chip duration. We assume that the spreading sequence is periodic with period \( N = T/T_c \), that is, \( a_j^{(k)} = a_j^{(k)+N} \). The received waveform is given by \( r(t) = n(t) + m(t) \), where \( n(t) \) denotes additive white Gaussian channel noise with 2-sided spectral density \( N_0/2 \), and \( m(t) \) denotes the multiple-access component of the received waveform. The multiple-access term, \( m(t) \), is given by

\[ m(t) = \sum_{k=1}^{K} (2P_k^R)^{1/2}a_k(t - \tau_k)b_k(t - \tau_k)\cos(\omega_ct + \phi_k), \]

where \( P_k^R \) is the received power from the kth user. \( \tau_k \) accounts for the propagation delay between the kth transmitter and a given receiver, and \( \phi_k \triangleq \theta_k - \omega_c\tau_k \). Without any loss of generality, we will restrict our attention to the receiver of the 1st user and set \( \phi_1 = 0 \) and \( \tau_1 = 0 \), since the kth receiver is assumed to be synchronized to the kth transmitter. We will also assume that \( \tau_k \in [0, T) \) and \( \phi_k \in [0, 2\pi) \) for \( k = 2, \ldots, K \), since we are only concerned with relative time delays modulo T and relative phase shifts modulo 2\pi. In this paper, we assume that the elements of the vector \((\tau_1, \ldots, \tau_K, \phi_1, \ldots, \phi_K, b_1^{(1)}, \ldots, b_1^{(K)})\) are mutually independent.

III. PARTIAL-BIT DS/CDMA RECEIVER

The partial-bit DS/CDMA receiver of [1] is shown in Figure 1. Note that the receiver despreads the received signal before it is fed to the partial-bit correlator. The discrete output of the integrate-and-dump filter is then processed by an M tap filter where the correlation properties of the interference are further exploited. We point out that our receiver can easily accommodate systems using a large processing gain. As an example, suppose the processing gain was 500 and due to implementation considerations, we are restricted to use a 50 tap receiver. For this scenario, we integrate over 10 chips prior to filtering. In other words, we have already reduced the interference to some extent, prior to any adaptive filtering. Our receiver has thus partially exploited the processing gain of a conventional spread spectrum receiver as well. Also, note that the despreaded desired signal is enhanced by integration over say, 10 chips.

The blind receiver of [2] to be discussed below was based on the innovative work of Griffiths, [3]. Before presenting the algorithms below, we first point out that the partial-bit DS/CDMA receiver starts out as the linear correlator, stated differently, the adaptive receiver attempts to produce \( \sum_{j=1}^{M} r(t)a_j(t) \), the output of the linear correlator in absence of any interference. The desired signal is therefore given by \( \sqrt{P_1^R/2 \cdot T \cdot b_1} \). Now, for the steepest descent algorithm, the weights are updated according to

\[ H_{l+1} = H_l + \mu P_g - \mu RH_l, \]

where \( P_g = E(d_iX_i) \), \( R = E(X_iX_i^T) \) and d is the desired signal stated above. Also, in (5), the tap weight vector H is given by \((h_0, \ldots, h_{M-1})^T\) and the vector X denotes the input to the adaptive filter. In particular, for \( j = 0, \ldots, M-1 \), the jth element of X is given by

\[ x_{j,l} = \int_{lT+jT_s}^{(l+1)T_s} r(t)a_1(t)\cos(\omega_c(t))dt. \]
For the normalized Griffiths LMS algorithm, we replace \( R \) by \( X_i X_i' \), yielding

\[
H_{l+1} = H_l + \frac{\mu}{X_i ' X_i} (P_g - y_i X_i),
\]

and \( y_l = H_l ' X_i \). Next, from [2], we replace \( P_g \) by

\[
\tilde{P}_g = \beta^2 M \cdot 1_{M \times 1}, \quad \beta = \frac{1}{\gamma} \sum_{l=-\gamma+1}^{0} \tilde{b}_l \cdot \sum_{j=0}^{M-1} x_{j,l},
\]

where \( \tilde{b}_l \) is initially given by \( \text{sign}(\sum_{j=0}^{M-1} x_{j,l}) \), and during tracking, if reliable, is obtained from the output of the adaptive receiver. Therefore \( \beta \) and \( \tilde{P}_g \) may be obtained on line. In (8), \( 1_{M \times 1} \) denotes the \( M \times 1 \) vector of all ones.

The blind Kalman algorithm is obtained in a similar manner, and here the taps are tuned according to

\[
H_{l+1} = H_l + \frac{\Sigma_{l,l-1} \tilde{P}_g}{X_i ' \Sigma_{l,l-1} X_i + \sigma^2} - y_l G_l,
\]

\[
G_l = \frac{\Sigma_{l,l-1} X_i}{X_i ' \Sigma_{l,l-1} X_i + \sigma^2},
\]

\[
\Sigma_l = (I - G_l X_i)' \Sigma_{l,l-1} (I - G_l X_i) + \sigma^2 \cdot G_l G_l',
\]

\[
\Sigma_{l+1,l} = \Sigma_l + \epsilon \cdot I_{M \times M},
\]

where \( G_l \) denotes the Kalman gain, \( \Sigma_l \) denotes the error covariance matrix and \( y_l \) denotes the output of the adaptive filter at bit index \( l \). Also, \( \epsilon \) is set to a small positive number. Finally, for decision directed LMS adaptation, the weights are tuned according to

\[
H_{l+1} = H_l + \frac{\mu}{X_i ' X_i} (\beta \cdot \tilde{b}_l - y_l) X_i,
\]

where \( \mu \) is fixed at 0.1 for all the simulation results presented in this paper. When using a training signal, we replace \( \tilde{b}_l \) with \( b_l \) in (13).

**IV. PERFORMANCE RESULTS**

In this section, we present results for a 23 user DS/CDMA system employing a processing gain equal to 100. The desired user is assigned a 33 tap partial-bit DS/CDMA receiver. All results correspond to setting \( E_B/N_0 \) equal to 15 dB for the desired user. The average bit error rate plotted in the curves is obtained by averaging over 2000 runs, where random spreading codes, delays and phases are assigned to the users at the beginning of each run, and fixed thereafter. For each run, we simulate the receivers for a total of 2000 bits. In particular, the bit error rates for the respective receivers are plotted as a function of bit index \( l \).

Our first set of results correspond to the scenario in which the desired user has been in the system for a long time prior to \( l = 1 \), i.e. the taps have converged to the optimum Weiner-Hopf solution given in [1]. In other words, the taps have accounted for 5 near-far interferers each having a 15 dB power advantage plus 15 interferers having a 0 dB power advantage. At \( l = 1 \), two interferers abruptly gain access to the system; they are not yet accounted for by the desired user receiver. One of these interferers is a narrow-band BPSK interferer enjoying a 25 dB power advantage, while the other interferer is a near-far DS-CDMA interferer having a 15 dB power advantage. Figure 2 displays the average bit error rates as a function of the bit index \( l \) for the desired user. Note that a full-time blind LMS will yield unsatisfactory performance; using a smaller step size for the blind LMS would have helped, but at the expense of tracking. As expected, the blind Kalman yields superior performance at the expense of increased computation. All receivers converged on all the runs, except the one using full-time decision directed suppression; it failed to converge on a single run out of the total 2000 runs. We note that all receivers started adapting with an initial average bit error rate of 0.2, and \( \beta \) was obtained from 100 bits, that is \( \gamma = 100 \).

Next in Figure 3, we provide bit error rates when the desired user powers on in presence of several near-far interferers. In particular, here the desired user starts out as the linear correlator and starts tuning it taps in presence of 7 near-far interferers, each having a 15 dB power advantage. The remaining 15 interferers have a 0 dB power advantage. We note that for this scenario, the receivers begin adapting with an average bit error rate of 0.13. Note again that when used alone, the full-time blind LMS does not yield satisfactory performance. We do not plot the results for the blind Kalman, which as above, yielded satisfactory performance at the expense of increased computa-
tion. Rather, for this scenario, we plot the results for a scheme using part-time decision directed and part-time blind suppression according to

\[ |H[X_i]| < \alpha \Rightarrow \text{Blind LMS} \]
\[ |H[X_i]| \geq \alpha \Rightarrow \text{Decision Directed LMS} \]

where for this study \( \alpha \) was set to \( \beta/2 \) and \( \gamma \) was equal to 100 in (8). All receivers converged on all the runs, except for the receiver using full-time decision directed suppression; it failed to converge on 13 of the total 2000 runs.

V. CONCLUSIONS

In this paper, we demonstrated that it is possible to suppress interference using a mixed mode partial-bit DS/CDMA receiver. We also demonstrated that after initial adaptation, in some applications, the receiver could stay in decision directed mode even as near-far interferers gain access to the system, see for example, the results of Figure 2. Current research focuses on part-time blind/part-time decision directed schemes based on the LMS and Kalman algorithms, and some results may be found in [6], including performance as a function of \( \alpha \), \( \beta \), and \( \mu \). Finally, the receiver is capable of rejecting both narrow-band and multi-user interference in systems employing an arbitrary large processing, but without requiring an absurd number of taps or computation.

REFERENCES


Figure 2. Performance of desired user in a 23 user/100 chip system using a 33 tap receiver.

Figure 3. Performance of desired user in a 23 user/100 chip system using a 33 tap receiver.