Supermode Transmission for MIMO-based Wireless Communications with Limited Feedback

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Abstract. In this paper, we propose a limited feedback transmission based on precoding mechanism for multiple-input multiple-output (MIMO) systems, referred as to supermode transmission. With a fixed data-rate, it allows different degree-of-freedom (DoF) depending on the current channel state information (CSI) and different transmission scheme with the same DoF.

Keywords: MIMO, Precoding, Limited Feedback, Multimode

1 Introduction

Multiple-input Multiple-output (MIMO) is well known to combat the fading and improve the spectral efficiency for wireless communication systems [1]. Spatial multiplexing and space-time block coding (STBC) are two core ideas of MIMO systems. Limited feedback from the receiver enables beamforming/precoding at the transmitter, which can reduce the interference among antennas/users, thus not only enhancing the MIMO channel throughput and/or reliability, but also simplifying the transceiver design. In this paper, we propose a new limited feedback transmission scheme named as supermode transmission. It merges MM-MIMO and MM-STBC without increasing the number of feedback bits. It allows different degree of freedom (DOF) depending on the current CSI and different transmission scheme with the same DOF. Compared to MM-MIMO and MM-STBC, the supermode can promise that the optimal transmission scheme is always selected and thus provides a better performance.

2 System Model

We consider a MIMO communication system with \( M_t \) transmit antennas and \( M_r \) receive antennas, shown in Fig.1. The system contains a transmitter with a switcher between MM-MIMO and MM-STBC, and a receiver that uses an estimate of the propagation channel to decide the optimal mode and corresponding precoder, and convey to the transmitter with a low-rate error-free feedback path.
Let $s$ represents a length-$M(< M_t/2)$ signal vector with unit energy per symbol. An $M_t \times M$ linear precoding matrix $P_i$ maps $s$ to an $M_r$-dimensional spatial signal that is transmitted on $M_t$ transmit antennas. Neglecting symbol timing errors and frequency offsets, the received signal vector is given by

$$R = \sqrt{\frac{E_s}{MN_0}} HP_i F(s) + N$$

where $F(\cdot)$ stands for a transmission codeword which is either $s$ or a $M \times 2$ space-time codewords in term of the current channel condition. We assume that $H$ has i.i.d entries with $\mathcal{CN}(0, 1)$ distributions. The noise $N$ is the additive white Gaussian noise with i.i.d $\mathcal{CN}(0, 1)$ entries.

### 3 Union bound

#### 3.1 MM-MIMO

We firstly consider the MM-MIMO scheme [4], i.e., $F(s) = s$. The key difference between MM-MIMO and the precoded spatial multiplexing is that $M$ is adapted using current channel conditions. The value of $M$ is thus referred as to the mode of the precoder. Define $\tilde{s} = s - \bar{s}$ with $\bar{s}$ being the hypothesized symbol vector, we have the following results:

**Corollary 1.** For a MM-MIMO system with a fixed transmit rate $R$, the union bound of pairwise error probability (PEP) with mode $M$ and the corresponding codebook with $N_M$ precoders is given as

$$P_r(M, N_M) \leq 1 - \prod_{i=1}^{2N_M} \sum_{j=1, \sigma_j > 0}^{2N_M} \sum_{k=0}^{M_r-1} \gamma_{jk} \sigma_j^{M_r-k}$$

where $\{\sigma_{2i-1}, \sigma_{2i}\} = \frac{D_i \pm \sqrt{D_i^2 + 4N_\sigma D_i}}{2}$ and $D_i = \frac{\lambda^2}{2\piD\sigma} \|s\|^2_F$.

#### 3.2 MM-STBC

The difference between MM-STBC and MM-MIMO is that MM-STBC utilizes a multiple number of $2 \times 2$ Alamouti orthogonal STBC [5].
Corollary 2. For a MM-STBC with a fixed transmit rate $R$, The union bound of PEP with a mode $M$ and a corresponding length-$N_M$ codebook is given as

$$P_r(M, N_M) \leq 1 - \prod_{i=1}^{2N_M} \sum_{j=1, \sigma_j > 0}^{2N_M} \sum_{k=0}^{2M_r-1} \sigma_{j,k}^{2M_r-k} \tag{3}$$

where $\{\sigma_{2i-1}, \sigma_{2i}\} = D_i \pm \sqrt{D_i^2 + 4NaD_i}$ and $D_i = \frac{\lambda^2}{2\eta_{\text{norm}}^2} \|\hat{s}\|^2$

4 Mode selection criterion

Instead of using the average covariance matrices, the instantaneous channel realization of the effective channel $HP_i$ is considered for each transmission time slot. The instantaneous union bound of PEP conditioned on the current channel state for the mode $M$ is given as

$$P_r(\hat{s}, M|H, P_i) = \begin{cases} 
1 - \prod_{i=1}^{2} \sum_{j=1, \sigma_j > 0}^{2} \sum_{k=0}^{M_r-1} \gamma_{j,k} \sigma_{j,2M_r-k} \\
1 - \prod_{i=1}^{2} \sum_{j=1, \sigma_j > 0}^{2} \sum_{k=0}^{M_r-1} \gamma_{j,k} \sigma_{j,2M_r-k} \end{cases} \tag{4}$$

Therefore, the mode and precoder selection criteria can be modeled as the following problems,

$$P_M = \arg \min_{P \in P_M} P_r(\hat{s}, M|H, P) \tag{5}$$

$$M = \arg \min_{M \in \{M_M \cup M_S\}} P_r(\hat{s}, M|H, P_M) \tag{6}$$

where $P_M$ denotes the codebook of precoders for mode $M$ belonging to $\mathcal{M} = \{M_M \cup M_S\}$.

The function (5) corresponds to finding the optimal precoder from an allocated codebook $P_M$ conditioned on a specific mode number $M \in \mathcal{M}$. The mode number is determined in (6) using the optimal precoder for each mode. Thus the receiver would send both the chosen mode number and the optimal precoder given that mode back to the transmitter.

5 Numerical Results and Discussions

We consider a MIMO communication system equipped with four transmit and two receive antennas. The vector symbol error rate (VSER) of the supermode transmission is addressed for the fair comparison with MM-MIMO and MM-STBC. The overall data-rate $R$ is fixed at 4 bps/Hz. The set of available modes is $\mathcal{M} = \{M_M \cup M_S\}$ with $M_M = \{1, 2\}$ and $M_S = \{2, 4\}$. Consequently, the corresponding constellations are 16QAM and 4QAM.

In fig.2 two feedback bits are assumed to be available. We notice that the supermode transmission achieves about 0.5dB and 1dB at the error rate $10^{-2}$, compared to MM-MIMO with UB and MM-STBC with UB, respectively. At
approximately SNR = 10dB, the performance of the supermode approaches that of the MM-STBC. That is because the MM-STBC always outperforms MM-MIMO when SNR is high, and is selected for transmitting signals in the supermode transmission.

6 Conclusion

In this paper, we proposed a supermode transmission scheme with limited feedback for MIMO-based systems. It provides better performance than MM-MIMO and MM-STBC with the same feedback bits, in particular, at low SNR regime. However, the solution of the feedback bits allocating problem is achieved via exhausted search. A more efficient distribution method is thus required.

References