Antenna Reliability Ordering Technique for Jointly Detected MIMO Systems

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Abstract

In this paper, we propose a novel ordering of transmit antennas in reliability for unequal error protection (UEP) in spatially multiplexed (SM) multiple-input multiple-output (MIMO) systems with joint detection at the receiver. The proposed ordering technique better meets the UEP requirement than the conventional ordering with a lower computational complexity.

I. Introduction

Multimedia streaming over wireless channels is a challenging task due to the unstable channel environment, limited spectral bandwidth, limited transmit power, and required high data rate [1]. Unequal error protection (UEP) is known to improve multimedia quality under these limitations. Especially, multiple-input multiple-output (MIMO) based UEP techniques have received recent interest due to their ability to provide further improvement of multimedia quality.

In this paper, we develop a novel UEP that can be applied to joint ML detection receivers when spatial multiplexing (SM) MIMO system is used. We first divide the logarithmic likelihood ratio (LLR) of each symbol into two components. Based on our analysis of the two components, we propose the use of post- equalization SNR as a criterion for reliability of transmit antennas in jointly detected MIMO systems.

II. Previous Antenna Reliability Ordering Technique in SM MIMO System

Assuming $N_t$ transmit and $N_r$ receive antennas, the relationship between the transmitted signals and the received signals is described as

$$
y = Hx + z
$$

(1)

where $x$ is the transmitted signal vector, $y$ is the received signal vector, $H$ is the $N_r \times N_t$ complex channel gain matrix, and $z$ is the additive complex white Gaussian noise with zero mean and variance $\sigma_z^2$.

A. Antenna reliability ordering by constructing virtually decoupled SISO system

Assuming $N_r \geq N_t$, zero-forcing (ZF) equalization can be applied to (1) for symbol estimation, offering the following post- equalization SNRs

$$
SNR_{i}^{\text{post}} = \frac{1/N_t}{[\sigma_z(Hx)^* + \sigma_z]^2}, i = 1, 2, \ldots, N_t
$$

(2)

The differentiated post- equalization SNRs of the transmitted symbols can be used as indicators of the reliabilities of the corresponding antennas, enabling UEP. However, as well known, ZF equalization incurs detrimental noise enhancement.

Another method to build multiple virtual SISO system out of a MIMO system is by the use of singular value decomposition (SVD)- based pre-coding. The effective SNR of each virtual SISO channel is expressed using the corresponding singular value, offering a reliability criterion for UEP. However, full CSI is required at the transmitter side.

B. Antenna reliability ordering for jointly detected MIMO systems

MIMO systems with joint signal detection at the receiver do not require the feedback of full CSI to the transmitter and at the same time, noise is not enhanced at the receiver. However, antenna reliability ordering for jointly detected MIMO systems is challenging because all signals are jointly detected. To our best knowledge, the antenna reliability ordering for jointly detected MIMO systems was first addressed in [2]. When reordered channel matrix

$$
H_{QR-LRL} = \begin{bmatrix} b_{h_{n_1}} & \ldots & b_{h_{n_M}} \end{bmatrix}
$$

is represented as

$$
H_{QR-LRL} = Q_{QR-LRL}R_{QR-LRL} \text{ with unitary matrix } Q_{QR-LRL}
$$

and upper triangular matrix $R_{QR-LRL}$, the equivalent reordered system of (1) is considered as

$$
\hat{y} = R_{QR-LRL}x_{QR-LRL} + \hat{z}
$$

(3)

where $\hat{y} = Q_{QR-LRL}^H y, \hat{z} = Q_{QR-LRL}^Hz$. MRL$_p$ means the $p$-th most reliable layer and LRL means least reliable layer. The QR-LRL signal detection generates a set of candidate vectors $S_{QR-LRL}$ as described in Table I.

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>Generation of the candidate vector set of QR-LRL joint detection</td>
</tr>
<tr>
<td>$S_{QR-LRL} \leftarrow {} \text{ initialization}$</td>
</tr>
<tr>
<td>For $m = 1 :</td>
</tr>
<tr>
<td>$\hat{x}_n \leftarrow \Omega(n)$</td>
</tr>
<tr>
<td>For $n = 1 : N_t - 1$</td>
</tr>
<tr>
<td>$\hat{x}<em>{N_t-n} \leftarrow D [(\sum</em>{i=n}^{N_t-1} r_{N_t-n,i} \hat{x}_i)] / \sigma_z$</td>
</tr>
<tr>
<td>End</td>
</tr>
<tr>
<td>$\hat{x} = [\hat{x}_1 \hat{x}<em>2 \ldots \hat{x}</em>{N_t}]^T$</td>
</tr>
<tr>
<td>$S_{QR-LRL} \leftarrow S_{QR-LRL} \cup {\hat{x}}$</td>
</tr>
<tr>
<td>End</td>
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</tbody>
</table>
The most likely symbol vector in the candidate set \( \hat{x}_{QR-LRL} \) is found as
\[
\hat{x}_{QR-LRL} = \arg \min_{x \in \mathbb{C}^{N_t}} \| y - R_{QR-LRL} x \|^2.
\]
The entries of QR–LRL jointly detected symbol vector \( \hat{x}_{QR-LRL} \) are ordered in terms of reliability as
\[
\hat{x}_{(p)} = \hat{x}_{(N_t)}, \quad p = 1, 2, \ldots, N_t.
\]

The ordering technique for jointly detected MIMO systems requires \( N_t \) pseudo inversions, which is computationally expensive.

III. Proposed Reliability Ordering of Antennas in Jointly Detected MIMO Systems

The LLR can be described as (5) using reordered channel matrix \( \mathbf{H} = \mathbf{Q} \mathbf{R} \) with \( \mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2, \ldots, \mathbf{h}_{N_t}] \).

\[
\text{LLR}(\hat{x}_{iML}) = \left\| y_{i} - \mathbf{R} [\hat{x}_{iML}] \right\|^2 - \left\| \tilde{y}_i - \mathbf{R} [\hat{x}_{iML}] \right\|^2
\]

where the \( i \)-th elements of \( \hat{x}_{iML} \) and \( \hat{x}_{iML} \) are dropped to be \( \hat{x}_{iML} \) and \( \hat{x}_{iML} \), respectively. We divided the LLR (5) into two components, collaborative component and individual component as

\[
\text{LLR}(\hat{x}_{iML}) = \text{ColT}(\hat{x}_{iML}) + \text{IndT}(\hat{x}_{iML})
\]

\[
\text{ColT}(\hat{x}_i) = \left\| \tilde{y}_i - \mathbf{R} [\hat{x}_{iML}] \right\|^2 - \left\| y_i - \mathbf{R} [\hat{x}_{iML}] \right\|^2
\]

\[
\text{IndT}(\hat{x}_i) = \left\| y_i - \mathbf{R} [\hat{x}_{iML}] \right\|^2 - \left\| y_i - \mathbf{R} [\hat{x}_{iML}] \right\|^2
\]

with \( \hat{x}_i = [\hat{x}_i \hat{x}_i \cdots \hat{x}_{i-1} \hat{x}_{i+1} \cdots \hat{x}_{N_t}]^T \). Using these two LLR components, we can derive the following statistical relationships.

\[
E[\text{IndT}_m(\hat{x}_{mML})] > E[\text{IndT}_o(\hat{x}_{oML})] \text{ if } \text{SNR}_{\text{post}}^m > \text{SNR}_{\text{post}}^o
\]

\[
E[\text{ColT}_m(\hat{x}_{mML})] > E[\text{ColT}_o(\hat{x}_{oML})] \text{ if } \text{SNR}_{\text{post}}^m > \text{SNR}_{\text{post}}^o
\]

From (9) and (10), we can derive the following statistical relationship between LLR and \( \text{SNR}_{\text{post}}^m \).s

\[
E[\text{LLR}(\hat{x}_{ML})] > E[\text{LLR}(\hat{x}_{ML})] \text{ if } \text{SNR}_{\text{post}}^m > \text{SNR}_{\text{post}}^o
\]

Thus multi-antenna UEP can be implemented using (11) if the order of \( \text{SNR}_{\text{post}}^m, i = 1, 2, \ldots, N_t \) is available at the transmitter of SM MIMO systems with ML detection at the receiver. Equation (11) means that the ZF-based reliability ordering criterion can also be used for the ML-based reliability ordering.

Let \( p \) denotes the antenna index that corresponds to the \( p \)-th largest \( \text{SNR}_{\text{post}}^m \), then \( \hat{x}_{(p)} \) is the \( p \)-th most reliable symbol according to (11). If we have multiple segmented data with different priorities from a perspective such as peak-SNR (PSNR) of video, the highest priority data segment can be transmitted from the (1)-st transmit antenna and the second highest priority data can be transmitted from the (2)-nd transmit antenna and so on when \( \text{SNR}_{\text{post}}^m < \cdots < \text{SNR}_{\text{post}}^2 < \text{SNR}_{\text{post}}^1 \). Furthermore, according to (2), only a single matrix inversion is required for the reliability ordering of antennas in the proposed schemes.

IV. Simulations

Fig. 1 shows the \( N_t = 4 \) differentiated symbol error rates (SERs) of sub-optimal joint QR–LRL detection when a 4-QAM is assumed. The curves with black circle symbols (prev(\( p \)) in the legends) denotes the SERs according to previous reliability ordering technique in (5), and the curves without symbols (prop(\( p \)) in the legends) are the SERs of the proposed ordering based on (12). The SERs are differentiated in accordance with both reliability ordering, enabling UEP data transmission in the SM MIMO systems. We can observe that the proposed method means that more controllability over \( N_t \) virtual wireless channels is offered to the higher layers of communication systems, enabling more flexible UEP.

V. Conclusion

In this paper, we proposed the use of the ZF-based antenna reliability assessment method for joint-detection-based systems. Simulations showed the better differentiated error performance by the proposed ordering than the previous rather complicated ordering.

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REFERENCE
