Joint Domain Localized Adaptive Processing for CDMA Systems

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I. Introduction

Combining space division multiple access (SDMA) with temporal multiple access techniques such as code division multiple access (CDMA) helps maximize system capacity without sacrificing bandwidth [1]. However, both forms of multiple access schemes are interference limited, therefore using interference suppression techniques can improve system effectiveness. In this regard, joint domain adaptive processing that integrates receive beamforming (spatial processing) and multiuser detection (temporal processing) outperforms all possible linear processing based on the minimum mean squared error (MMSE) criterion [2]. Unfortunately, this processor is also prohibitively computation expensive and data inefficient in terms of the required number of training symbols.

To overcome the drawbacks of the jointly optimal MMSE (OMMSE) processor, researchers have recently proposed suboptimal schemes with fewer adaptive unknowns [2]. The authors introduce a constrained optimal MMSE (COMMSE) processor, with iterative cascaded spatial and temporal processing, which only yields additive gains while the OMMSE processor yields multiplicative gains. Clearly, a data efficient joint domain processor with reduced computational load would be a significant advance over the state of the art.

This paper introduces a practical Joint Domain Localized (JDL) adaptive processing algorithm for uplink CDMA systems that has extremely low computational load and fast convergence rate in terms required training symbols. The algorithm builds on an efficient joint domain technique developed for radar systems [3], [4]. The algorithm adaptively processes the joint domain data in the localized region in beamspace. Simulations in section III show that the new algorithm performs better than the COMMSE processor with significantly reduced computational load. The next section describes the JDL algorithm for the simplest case of a BPSK data modulation.

II. Joint Domain Localized Processing

Consider a system with N linear receive antennas and K users using random spreading codes with processing gain G. The received spatial-temporal data signal at the base station for a symbol period is defined as an NG-dimensional vector $\mathbf{x}$ given by

$$\mathbf{x} = \sum_{i=1}^{K} \sqrt{p_i} b_i \mathbf{s}_i \otimes \mathbf{h}_i + \mathbf{n}, \tag{1}$$

where $\otimes$ denotes the Kronecker product and p_i, b_i, $\mathbf{s}_i$, $\mathbf{h}_i$ are the received power, data bit, spreading codes and channel of user i respectively. Received noise, $\mathbf{n}$, is modelled as white and Gaussian.

The JDL algorithm is a two-stage beamspace-based scheme. The first stage transforms the spatial-temporal received signal, $\mathbf{x}$, to spatial-temporal "beamspace" by correlating the received signals with selected spatial-temporal "beams". The spatial-temporal "beamspace" is equivalent to the physical beamspace in spatial processing with no fading. While the physical interpretation does not hold in joint domain processing with fading, the approach is nonetheless valid. For each desired user, spatial-temporal "beams" are constructed by all combinations of a spatial beam, defined as one of the η_s most correlated channels (spatial signatures) amongst all K users, and a temporal "beam", defined as one of the η_t most correlated spreading codes (temporal signatures) amongst all K users. Clearly, the channel and spreading code of the desired user itself are amongst the most correlated channels/codes. This first stage provides some interference suppression by decorrelating the received signals. The localized beamspace data can be obtained using a transformation matrix, $\mathbf{T}$. The transformation process is given by

$$\tilde{\mathbf{x}} = \mathbf{T}^H \mathbf{x}, \tag{2}$$

where ^{H} is the Hermitian operator and the tilde ($\tilde{}$) denotes the beamspace domain. If $\eta_s = \eta_t = 3$, the localized region covers the three channels $(\mathbf{h}_1, \mathbf{h}_2, \mathbf{h}_3)$ and three spreading codes $(\mathbf{s}_1, \mathbf{s}_2, \mathbf{s}_3)$ most correlated to the desired user, the LPR size is $\eta_s \times \eta_t = 9$ and

$$\mathbf{T} = [\mathbf{s}_1 \ \mathbf{s}_2 \ \mathbf{s}_3] \otimes [\mathbf{h}_1 \ \mathbf{h}_2 \ \mathbf{h}_3]\,. \tag{3}$$

The size of the LPR, η_s and η_t beams in the spatial and temporal dimensions respectively, is an implementation issue and can be chosen to tradeoff between performance and computational load.

In the second stage, localized beamspace data $\tilde{\mathbf{x}}$ are adaptively combined, in terms of MMSE, to produce a decision statistic for the information bit. The MMSE weights are found in beamspace by

$$\tilde{\mathbf{w}} = \tilde{\mathbf{R}}^{-1}\tilde{\mathbf{v}}, \tag{4}$$

$$\tilde{\mathbf{R}} = E\{\tilde{\mathbf{x}}\tilde{\mathbf{x}}^H\}, \tag{5}$$

$$\tilde{\mathbf{v}} = E\{\tilde{\mathbf{x}}d^*\} \tag{6}$$

where d^* is the conjugate of the desired information bit and E denotes the expectation operator. In practice, the MMSE weights may be obtained by estimating $\tilde{\mathbf{R}}$ and $\tilde{\mathbf{v}}$ or using a training-based scheme such as the least mean squares (LMS) algorithm. The final soft decision statistic to determine the transmitted bit is

$$y = \tilde{\mathbf{w}}^H\tilde{\mathbf{x}}. \tag{7}$$

In terms of computational complexity, the advantage of the JDL algorithm is clear. The OMMSE processor requires NG adaptive weights while JDL requires only $\eta_s\eta_t$ adaptive weights. The complexity is therefore reduced from the order of $(NG)^2$ to NG per user. For the same reason, the convergence rate of the adaptive weights using the LMS algorithm is also much faster than the OMMSE processor. The COMMSE processor has order of complexity $K(N^2+G^2)$ per user which is significantly higher than the JDL algorithm.

III. Simulation Results

This section compares the performance of OMMSE, JDL, and COMMSE algorithms in terms of symbol error rate and convergence time. The example uses $N = 11$ receive antennas, $K = 20$ equal power users and processing gain of $G = 16$. The channels are modelled as constant over the time period used to estimate the covariance matrix $\tilde{\mathbf{R}}$ and $\tilde{\mathbf{v}}$.

Figure 1 compares the symbol error rates of OMMSE, two implementations of JDL ($\eta_s = \eta_t = 5$ and $\eta_s = \eta_t = 7$), and COMMSE algorithms in slow, flat, uncorrelated Rayleigh fading channels. The figure shows that, as expected, OMMSE always outperforms other algorithms. However, at significantly reduced computational load, JDL processing provides good performance. An interesting characteristics of this processor is that increasing the size of the LPR results in approaching the OMMSE performance at the cost of higher complexity. Importantly, the JDL algorithm, with lower computational load, performs better than the COMMSE processor.

When obtaining the adaptive weights by training, the performance discrepancy of JDL and OMMSE can be justified by the lower computational load and faster convergence rate of JDL processing. Figure 2 illustrates the significantly faster convergence rate of the JDL algorithm ($\eta_s = \eta_t = 5$) using the LMS algorithm with step size of 0.00003. The figure also shows that the training period is hugely reduced from 8000 to 400 iterations at the expense of slightly higher mean squared error.

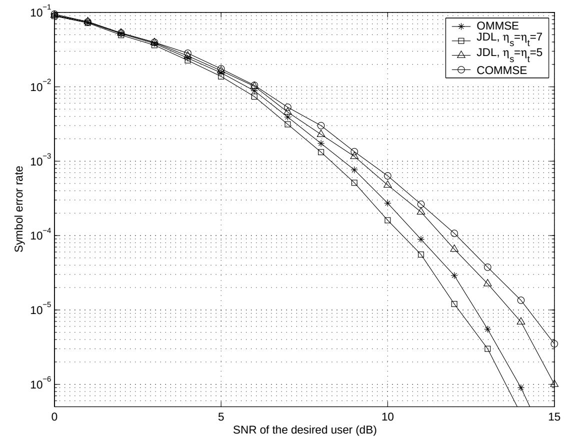

Fig. 1. Performance comparison of joint domain processing.

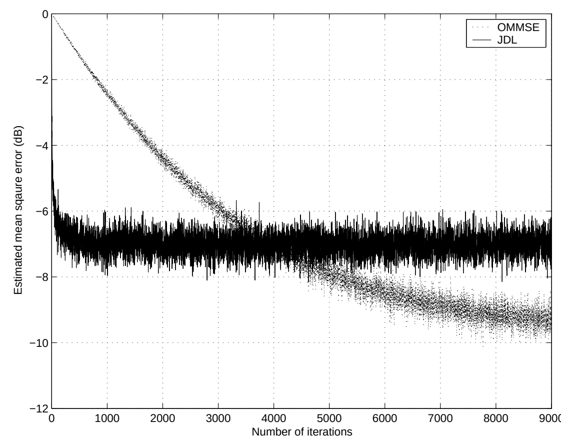

Fig. 2. Convergence time comparison of OMMSE and JDL algorithms

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