first-order Markovian binary sources. Experimental results show that this customised version is very effective in compressing first-order Markovian binary sources, especially when the transition probabilities are time-varying.

References

Modified constant modulus algorithm for blind DS/CDMA detection

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A new blind adaptive multiuser detector for synchronous DS/CDMA systems based on a modified constant modulus algorithm is proposed. This detector is shown to outperform the minimum output energy detector in a downlink channel occupied by a large number of users. This blind detector is a good candidate for downlink receivers.

Introduction: Multiuser detection for direct sequence/code division multiple access (DS/CDMA) systems has received considerable attention in recent years, with the aim of improving their capacity. Several multiuser detection schemes have been proposed since the appearance of Verdu's optimum detector [1]. One of the important classes of multiuser detectors is that of adaptive receivers [2], the operation of which is based on using only the desired user's spreading sequence. These types of receivers have the advantage of being eminently suitable for implementation both as downlink receivers and central station receivers. Adaptive receivers not only help to effect interference cancellation from within the cell, but also have the ability to cancel inter-cell interference. However, owing to the need for the periodic transmission of training sequences for adaptive receivers, recent research has been directed towards developing blind adaptive schemes that eliminate the need for the use of a training sequence.

A number of blind adaptive detectors have been proposed in the literature [3, 4]. One of the recently proposed blind methods is the so-called constant modulus algorithm (CM A). In [5] a CM A was proposed where the users' spreading codes were used to initialise the adaptive receiver. However, it has been pointed out by Lambotharan et al. [6] that this initialisation does not guarantee signal separation for all the users. These authors [6] have proposed a modification to the CMA in which the cross-correlation properties of the receiver outputs are employed to retrieve all user signals. However, such a strategy is suitable only for the central station, where there is a need for the detection and separation of all the users. In the work presented in this Letter, we are interested in modifying the CMA to make it useful for the single user case. This requires the ability of the algorithm to decode only the desired user using only his own spreading sequence. It is shown through computer simulation results that such a modified CMA (M-CMA) can efficiently and blindly detect desired user data in a channel occupied by a large number of users. Its performance is shown to be significantly better than that obtained when the constrained minimum output energy CMOE [3, 4] algorithm is used for such channels.

System model: The system assumed here is a synchronous DS/CDMA system in an additive white Gaussian noise (AWGN) channel. Assuming perfect bit and chip synchronisation, the received signal is sampled at the chip rate to yield the received vector

\[ r = z \hat{s} + n \]  

Here \( a_i \), \( b_i \), and \( s_i \) denote the amplitude, data and spreading sequences for the \( r \)-th user, \( n \) denotes the noise vector, and \( k \) denotes the number of users. The vectors \( r \), \( s \), and \( n \) are all \( N \)-dimensional, where \( N \) denotes the number of chips in the spreading sequence, the period of which is assumed equal to one bit period. Binary phase shift keying is assumed so that the hfi represent bipolar data.

Modified CMA: In the conventional CMA, a linear receiver is chosen comprising a weight vector \( w \) that operates on the vector \( r \) to yield the output \( y \). The weight vector \( w \) is chosen to minimise the deviation of the receiver's output from a constant modulus. Such a cost function is usually chosen to be

\[ J = E[(y - \hat{y})^2] \]  

where \( \hat{y} \) denotes the signature sequence of the desired user. While this would enable the production of a fixed gain to the desired user, such an approach cannot guarantee that the average-value \( Ey \) can be made to approach unity, since that would depend on the received level of the desired signal.

To overcome this problem, while staying close to the basic philosophy of the CMA cost function, in this Letter we propose a modified cost function based on the premise that \( Ey \) can be rendered constant by minimising the expectation of the change in \( y \) between two successive bits. This expectation of change is chosen here as

\[ E[ (y_i - y_{i-1})^2 ] \]

where \( y_i = w^T r_i \)

and \( r_i \) is the received vector in the current bit interval and \( r_{i-1} \) the received vector in the previous bit interval. Motivated by this argument, the new M-CMA cost function is defined as

\[ J = E[(y - \hat{y})^2] \]

This cost function could be minimised under the constraint of eqn. 3 to yield the optimum weight vector. An adaptive implementation of this receiver can be obtained as follows: The gradient vector of the cost function \( J \) with respect to the vector \( w \) is given by

\[ V w J = \sum_i \{ V w (y_i - \hat{y})^2 \} \]

The instantaneous estimate of the gradient for use in an (LMS-like) adaptive algorithm is approximated by

\[ \hat{V} w J = 4 \langle (y_i - \hat{y})^2 \rangle / 2 \langle r_i - \hat{r}_i \rangle \]

Combining eqn. 6 with Frost's approach [7] for implementing the linear constraint of eqn. 3 yields the adaptive algorithm given below:

\[ w_{init} = c_0 \widetilde{w} \]

(7)

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Adaptation mode:

\[ w^{t+1} = w_t - \frac{1}{N} \sum_{j=1}^{N} y_j \]

\[ A = (w_f x_j - 1) I/N \]

where \( i \) is a suitably chosen step size.

The computational complexity of the M-CMA is estimated to be about twice that of the CMOE since it needs to process two bits in each iteration. However, this additional complexity is shown to be compensated for by a significant improvement in performance.

Finally, regarding convergence, it is conjectured that the proposed cost function has no local minima implying that the adaptation algorithm would always converge globally. However, we have no proof of this at present. This observation was always seen to be true in the extensive computer simulation studies carried out by us.

**References**


**Fig. 1** Performance of M-CMA and CMOE receivers for SNR of 6dB

(i) M-CMA
(ii) CMOE: \( \mu \) = 7 \times 10^{-6}
(iii) CMOE: \( \mu \) = 1.4 \times 10^{-6}

**Fig. 2** Performance of M-CMA and CMOE receivers for SNR of 3dB

(i) M-CMA
(ii) CMOE: \( \mu \) = 7 \times 10^{-6}
(iii) CMOE: \( \mu \) = 1.4 \times 10^{-6}

Computer simulations: The blind M-CMA proposed here, as well as the CMOE, have been subjected to simulation studies in a downlink of 20 users with equal powers. Gold sequences of length 31 were assumed as the spreading codes. Two values of signal-to-noise power ratio, 10 and 13dB, respectively were chosen for a detailed study. For each SNR, the experiment was repeated 200 times and the resulting output signal-to-interference power ratio averaged over all the experiments. For the M-CMA, the step size \( H \) was selected to be 10^{-2} to give the fastest possible convergence. For the CMOE, we include here results corresponding to the best choice of \( \mu \), in the range 0.7 \times 10^{-6} to 1.4 \times 10^{-6}, to provide justifiable comparison.

The curves for these two cases are shown in Figs. 1 and 2, respectively, and depict clearly that the M-CMA has faster convergence and significantly better SIR than the CMOE in this dense-user environment. For both the SNR values under consideration here, the M-CMA is seen to detect the desired user more efficiently than the CMOE.

Conclusions: A new blind adaptive detector based on a modified CMA is proposed. Its performance is studied and compared to that of the CMOE receiver in a downlink channel with a large number of users. The M-CMA is shown to perform better than the CMOE in this environment. Accordingly, we believe that it will make a good candidate for downlink multiuser DS/CDMA receivers.

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**Noncoherent adaptive linear MMSE equalisation for 16DAPSK signals**

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A novel adaptive noncoherent linear minimum mean squared error equaliser for 16-level differential amplitude/phase shift keying signals is proposed. A novel modified least mean square algorithm is derived which allows an efficient equaliser adaptation. Simulations confirm the high performance of the proposed noncoherent equaliser and its robustness against carrier phase variations.

**Introduction:** Recently, 16 level differential amplitude/phase-shift keying (16DAPSK) has received much attention [1 - 4]. Both the amplitude and phase of 16DAPSK symbols are differentially encoded and thus robust noncoherent equalisation is possible. The disadvantage of conventional (noncoherent) differential detection (DD) [1] is a high loss in power efficiency compared to coherent detection (CD). Therefore, for frequency-nonselective channels several improved noncoherent detectors have been proposed [2 - 4]. For transmission over frequency-selective channels, however, no noncoherent receiver has been reported so far. Note that conventional (coherent) equalisers [5] are very sensitive to frequency offset, as will be shown in this Letter by computer simulations. Thus, we propose a novel noncoherent minimum mean squared error (MMSE) equaliser which takes full advantage of the differential encoding of 16DAPSK and is robust against phase variations.

**Transmission model:** In this Letter, all signals are represented by their complex-valued baseband equivalents. For simplicity, only T-spaced equalisers are considered here. However, these results can easily be extended to the fractionally-spaced case. The transmitted 16APSK symbol \( s[k] \) is given by

\[ s[k] \sim R[k] b[k] \text{ (i)} \]

with absolute amplitude symbol \( R[k] \), \( R[k] \in \{ R_L, R_U \} \), \( R_U > R_L \), and absolute phase symbol \( b[k] \in \{ 0, \pi \} \). For convenience, \( s[k] \{ s[k] \}^T \) (where \( E[-] \) denotes expectation) is