Research Letter

On the MMSE Criterion for Space-Time Coded Signaling in the Presence of Unknown Interference

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The primary goal of this letter is to provide comparative assessments to the two cases where different criteria are used in joint over antenna minimum mean squared error (JA-MMSE) spatial filtering for space-time coded systems in the presence of unknown interference. It is shown that additional constraints to preserve the space-time coded signal structure in JA-MMSE spatial filtering place floor in bit error rate (BER) performance, while imposing no additional constraint places no error floor.

1. INTRODUCTION

Space-time (ST) coding has been intensively studied [1] because of its potential in achieving diversity and coding gains. In ST-coded systems, receiver has to be equipped with multiple receive antennas if unknown interference (UKIF) components have to be suppressed while detecting the desired ST-coded signals. To preserve the ST-coded signal structure while suppressing the interference, joint-over-antenna (JA) detection techniques based on the minimum mean-squared error (MMSE) criterion have been introduced for channels without frequency selectivity in [2] and with frequency selectivity in [3, 4]. Two different criteria for MMSE spatial filtering have been proposed for this purpose; one is to minimize the mean-squared error (MSE) between the spatial filter output and the *actually* received composite signal comprised of the *desired* ST-coded signals [2, 4], which is referred to as H-Criterion in this letter, where H represents the actual channel matrix; the other is to minimize the MSE also between the two terms but the desired signal term should not necessarily be *actually* received composite signal [3], referred to as A-Criterion, where A represents an equivalent channel matrix; they were presented independently in different publications.

In fact, one of the authors of this letter used those criteria in different publications for iterative (turbo) equalization of intersymbol interference in broadband single-carrier signaling. The primary focus points of those papers are *not* the performance comparison between the two criteria, and relatively strong channel code is assumed in [4]. Results of bit-error rate (BER) simulations presented in those publications show that the BER curve decays match the asymptotic equivalent diversity order supported by the theory. This fact may have hidden the more fundamental issue which is related to the choice of the MMSE criterion than what are provided in the papers themselves.

The motivation of this letter is to reveal the performance difference between the two criteria, for which we eliminate all auxiliary techniques such as channel coding and iterative detection, and stay on a very simple system model needed only for fair comparison; we only assume frequency-flat fading. It is shown that with the A-Criteria, the number of the receive antennas, required to suppress UKIF while preserving the ST-coded signal structure at the spatial filter output, is $1 + $ UKIF number. If this condition is satisfied, A-Criterion places no error floor. On the contrary, the H-Criterion places error floor if the receiver does not have enough antennas. The reason for this is because the H-Criterion imposes additional constraints to preserve the ST-coded signal structure at the spatial filter output; and to satisfy the constraints the available degrees of freedom have to be wasted.

This letter is organized as follows. Section 2 introduces the system model assumed in this letter. Section 3 proposes
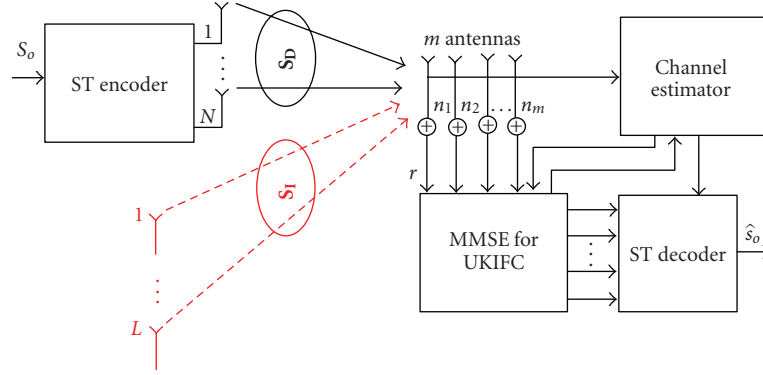
FIGURE 1: System structure with $N + L$ antennas, N desired antennas, L unknown cochannel interference, and one common destination.
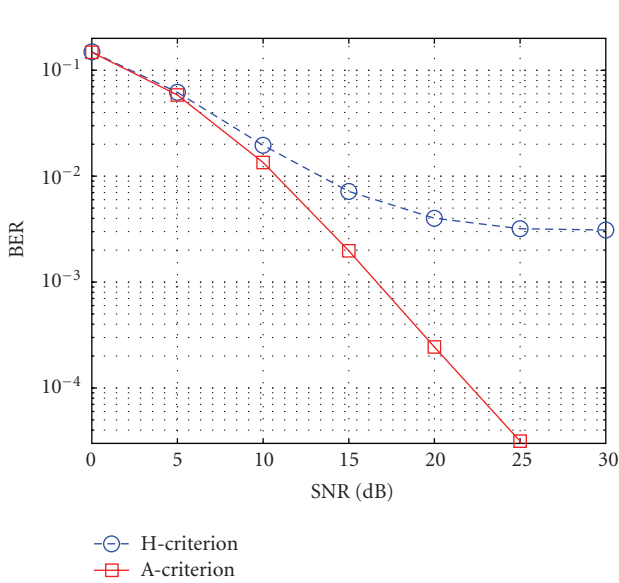

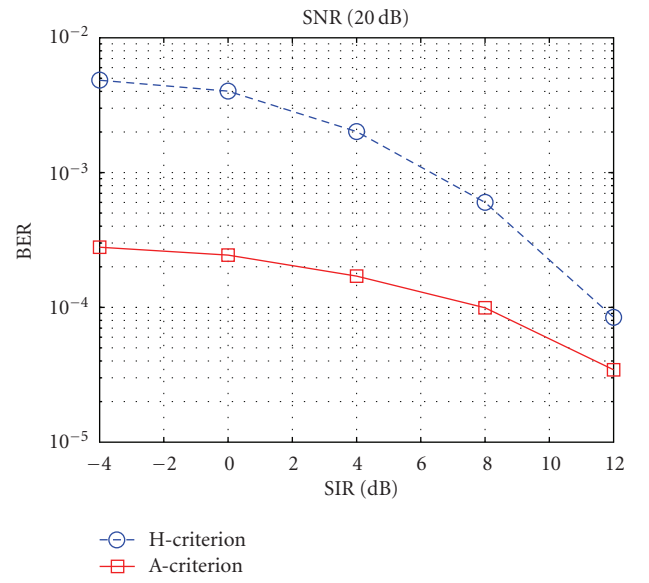FIGURE 2: BER performance of JA-MMSE with A- and H-Criterion (SIR = 0 dB).

FIGURE 3: BER performance of JA-MMSE with A- and H-Criterion (SNR = 20 dB).

a JA signal detection algorithm based on two MMSE criteria that detect multiple antennas' composite signal while suppressing UKIF. Section 4 presents numerical results using an example scenario. Finally, Section 5 concludes the paper.

Notation

Throughout this paper, matrices and vectors are indicated by bold face while the elements in the matrices/vectors are indicated by lower case. $(\cdot)^T$, $(\cdot)^H$, and $E\{(\cdot)\}$ denote transpose, conjugate transpose, and expectation of $(\cdot)$, respectively.

2. SYSTEM MODEL

Consider a wireless communication system presented in Figure 1. There is one desired user transmitting his ST-coded signal using N transmit antennas to the receiver. The receiver has a full knowledge about the ST-coded signal structure. There are L UKIF components also arriving at the receiver,

but it has no knowledge about the coding method used by the L UKIFs. The receiver has m ($m \geq L + 1$) antennas.

The channel is suffering from frequency flat Rayleigh fading. It is assumed that the fading variation stays the same during each transmission (= block fading). The received signal vector $\mathbf{r}$ can be expressed as

$$\mathbf{r} = \underbrace{\mathbf{HS_D}}_{\text{desired}} + \underbrace{\mathbf{GS_I}}_{\text{UKIF}} + \underbrace{\mathbf{n}}_{\text{noise}}$$
$$= [\mathbf{H}\,\mathbf{G}][\mathbf{S_D}\,\mathbf{S_I}]^T + \mathbf{n} = \mathcal{H}\mathcal{S} + \mathbf{n}, \quad (1)$$

where $\mathbf{S}_D$ is the transmitted signal vector corresponding to the desired user's information, expressed in the ST-coded format [5]. $\mathbf{S_I}$ is the interference signal vector, and $\mathbf{n}$ is the additive white Gaussian noise vector with power σ^2. $\mathbf{H}$ and $\mathbf{G}$ are the desired user's and UKIF's channel matrices, respectively. The dimensionality of those vectors and matrices is properly defined according to the system model described above. It is assumed that the transmission power totaling

over all desired antennas is fixed to a certain value, which is a parameter specifying signal-to-interference power ratio (SIR).

3. JA-MMSE CRITERIA

The key idea behind JA-MMSE technique is that UKIFs are suppressed, while preserving the space-time signal structure of ST code. Two JA-MMSE criteria, A-Criterion [3] and H-Criterion [2, 4], were presented independently in different literatures. As described in Section 1, the primary purpose of this letter is to provide comparative assessments to JA-MMSE using those different criteria.

3.1. JA-MMSE A-criterion

The JA-MMSE detector determines the spatial filtering weights $\mathcal{W}_{\mathcal{A}}$ and $\mathcal{A}$ according to error cost function $e_{\mathcal{A}}$:

$$\arg \min_{\mathcal{W}_{\mathcal{A}}, \mathcal{A}} E\{\|e_{\mathcal{A}}\|^2\} = \arg \min_{\mathcal{W}_{\mathcal{A}}, \mathcal{A}} E\{\|\mathcal{W}_{\mathcal{A}}^H \mathbf{r} - \mathcal{A}^H \mathbf{S}_D\|^2\}, \quad (2)$$

where matrices $\mathcal{W}_{\mathcal{A}}$ and $\mathcal{A}$ are subjected to an appropriate constraint in order to avoid the trivial solution $[\mathcal{W}_{\mathcal{A}}, \mathcal{A}] = [\mathbf{0}, \mathbf{0}]$ [3].

Following the mathematical derivation process shown in [3], we can easily obtain the ith, $1 \leq i \leq m$, column of the optimal solution of matrix pair $\mathcal{W}_{\mathcal{A}}$ and $\mathcal{A}$, as

$$\mathbf{w}_i = \left(\mathbf{M} - \sum_{j=1, j \neq i}^{N} \mathbf{h}_j \mathbf{h}_j^H\right)^{-1} \mathbf{h}_i, \quad (3)$$

$$\mathbf{a}_i = [\mathbf{h}_1^H \mathbf{w}_i, \ldots, \mathbf{h}_{i-1}^H \mathbf{w}_i 1, \mathbf{h}_{i+1}^H \mathbf{w}_i, \ldots, \mathbf{h}_N^H \mathbf{w}_i]^T,$$

respectively, where

$$\mathbf{M} = \mathcal{H}\mathcal{H}^H + \sigma^2 \mathbf{I}, \quad (4)$$

and $\mathbf{h}_i$ denotes the ith column of channel matrix $\mathbf{H}$.

3.2. JA-MMSE H-Criterion

Instead of using $\mathcal{A}\mathbf{S}_D$ in (2), the the received composite signal comprised of the desired signal components alone, $\mathbf{HS}_D$, is used as the reference signal for the JA-MMSE detection with the H-Criterion. The cost function e_H can then be given as

$$\arg \min_{\mathcal{W}_H} E\{\|e_H\|^2\} = \arg \min_{\mathcal{W}_H} E\{\|\mathcal{W}_H^H \mathbf{r} - \mathbf{HS}_D\|^2\}. \quad (5)$$

The optimal spatial filtering weight vector $\mathcal{W}_H$ is given by [2, 4]

$$\mathcal{W}_H^H = \mathbf{HH}^H \mathbf{M}^{-1}. \quad (6)$$

4. NUMERICAL SIMULATION

We use a very simple example scenario to assess the system performance. There are two antennas with the desired user, and one UKIF. The receiver has two antennas. QPSK modulation is assumed in the simulation. We evaluate average BER as a performance measure.

Alamouti encoding [5] is performed over the two desired antennas. The signals transmitted from the two transmit antennas are combined, according to the decoding rule for the Alamouti code, and decisions are made, symbol by symbol. The BER curves with the A- and H-Criterion are shown in Figure 2 for SIR = 0 dB. It is observed in Figure 2 that a floor is placed to the BER curve with the H-Criterion when SNR value becomes large while the curve with the A-Criterion tends to have a constant slope. The reason for this is because the H-Criterion imposes additional constraints to preserve the ST-coded signal structure at the spatial filter output, and to satisfy the requirement for the constraints, the available degrees of freedom have to be wasted. If the receiver does not have enough degrees of freedom, error floor is placed. On the contrary, with the A-Criterion, no additional constraints are imposed, resulting in no error floor placed.

Figure 3 shows for average received SNR = 20 dB, the BER performances with the H- and A-Criterion versus SIR. It is found from this figure that the BER gap between A- and H-Criterion becomes smaller with increased SIR.

5. CONCLUSIONS

JA-MMSE spatial filtering followed by ST-combiner can preserve the structure of ST code while suppressing UKIFs. It is found from numerical results that the A-Criterion can provide better BER performance than the H-Criterion where error floor placed when the destination has no enough DOF. Furthermore, JA-MMSE with A-Criterion minimizes the number of required antennas at the destination to $L + 1$ while suppressing UKIFs, because with the A-Criterion, detecting the received *composite single* signal comprised of the N desired signals imposes decrease in degree of freedom only by one.

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