Precoding with Partial Channel Information for CDMA with Ultra-Low Complexity Receivers

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Abstract

We consider transmitter precoding for interference suppression and diversity exploitation for multi-antenna CDMA. The receivers are constrained to matched filter detection without channel state information (CSI) or receiver-based multiuser detection. We first develop precoders for scenarios where perfect downlink channel information is available at the transmitter. We show that full transmit antenna diversity is achievable, even for non-orthogonal codes, though we suffer an SNR loss that is a simple function of the spreading code crosscorrelations. We also develop precoders for cases in which the transmitter has partial channel information, modelled as knowledge of conditional channel correlation matrices, and we apply them to Jake's fading model. We show, in summary, that transmitter precoding offers a reasonable alternative to receiver-based multiuser signal processing when minimizing computational complexity at the mobile unit is a priority.

1 Introduction

As conventional signal processing technique for communications become more sophisticated, they place an ever increasing computational and cost burden on detectors, demodulators, and decoders. The precoding approach, in its present context, allows for dramatic reductions in receiver complexity by suppressing interference and exploiting diversity at the transmitter.

Precoding for fading multipath channels with low-complexity receivers and its associated problems, including antenna and multipath diversity exploitation, have not yet been investigated in a systematic way. In addition, existing work on downlink precoding for fading channels generally assumes that the uplink and downlink channels are identical or that the downlink channel is otherwise perfectly known at the base station [1]. We address these limitations in the present work.

2 Precoding Performance and Achievable Diversity

We consider two transmit antennas and one receive antenna. Extensions to more transmit antennas is straightforward. The discrete-time BPSK modulated signal transmitted from antenna $a \in \{1, 2\}$ is $\boldsymbol{x}^{(a)} = \alpha \boldsymbol{S} \boldsymbol{M}^{(a)} \boldsymbol{b}$ where the columns of $\boldsymbol{S} \in \mathbb{C}^{N \times K}$ are the normalized spreading codes of the K users, $\boldsymbol{b} \in \{\pm 1\}^K$ contains the downlink bits corresponding to the K users, $\boldsymbol{M}^{(a)} \in \mathbb{C}^{K \times K}$ is a complex precoding matrix used for multiple-access interference (MAI) suppression and transmitter antenna diversity exploitation and is optimized in the following proposition.

Proposition 1 *The choice of* $\boldsymbol{M}^{(a)}, a \in \{1, 2\}$ *that minimizes the MMSE cost function*

$$J^{(a)} = E\left\{ \left\| \boldsymbol{D}^{(a)} \boldsymbol{b} - \boldsymbol{H}^{(a)} \boldsymbol{R} \boldsymbol{M}^{(a)} \boldsymbol{b} - \boldsymbol{n} \right\|^2 \right\} \tag{1}$$

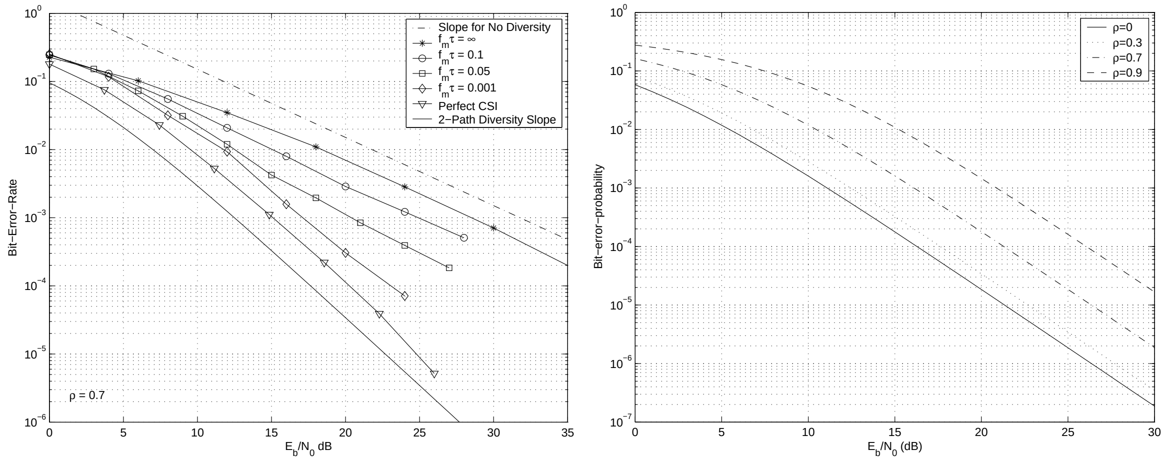

Figure 1: **Left:** Performance of precoding with partial CSI averaged over all 10 users and the fading channel. The spreading waveform crosscorrelation is $\rho = 0.7$. **Right:** The bit-error-probability for the equicorrelated spreading code case, averaged over all 20 users and their channel gains, versus E_b/N_0 for precoding with two transmit antennas and one receiver antenna and for crosscorrelation values of $\rho = 0, 0.3, 0.7, 0.9$. The transmit energy per user per bit is 1.

is

$$\boldsymbol{M}^{(a)} = \boldsymbol{R}^{-1}\left[\boldsymbol{H}^{(a)}\right]^{-1}\boldsymbol{D}^{(a)} \tag{2}$$

where $\boldsymbol{R} = \boldsymbol{S}^H\boldsymbol{S}$, $\boldsymbol{H}^{(a)}, a \in \{1,2\}$ are MISO channel matrices and $\boldsymbol{D}$ is a power loading matrix defined in [2]. The proof also appears in [2]. It is easy to show that the performance for equicorrelated spreading codes with crosscorrelation $\rho = [\boldsymbol{S}]^H_{:,l}[\boldsymbol{S}]_{:,k}, l \neq k$, is nearly equivalent to two-branch maximum ratio combining with a SNR penalty of $10\log_{10}(1-\rho)$ dB. See the plots in Fig. 1 (right). Notice that precoding fully exploits transmit antenna diversity.

3 Precoding with Partial Channel Information

Proposition 2 *Define the following correlation matrices:*

$$\boldsymbol{C}^{(a)}_{\boldsymbol{HH}} \overset{\triangle}{=} E\left\{\boldsymbol{H}^{(a)H}\boldsymbol{H}^{(a)}\middle|\,\hat{\boldsymbol{H}}^{(1)},\hat{\boldsymbol{H}}^{(2)}\right\},\ \ a \in \{1,2\} \tag{3}$$

$$\boldsymbol{C}^{(a)}_{\boldsymbol{HD}} \overset{\triangle}{=} E\left\{\boldsymbol{H}^{(a)H}\boldsymbol{D}^{(a)}\middle|\,\hat{\boldsymbol{H}}^{(1)},\hat{\boldsymbol{H}}^{(2)}\right\},\ \ a \in \{1,2\}. \tag{4}$$

The choice of $\boldsymbol{M}^{(a)}, a \in \{1,2\}$ *that minimizes the MMSE cost function*

$$J^{(a)}_p = E\left\{\left\|\boldsymbol{D}^{(a)}\boldsymbol{b} - \boldsymbol{H}^{(a)}\boldsymbol{R}\boldsymbol{M}^{(a)}\boldsymbol{b} - \boldsymbol{n}\right\|^2\middle|\,\hat{\boldsymbol{H}}^{(1)},\hat{\boldsymbol{H}}^{(2)}\right\},\quad a \in \{1,2\} \tag{5}$$

is

$$\boldsymbol{M}^{(a)} = \boldsymbol{R}^{-1}\left[\boldsymbol{C}^{(a)}_{\boldsymbol{HH}}\right]^{-1}\boldsymbol{C}^{(a)}_{\boldsymbol{HD}} \tag{6}$$

The proof appears in [2]. The performance, assuming Jakes channel correlation model and the availability of old channel estimates, is given in Fig. 1 (left). As channel estimates become unreliable, diversity is lost.

References

[1] R.L.U. Choi and R.D. Murch, "Transmit MMSE pre-rake processing with simplified receivers for the downlink of MISO TDD-CDMA systems," in *Proc. 2002 GLOBECOM*, 2002, pp. 429–433.

[2] D. Reynolds, X. Wang, and K.N. Modi, "Interference suppression and diversity exploitation for multi-antenna CDMA with ultra-low complexity receivers," submitted to *IEEE Trans. Sig. Proc.*, 2003. Preprint available on-line at `http://csee.wvu.edu/~reynolds/multiprecoding.pdf`.