Transmit Antenna Selection Strategies for Cooperative MIMO AF Relay Networks

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Introduction
The performance of cooperative relay networks can be improved by integrating multiple-input multiple-output (MIMO) technology and transmit antenna selection (TAS) [1, 2]. Although TAS is a suboptimal beamforming technique, it substantially reduces the complexity and the power requirements of the transmitter. TAS is more robust against channel estimation errors and time variations of the channels than other beamforming techniques, for example, transmit diversity.

Motivation: The current TAS strategies for general MIMO relay networks [1, 2] lack a suitable performance analysis framework. Thus, a robustness performance metric is needed to evaluate the performance of TAS strategies for MIMO AF relaying.

Objective: Develop a performance analysis framework for TAS strategies for MIMO AF relaying.

System Model and Problem Formulation
System model: Consider a dual-hop AF relay network with MIMO-enabled source (S), relay (R) and destination (D) having NR, NS, and ND antennas.

The end-to-end SNR is given by

\[ \gamma_{\text{ej}} = \gamma_{\text{SD}} + \frac{\gamma_{\text{JR}}}{\gamma_{\text{RD}}} \]

Three TAS strategies are treated.
1. TASopt [1]: \( I, K = \arg \max_{1 \leq i \leq N_R} \left( \gamma_{\text{SD}} \right) \)
2. TASsub-opt [2]: \( I = \arg \max_{1 \leq i \leq N_R} \left( \gamma_{\text{SD}} \right) \) and \( K = \arg \max_{1 \leq k \leq N_D} \left( \gamma_{\text{RD}} \right) \)
3. TASsub-opt [2]: \( I = \arg \max_{1 \leq i \leq N_R} \left( \gamma_{\text{SD}} \right) \) and \( K = \arg \max_{1 \leq k \leq N_D} \left( \gamma_{\text{RD}} \right) \)

Remark I: When the direct channel is unavailable, TASopt simplifies to \( I = \arg \max_{1 \leq i \leq N_R} \left( \gamma_{\text{SR}} \right) \) and \( K = \arg \max_{1 \leq k \leq N_D} \left( \gamma_{\text{RD}} \right) \).

Performance Analysis
The following performance metrics are derived in closed-form:

1. Tight upper bounds for the outage probability and the average SER of the TASopt.
2. Accurate approximations for the outage probability and the average SER of the TASsub-opt and TASsub-opt2.
3. The asymptotic outage probability and the average SER at high SNRs, diversity order and array gain.

For example, the asymptotic average SER of the three strategies are given by

\[ P_e = \frac{\Omega \alpha^{-2} \gamma_{\text{SR}} + \frac{1}{2}}{\sqrt{\Gamma(\theta)^{-1}}} + \phi \left( \frac{1}{2} \right) \cdot \frac{1}{\Gamma(\theta)^{-1}} \]

The diversity orders are given by

\[ \gamma_{\text{SR}} = m_0N_SD + N_D \cdot \min \left( m_1N_R, m_2N_D \right) \]

Simultaneous selection strategy
\[ \gamma_{\text{SR}} = m_0N_SD + N_D \cdot \min \left( m_1N_R, m_2N_D \right) \] and \( \gamma_{\text{RD}} = m_0N_RD + \min \left( m_1N_R, m_2N_D \right) \)

Remark II: When the direct path is unavailable, the diversity order of TASopt is given by \( \gamma_{\text{SR}}^\text{TASopt} = N_D \cdot \min \left( m_1N_R, m_2N_D \right) \).

Remark III: When the direct path is unavailable, the diversity order of TASopt under outdated CSI is given by \( \gamma_{\text{SR}}^\text{TASopt} = \min \left( m_1N_R, m_2N_D \right) \).

The average bit error rate of BPSK:

\[ P_e = \frac{\Omega \alpha^{-2} \gamma_{\text{SR}} + \frac{1}{2}}{\sqrt{\Gamma(\theta)^{-1}}} + \phi \left( \frac{1}{2} \right) \cdot \frac{1}{\Gamma(\theta)^{-1}} \]

Impact of Feedback Delays
Channels are modeled as \( h_i(t) \) = \( \rho h_i(t - t_i) \) + \( e_i(t) \), where \( \rho_i \) is the normalized correlation coefficients between \( h_i(t) \) and \( h_i(t - t_i) \). For Clarke’s fading spectrum, \( \rho_i = 0(\theta_1 \cap \theta_2) \), where \( \theta_1 \) is the Doppler fading bandwidth. Further, \( e_i(t) \) is the error matrix, incurred by feedback delay, having mean zero and variance \((1 - \rho^2) \) Gaussian entries.

For example, the asymptotic average SER of TASopt with feedback delays is given by

\[ P_e = \frac{\Omega \alpha^{-2} \gamma_{\text{SR}} + \frac{1}{2}}{\sqrt{\Gamma(\theta)^{-1}}} + \phi \left( \frac{1}{2} \right) \cdot \frac{1}{\Gamma(\theta)^{-1}} \]

For all three TAS strategies, the diversity order is given by \( \gamma_{\text{SR}} = m_0N_SD + \min \left( m_1N_R, m_2N_D \right) \).

Conclusion
1. TASopt always performs better than TASsub-opt and TASsup-opt for the given antenna set-ups at the expense of higher implementation complexity.
2. TASsub-opt1 performs very close to TASopt in terms of outage when D is equipped with a single-antenna. TASsub-opt2 is thus a better choice than TASopt for networks with \( N_D = 1 \).
3. The choice between TASsub-opt1 and TASsub-opt2 depends upon the availability of stronger S \( \rightarrow \) D or S \( \rightarrow \) R channels, and the suboptimal TAS strategies perform closely to the optimal TAS strategy, while retaining significant implementation simplicity than the optimal TAS.
4. Whenever S is equipped with a single-antenna, the performance of the three TAS strategies is identical. This insight thus shows that any of the three strategies can effectively be used for S \( \rightarrow \) R \( \rightarrow \) D up-link, where S is usually a mobile device equipped with a single-antenna due to power and space constraints.
5. Similarly, TASsub-opt3 can be used instead of TASopt for the D \( \rightarrow \) S \( \rightarrow \) S down-link as both of them provide the same diversity order whenever \( N_D = 1 \).

References