Transmit Antenna Selection Strategies for Cooperative MIMO AF Relay Networks

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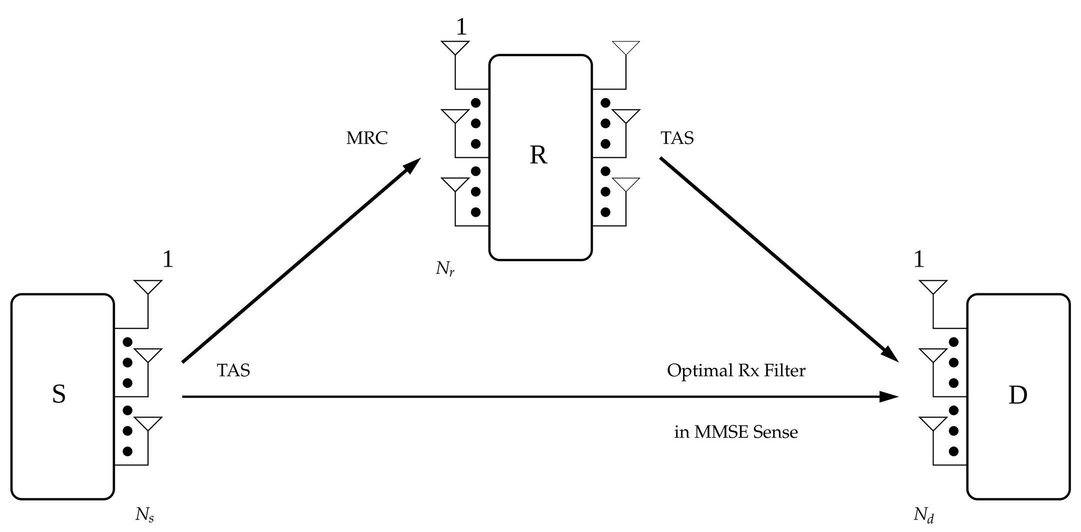
Introduction

- 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.
- **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 N_s, N_r and N_d antennas.



- **The end-to-end SNR is given by**

$$\gamma_{eq}^{(i,k)} = \gamma_{SD}^{(i)} + \frac{\gamma_{SR}^{(i)}\gamma_{RD}^{(k)}}{\gamma_{SR}^{(i)} + \gamma_{RD}^{(k)}}.$$

- **Three TAS strategies are treated.**

1. TAS_{opt} [1] : $(I, K) = \underset{1\le i\le N_s, 1\le k\le N_r}{\text{argmax}} \left(\gamma_{\text{eq}}^{(i,k)}\right)$.
2. $\text{TAS}_{\text{sub-opt}_1}$ [2] : $I = \underset{1\le i\le N_s}{\text{argmax}} \left(\gamma_{SD}^{(i)}\right)$ and $K = \underset{1\le k\le N_r}{\text{argmax}} \left(\gamma_{RD}^{(k)}\right)$.
3. $\text{TAS}_{\text{sub-opt}_2}$ [2] : $I = \underset{1\le i\le N_s}{\text{argmax}} \left(\gamma_{SR}^{(i)}\right)$ and $K = \underset{1\le k\le N_r}{\text{argmax}} \left(\gamma_{RD}^{(k)}\right)$.

- **Remark I:** When the direct channel is unavailable, TAS_{opt} simplifies to $I = \underset{1\le i\le N_s}{\text{argmax}} \left(\gamma_{SR}^{(i)}\right)$ and $K = \underset{1\le k\le N_r}{\text{argmax}} \left(\gamma_{RD}^{(k)}\right)$.

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 TAS_{opt}.
2. Accurate approximations for the outage probability and the average SER of the $\text{TAS}_{\text{sub-opt}_1}$ and $\text{TAS}_{\text{sub-opt}_2}$.
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**

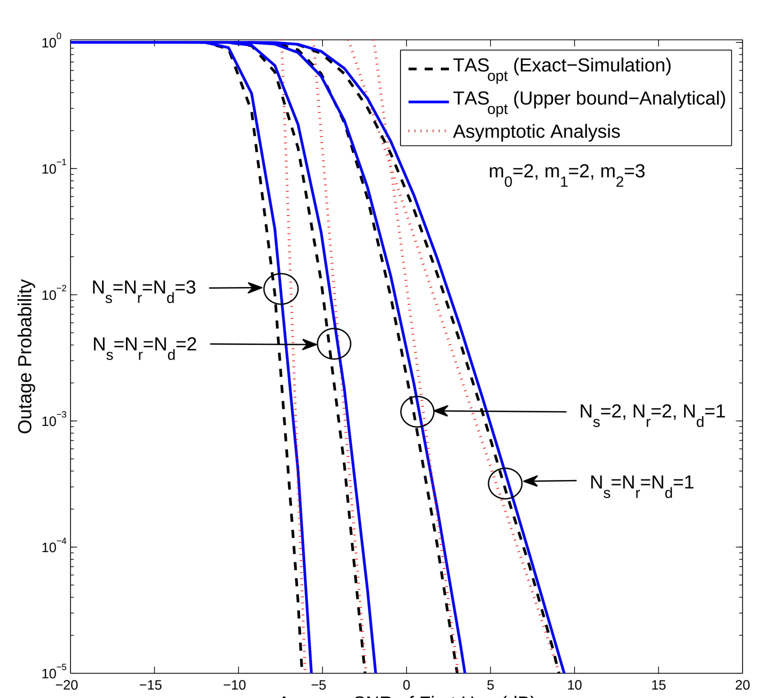
$$\bar{P}_e^{\infty} = \frac{\Omega\alpha 2^{G_d-1}\Gamma\left(G_d+\frac{1}{2}\right)}{\sqrt{\pi}(\varphi\bar{\gamma})^{G_d}} + o\left(\bar{\gamma}^{-(G_d+1)}\right).$$

The diversity orders are given by

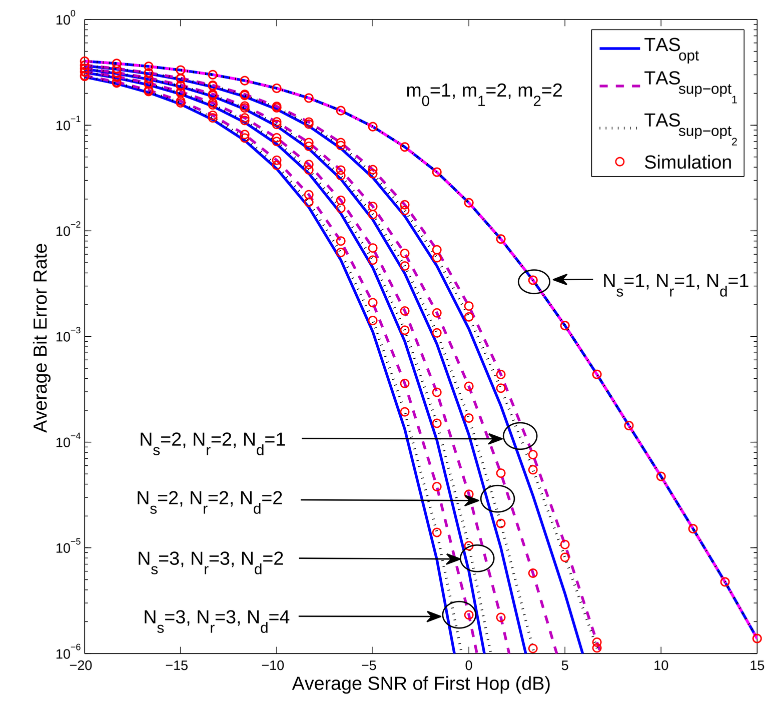
$$G_d^{\text{TAS}_{\text{opt}}} = m_0 N_s N_d + N_r \min\left(m_1 N_s, m_2 N_d\right),$$
$$G_d^{\text{TAS}_{\text{sub-opt}_1}} = m_0 N_s N_d + N_r \min\left(m_1, m_2 N_d\right) \quad \text{and}$$
$$G_d^{\text{TAS}_{\text{sub-opt}_2}} = m_0 N_d + N_r \min\left(m_1 N_s, m_2 N_d\right).$$

Simulation Results

- **The outage probability bounds of TAS_{opt}:**



- **The average bit error rate of BPSK:**



- **Remark II:** When the direct path is unavailable, the diversity order of TAS_{opt} is given by $G_d^{\text{TAS}_{\text{opt}}} = N_r \min\left(m_1 N_s, m_2 N_d\right)$.
- In order to obtain direct system-deign insights, the diversity orders of the three TAS strategies can be summarized as follows:

TAS Strategy	Diversity Order		
	$N_s=1$	$N_d=1$	$N_s=N_r=N_d=N$
TAS_{opt}	$m(N_r+N_d)$	$m(N_s+N_r)$	$2mN^2$
$\text{TAS}_{\text{sub-opt}_1}$	$m(N_r+N_d)$	$m(N_s+N_r)$	$mN(N+1)$
$\text{TAS}_{\text{sub-opt}_2}$	$m(N_r+N_d)$	$m(N_r+1)$	$mN(N+1)$

Impact of Feedback Delays

Channels are modeled as $\mathbf{H}_l(t)|_{l=0}^{2} = \rho_l \mathbf{H}_l(t-\tau_l) + \mathbf{E}_{d,l}$, where ρ_l is the normalized correlation coefficients between $h_l^{i,j}(t)$ and $h_l^{i,j}(t-\tau_l)$. For Clarke's fading spectrum, $\rho_l = \mathcal{J}_0(2\pi f_l \tau_l)$, where f_l is the Doppler fading bandwidth. Further, $\mathbf{E}_{d,l}$ is the error matrix, incurred by feedback delay, having mean zero and variance $(1-\rho_l^2)$ Gaussian entries.

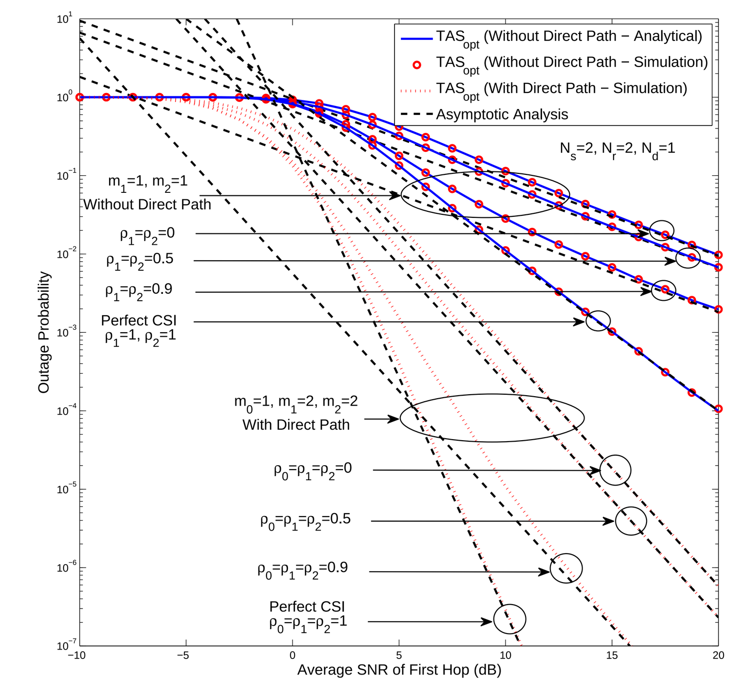
- For example, the asymptotic average SER of TAS_{opt} with feedback delays is given by

$$\bar{P}_e^{\infty} = \frac{\hat{\Omega}\alpha 2^{\hat{G}_d-1}\Gamma\left(\hat{G}_d+\frac{1}{2}\right)}{\sqrt{\pi}(\varphi\bar{\gamma})^{\hat{G}_d}} + o\left(\bar{\gamma}^{-(\hat{G}_d+1)}\right).$$

For all three TAS strategies, the diversity order is given by $\hat{G}_d = m_0 N_d + \min\left(m_1 N_r, m_2 N_d\right)$.

- **Remark III:** When the direct path is unavailable, the diversity order of TAS_{opt} under outdated CSI is given by $\hat{G}_d^{\text{TAS}_{\text{opt}}} = \min\left(m_1 N_r, m_2 N_d\right)$.

- **Impact of feedback delays on outage probability:**



Conclusion

1. TAS_{opt} always performs better than $\text{TAS}_{\text{sub-opt}_1}$ and $\text{TAS}_{\text{sub-opt}_2}$ for the given antenna set-ups at the expense of higher implementation complexity.
2. $\text{TAS}_{\text{sub-opt}_1}$ performs very close to TAS_{opt} in terms of outage when D is equipped with a single-antenna. $\text{TAS}_{\text{sub-opt}_1}$ is thus a better choice than TAS_{opt} for networks with $N_d = 1$.
3. The choice between $\text{TAS}_{\text{sub-opt}_1}$ and $\text{TAS}_{\text{sub-opt}_2}$ depends upon the availability of stronger $S \to D$ or $S \to R$ 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 $S \to R \to D$ up-link, where S is usually a mobile device equipped with a single-antenna due to power and space constraints.
5. Similarly, $\text{TAS}_{\text{sub-opt}_1}$ can be used instead of TAS_{opt} for the $D \to R \to S$ down-link as both of them provide the same diversity order whenever $N_d = 1$.

References

[1] S. Peters and R. W. Heath, "Nonregenerative MIMO relaying with optimal transmit antenna selection," *IEEE Signal Process. Lett.*, vol. 15, pp. 421–424, 2008.

[2] L. Cao, X. Zhang, Y. Wang, and D. Yang, "Transmit antenna selection strategy in amplify-and-forward MIMO relaying," in *Wireless Communications and Networking Conference, IEEE*, Budapest, Apr. 2009.