On Optimal Signal Detection using Covariance shaping method

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ABSTRACT:-In this paper, a new class of linear multiuser detector, referred to as the Covariance Shaping Multiuser (CSMUD) detector has been designed for the suppression of Multi Access Interference (MAI) in multiuser wireless communication systems. We develop an algorithm using quantum constraints and some of its axioms to minimize the total variance of the weighted error between the receiver output and observed signal, subject to the limit that the covariance of the noise component in the receiver output proportional to a given covariance matrix, with the intention that we control the dynamic range and spectral shape of the output noise. We consider the problem of multiuser detection in which we seek to detect probability of bit error for some set of users with different noise levels. The exact and approximate expressions for the probability of bit error for some set of users with different noise level are illustrated. The performance of the CSMU receiver is characterized and finally through examples that the CSMU receiver can significantly increase the performance over the conventional multiuser receivers.

Keywords:-Covariance, Bit error rate, Decorrelator, Multiple access interference, Orthogonality.

I. Introduction

Multiuser receivers for detection of Code Division Multiple Access (CDMA) [1] signals try to mitigate the effect of Multiple-Access Interference (MAI) and background noise. Both the optimal receiver and the linear MMSE receiver require knowledge of the channel parameters. On the other hand, the MF and the decorrelator receivers are linear receivers that only require knowledge of the signature vectors. The MF optimally compensates for the white noise, but does not utilize the structure of the MAI. The decorrelator optimally rejects the MAI, but does not consider the white noise. Like the MF and the decorrelator, the receivers we develop in this chapter do not require knowledge of the channel parameters and rely only on knowledge of the signature vectors.

However, in contrast to the MF and the decorrelator, these receivers take both the background noise and the MAI into account. Consider an m-user white Gaussian synchronous CDMA system where each user transmits information by modulating a signature series. The discrete model for the received signal y is given by y = Hbx + n, where H is the n x m matrix of signatures H_j being the signature vector of the i^{th} user, b = diag (b_i,... , b_m) is the matrix of received amplitudes with $b_i > 0$ being the amplitude of the i^{th} user's signal, b is the data vector of components being in the i^{th} user's transmitted symbol, and n is a noise vector whose elements are independent. We assume that all data vectors are equally likely with covariance.

A new class of linear multiuser receivers, known as the covariance shaping multiuser (CSMU) receiver, has been projected for suppression of interference in multiuser wireless communication systems. This class of receivers is based on recently put forward covariance shaping least squares estimator, and is designed to reduce the total variance of the weighted error between the receiver output and the observed signal, subject to the restriction that the covariance of the noise component in the receiver output is proportional to a specified covariance matrix, accordingly we control the dynamic range and spectral shape of the output noise. This allows us to infer these receivers as the receivers that minimize the total error variance in the observations.

2. Problem Formulation

In [1], an overview of the most common strategies of multiuser detection can be found. Extensive references to significant research work are found in the book of Verdu [2], Verdu proposed the novel idea that detection of CDMA signals should develop the structure inherent in the MAI and not just treating it as noise [2]. With this notion, the conventional matched filter is no longer the optimal detector, and there is a set of multiuser detectors, which are capable to reduce MAI and hence, lead to superior performance. The simplest scheme to demodulate CDMA signal is to use the conventional matched filter detector, which is optimal in Additive WGN noise but is suboptimal because the MAI does not necessarily resemble additive white Gaussian noise.

The received signal is passed through a bank of matched filters attached in Rake configuration that coherently demodulates and dispreads each of the received paths and that was proposed by Turin [3]. The problem of this receiver begins from the fact that, even if the powers of all users are equal, some cross correlation among signals have high values due to different path delays. Therefore even by adjusting the power level using fast power control and selecting codes with low cross correlations, the matched filter receiver performance is limited and so is the capacity to maintain acceptable interference limits. P.Rapajic and B.S.Vucetic [4] presented a receiver structure in which the bank of matched filters is replaced by an adaptive fractionally spaced LMS filter. In [5] bank of LMS filters replaces the user's bank of matched filters attached to the RAKE

Among the DS-CDMA detectors utilizing knowledge of the interferers the first is the detector proposed by Schneider in [6]. The optimal multiuser detector for CDMA systems using Viterbi's algorithm and assuming a perfect knowledge of the channel, is proposed by Verdu in the mid of 1980's in [7-9]. The optimal detector developed in [9] by Verdu presents the optimal solution for the asynchronous case.

We propose to integrate delay tracking into a successive interference cancellation (SIC) code division multiple access (CDMA) multiuser detector as a selected survey in the area of Multiuser Detection techniques [10]. Delay-robust SIC was initially proposed for CDMA multiuser detection when there exists time delay estimation errors [11].The development of a new resource allocation scheme using adaptive power control and multirate multiuser receiver to guarantee users' quality of service requirements in multipath fading environment. A multiuser receiver that maximizes the signal-to-interference ratio (SIR) for each symbol is proposed for multirate CDMA system [12].

In the MMSE receiver, a linear transformation on the matched filter outputs is performed that minimizes the Mean Square Error (MSE), but the decorrelating receiver uses the cross-correlation between the signature sequences. A range of multiuser detectors [13] have been proposed to mitigate the MAI. The CSLS estimator[14] is a linear estimator for the unknown deterministic parameters in a linear model, and is directed at improving the performance of the traditional least-squares estimator by choosing the estimator to minimize the (weighted) total error variance in the observations, subject to the constraint that the covariance of the estimation error is proportional to some given covariance matrix ,so that we control the dynamic range and spectral shape of the covariance of the estimation error.

The CSLS estimator is a biased estimator directed at improving the performance of the traditional least-squares (LS) estimator by choosing the estimate of x to minimize the (weighted total error variance in the observations subject to a constraint on the covariance of the estimation error so that we control the dynamic range and spectral shape of the covariance of the estimation error [15][16].

A block thresholding estimation procedure is introduced, which alter all parameters adaptively to signal property by minimizing a Stein estimation of the risk. Statistical experiments reveal the performance and robustness of this procedure through objective and subjective evaluations [18]. Again the analog represented signal can be converted in to digital described format by R.W.schanfer [17].

The first reference for parallel interference cancellation is the multistage algorithm presented by Varanasi and Aazhang in [19]. Here the multistage algorithm is based on the concept of optimization process between complexity and performance. Kohono et al. presented multistage PIC using hard decisions. Then we have to find the fast Fourier transform for the digitized signal the calculation of Fourier transform is done using the FFT [20].

To address the above issues, we present herein a new detector for the detection problem underlying the CSLS estimation .The remainder of the paper is organized as follows. Section II contains general linear receiver and a summary of decorrelator detector and MMSE detector where an underlying detection of bit error arte if highlighted. A new orthogonal multiuser receiver and Covariance shaping multiuser receiver is introduced in Section III which leads to performance improvement presented in section IV. Numeric results and conclusions are proposed in Section V and IV respectively.

Building on the property of the CSLS estimator, equivalent representation of the receivers that are mathematically equivalent but may have different implications in terms of implementation is proposed. In the first, the receiver consist of a bank of correlators with the correlating vectors that have a specified inner product structure, and all nearby in a LS sense to the user's signature vectors.

In the second, the receiver consists of a decorrelator demodulator followed by a WMMSE covariance shaping transformation that optimally shapes the noise component in the output of the decorrelator prior to detection. In the third, the receiver consists of an MF demodulator followed by an MMSE covariance shaping transformation that optimally shaped the noise component in the output of the MF.

To improve the performance of the decorrelator and MF receivers without assuming knowledge of the channel parameters, the estimated value x using a CSLS estimator, this leads to a class of receivers that we define as the covariance shaping multiuser (CSMU) receivers. The CSMU demodulator minimizes the total error variance in the received signal subject to the constraint that the covariance of the noise component in the output of the demodulator is control the dynamic range and spectral shape of the noise at the output of the demodulator. The particular shaping can be tailored to the specific set of signature vectors. Like the MF and the decorrelator, this receiver requires knowledge of the signature vectors only.

3. General linear receiver

A General linear receiver shown in figure 3.1 consists of a bank of correlators with correlating signals matched to a set of signals with a specified inner product structure R and is closest in an LS sense to the transmitted signals. These receivers depend only on the transmitted signals so that they do not require knowledge of the noise distribution refer to as MF receivers.

In the special case in which R=I (identity), the receiver consists of a bank of correlators with orthogonal correlating signals that are closest in an LS sense to the transmitted signals referred to as the Orthogonal Matched Filter (OMF) receiver.

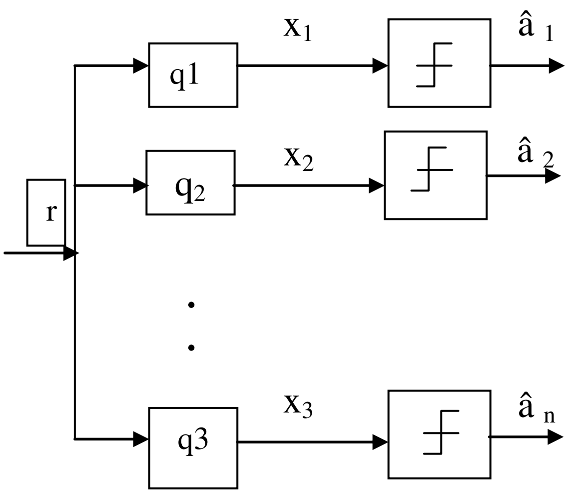

Figure 3.1. General Linear receiver

Multiuser receivers include the optimal multiuser receiver, the linear minimum mean squared error receiver, the decorrelator, and the Matched Filter (MF) receiver for CDMA signals. Both the optimal and the linear minimum mean square error detector require information of the channel parameters. The MF and the decorrelator receivers are linear receivers that only require knowledge of the signature vectors.

The MF optimally compensates for the white noise, but does not exploit the arrangement of the MAI. The decorrelator optimally rejects the MAI for linearly independent signature vectors, but does not consider the white noise.The receiver shown in Figure 3.2 consists of a decorrelator demodulator followed by an optimal minimum mean square error whitening transformation on a space formed by the signature vectors. This whitening transformation is designed to optimally decorrelate the outputs of the decorrelator prior to detection. Specifically, under the whitening constraint it minimizes the Mean Square Error (MSE) between the vector output of the decorrelator and the output of the whitening transformation, so that distortion to the output vector is minimized.

The demodulator consists of a bank of correlators with correlating vectors that are projections of a set of orthogonal vectors, and closest in a least squares sense to the signature vectors. The decorrelating detector suppresses the interference by finding a linear transformation such that the transmitted symbols for all users are completely recovered in the absence of noise.

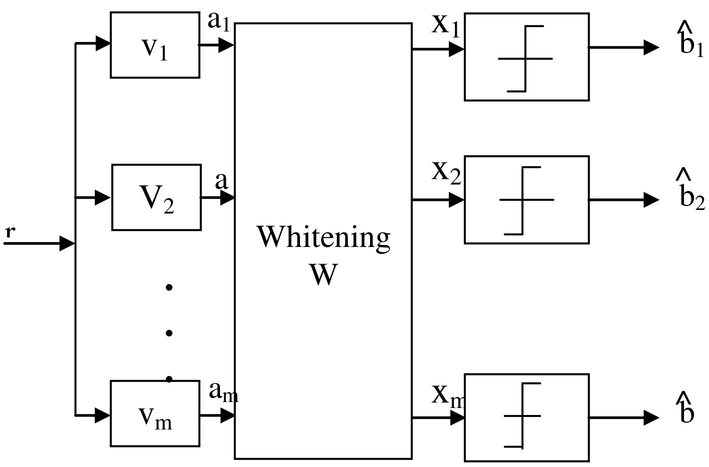

Figure 3.2 Decorrelator Receiver

Although Schneider studied decorrelator type receivers and erroneously claimed they were optimal with respect to bit error probability. When the received signal can be fed into a bank of matched filters, each matched to the signature sequence of a different user which is optimal. The asynchronous decorrelating detector has two steps. First the MAI is removed while introducing the intersymbol interference (ISI). Second, zero forcing equalizer removes the ISI.

One way of reducing the complexity of a decorrelating detector is to use a FIR filter, found by restricting the optimal decorrelating IIR filter. By ensuring that users are received synchronously, interference can be rejected without exact knowledge of the interfering user's delays by projecting the received vector onto a line orthogonal to all time shifts in a small region of the interfering users' spreading codes. Non-linear receivers employing decision feedback are proposed. Here the first user is demodulated by its decorrelating detector whereas other users subtract a linear combination of previous decisions from the whitened matched filter outputs.

3.2. Minimum mean square error detector

A multiuser detector that is closely related to the decorrelating detector is the linear minimum mean square error detector. The goal is to reduce the mean-square-error (MSE) between the user *k*'s bit and the output of the k^{th} linear transformation. The MMSE detector approaches the conventional matched filter as noise tends to infinity. As the signal-to-noise goes to eternity, the linear MMSE detector acts like decorrelator. The probability of error analysis has some discussions on the Gaussian approximation. The benefit of the adaptive MMSE receiver is that it requires no knowledge of the interference parameters and also it can completely suppress the narrow band interference while it adapts to the actual interference.

Here the receiver consists of an MF demodulator followed by an optimal minimum mean square error whitening transformation on a space formed by the signature vectors, which minimizes the MSE between the vector output of the MF and the output of the whitening transformation.

3.3. Orthogonal Multiuser Receiver

In the decorrelating decision feedback detector, the components of the output vector of the feed forward filter are indeed whitened, but not according to the criterion used by the OMU demodulator. Rather, the whitening transformation is chosen in anticipation of a nonlinear feedback loop. A noise whitening approach is also used, where the whitening has a different context.

Unlike the decorrelating decision feedback detector, where the whitening is made across users in the similar symbol period, the detector performs power spectrum whitening of the received chip waveform trailed by MF detection of the desired user. The results shows poorer performance than typical multiuser detectors for a wider set of conditions and the spreading codes of interferers are not mandatory to be identified.

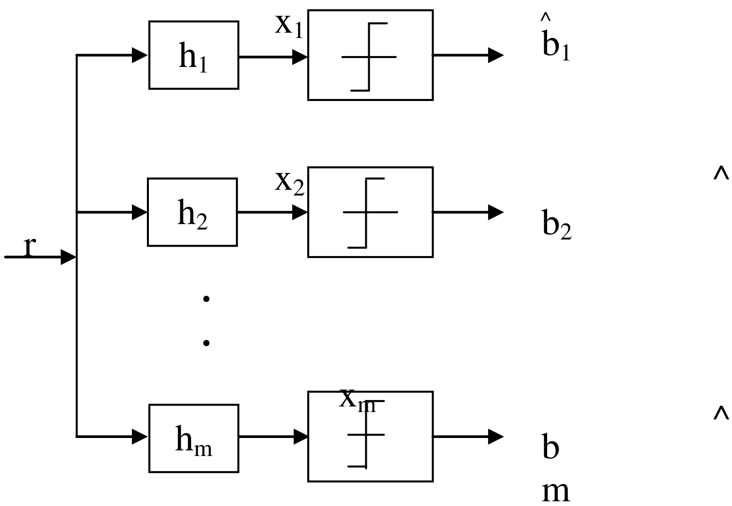

Figure 3.3 Orthogonal Multiuser receiver

Here the OMU demodulator maximizes both the total Signal to Interference Ratio (SIR) and the total Signal to Noise Ratio (SNR) at the output subject to the whitening constraint. The OMU demodulator also approximately maximizes both the total output SIR and the total output SNR for nearly orthogonal signature vectors.

This provides some additional justification for this receiver. The performance of the OMU receiver depends on the probability of error and the exact expressions for the probability of error also derived. Specifically, the output Signal to Interference Noise Ratio (SINR) of the output of the OMU receiver converges to a deterministic limit. This method of proof can be easily modified to characterize the performance of other Multiuser Detectors in the large system limit.

3.4. Conventional matched filter detector

The simplest scheme to demodulate CDMA signal is to use the conventional matched filter detector, which is optimal in AWGN noise but is sub-optimal because the MAI does not necessarily resemble white Gaussian noise. The received signal is passed through a bank of matched filters attached in Rake configuration that coherently demodulates and despreads each of the received paths.

The problem of this receiver arises from the fact that, even if the powers of all users are equal, some cross correlation among signals might still have high values due to different path delays. Therefore even by adjusting the power level using fast power control and codes with low cross correlations, the performance of the matched filter receiver is limited and, to maintain satisfactory interference limits, the number of users have to be reduced.

3.5 Covariance shaping multiuser receiver

Direct-sequence spread-spectrum code-division multiple access (CDMA) has many desirable features; dynamic channel sharing, toughness to channel impairments, smooth degradation, and more. These advantages result from the assignment of signature waveforms with large time–bandwidth product to every potential user of the system. Each user transmits information by modulating a signature sequence. Multiuser receivers for detection of CDMA signals try to mitigate both the background noise and the multiple-access interference (MAI).

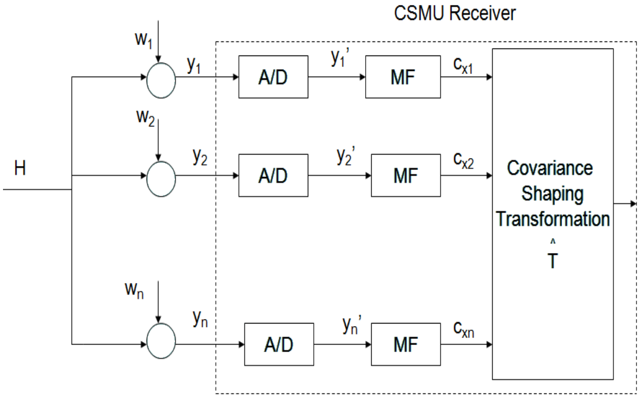

Figure 3.4 CSMU Receiver

Since the optimal receiver for detecting the symbols transmitted by each of the users has exponential complexity, several suboptimal linear receivers based on single-user decoding have been proposed, which are practically appealing. These include linear minimum mean-squared error (MMSE) receiver, decorrelator receiver, matched filter (MF) receiver, and orthogonal multiuser (OMU) receiver. Computationally efficient approximations of the decorrelator and MMSE receivers have been developed.

To develop the class of CSMU receivers, we view multiuser receivers as demodulators, directed at extracting good estimates of the coded symbols of each user, which are then used as inputs to the individual channel decoders. The receiver consists of an MF receiver followed by an MMSE shaping transformation, which minimizes the MSE between the vector output of the MF and the output of the shaping transformation.

IV. Numerical Examples

In this section several simulation results are provided to illustrate the performance of the proposed detection techniques. We consider simulated data generated through channel 1. The analog input speech signal is obtained through the channel 1 at the sample rate of 8000 and the duration of 1.25 seconds and the number of samples obtained form the speech signal is about 10000 as shown in figure 4.2.

The values of analog data can be converted into digital by Quantizing and encoding the floating-point inputs to integer outputs. The floating-point input value to an integer value is determined by the requirement for 2^n levels of quantization. The input range [-v,v] is divided into 2n evenly spaced intervals. Input entries in the range [-v,v] are first quantized according to this subdivision of the input range, and then mapped to one of 2n integer.

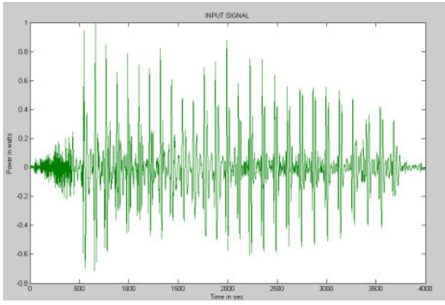

Fig 4.1 Input Signal

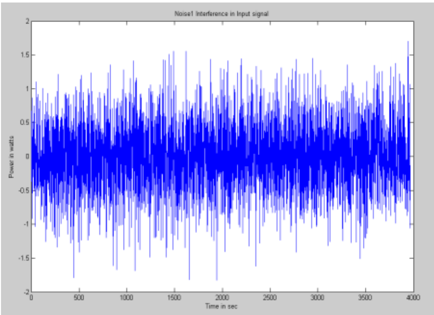

Fig 4.2 Noisy Signal

For decorrelator receiver with low SNR values ranging from 0 db to 5 db, the probability of error will be less than 0.5. The SNR values ranging from 5 db to 10 db the probability of error will be greater than1. The probability of error can be calculated for both linearly independent and dependent vectors.

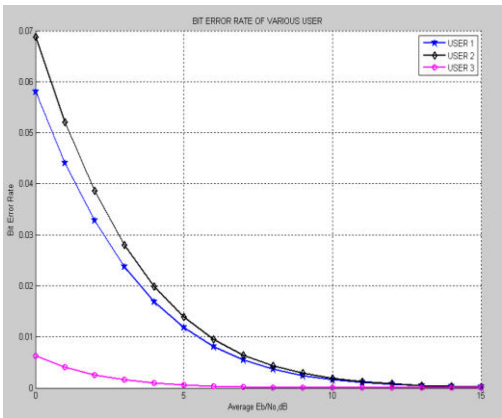

Fig 4.5 Bit Error Rate of 3 Users

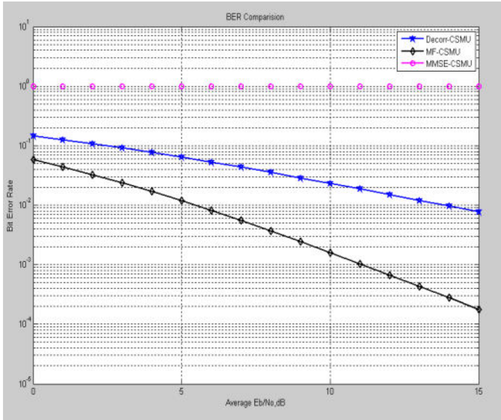

Fig 4.6 Comparision of User with Various Detectors

Comparision of Bit error rate of MF-CSMU with other detector is shown in fig 4.As can be seen from the figure the performance of CSMU receiver is compared with MF receiver, MMSE receiver. For the SNR range shown the result suggests that the CSMU receiver performance better than the MF and MMSE receiver.

Table 4.1 BER Comparison for Various Detectors

Eb/No	Matched Filter Detector	Minimum Mean Square Error Detector	Covariance Shaping Multiuser Detector
0	0.0580	0.0687	0.0628
1	0.0441	0.0521	0.0407
2	0.0327	0.0386	0.0255
3	0.0237	0.0280	0.0155
4	0.0169	0.0199	0.0091
5	0.0118	0.0138	0.0052
6	0.0081	0.0095	0.0029
7	0.0055	0.0064	0.0016
8	0.0036	0.0043	0.0008
9	0.0024	0.0028	0.0008
10	0.0015	0.0018	0.0007

11	0.0010	0.0012	0.0006
12	0.0006	0.0007	0.0005
13	0.0004	0.0006	0.0004
14	0.0002	0.0005	0.0003
15	0.0001	0.0003	0.0002

Here we report the detection performance under the same setup as in figure 4.5 and 4.6.We compare various detection include matched filter, MMSE and the proposed CSMU receiver. Figure shows the probability of Bit error versus Eb/No for various detectors where the number of temporal samples n=32.It seems that the CSMU slightly outperforms the MF and MMSE with each user levels.

CONCLUSION

The performance evaluation of CSMU, Decorrelator, and MMSE detector was carried out in additive white Gaussian noise environment. Also the performances of CSMU, Decorrelator and MMSE where compared for various number of users from the plots obtained, we conclude that CSMU performance is relatively better with respect to other detectors. The exact and approximate expressions for the probability of bit error for some set of users are derived. The result suggests that the probability of bit error for the designed CSMU receiver is lower when compared with other type of multiuser receiver.

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