Spatial Modulation vs Transmit Antenna Selection

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Overview

Conventional MIMO

- Multiple RF chains, hence, more hardware, and cost involved.
- Presence of ICI
- Antenna synchronization is required.
- Relatively high spectral efficient.

What is Spatial Modulation?

- A new modulation technique.
- It is open loop.
- Aided with single RF chain.
- Antenna indices also conveys information, besides the base constellation at the transmitter.

Spatial Modulation

- No ICI
- No antenna synchronization is required.
- Low cost and hardware involved.

Past Works

Most of the recent works are focused on:

- Optimal receivers
- Bit error probability
- Power allocation

but these works assumes Gaussian alphabet which is less realized in practice.

J. Jeganathan, A. Ghrayeb, and L. Szczecinski, "Spatial modulation: optimal detection and performance analysis", *IEEE Communication Letters, vol. 12, no. 8, pp. 545547, Aug. 2008*

Our Work

We focus on

- Maximizing the lower bound of mutual information for spatial modulation for Finite alphabets[1]
- Minimizing the bit error probability

Assumption: CSI is globally available.

[1] Signals drawn from constellation which are discrete and uniformly distributed.

Contd...

System model

$$y = hx_a x_d + z \tag{1}$$

- a and d denotes the antenna index, and data stream radiated from the transmitter.
- h is channel of size $1 \times N_t$ whose entities are i.i.d Rayeligh distribution $\mathcal{CN}(0, \sigma^2)$

Mutual Information

Mutual information for SM is calculated as

$$I\left(x_a, x_d; y\right) = H(y) - H\left(y | x_a, x_d\right) \tag{2}$$

For the system model described in Eq.1,

- $H(y|x_a, x_d) = H(z)$
- So, only $H(y)$ in Eq.2 needs to be maximized.

Contd...

$$H(y) = \log_2 (N_t M) - \frac{1}{N_t M} \sum_{k_1=1}^{N_t} \sum_{i_1=1}^{M} \mathbb{E}_z \left[\log_2 \left(\sum_{k_2=1}^{N_t} \sum_{i_2=1}^{M} \frac{1}{\pi \sigma^2} \right.\right.$$

$$\left.\left. \exp \left(- \frac{\| h x_a(k_1) x_d(i_1) - h x_a(k_2) x_d(i_2) + z \|^2}{\sigma^2} \right) \right) \right] \tag{3}$$

- Using Jenson's inequality, Eq.3 can be lower bounded as:

Lower bound on Mutual Information

Lower bound on MI:

$$H(y) \geq \log_2(N_t M) - \frac{1}{N_t M}\sum_{k_1=1}^{N_t}\sum_{i_1=1}^{M}\log_2\left(\sum_{k_2=1}^{N_t}\sum_{i_2=1}^{M}\frac{1}{\pi\sigma^2}\cdot\right. \tag{4}$$

$$\left.\exp\left(-\frac{\|hx_a(k_1)x_d(i_1) - hx_a(k_2)x_d(i_2)\|^2}{2\sigma^2}\right)\right)$$

Contd...

From the above expression, it is obvious that, maximizing the distance between two symbols maximizes the lower bound.

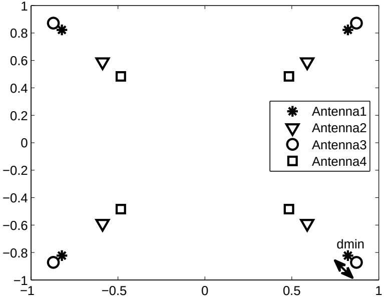


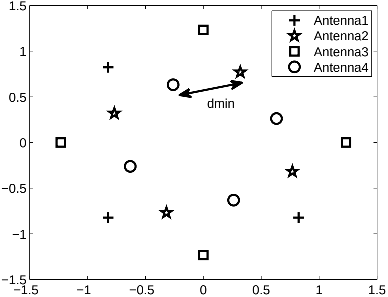
Figure: Constellation points with, $N_t = 4$

Precoder Design

We maximize the **minimum distance (dmin)** as follows:

- Channel phase compensation
- Constellation rotation

Remark: Excluding any of the above steps i.e., (employing only channel phase compensation or constellation rotation) will aggravate the performance.



Transmit Antenna Selection

- It is closed loop
- Aided with single RF
- Low cost and complexity
- No ICI
- No antenna synchronization.

Past/Recent Works

- Antenna selection with Alamouti shceme
- Secure transmission using TAS
- Antenna selection using imperfect CSIT.

Shihao Yan, Nan Yang, Robert Malaney, and Jinhong Yuan, "Transmit Antenna Selection with Alamouti Scheme in MIMO Wiretap Channels", *available at arXiv:1303.5157v1*

Transmit Antenna Selection

System Model:

$$y_{\text{tas}} = h_{\max} x_{\text{tas}} + z \tag{5}$$

Mutual Information

$$I(x_{\text{tas}}; y_{\text{tas}}) = \log_2(Q) - \frac{1}{Q} \sum_{k_1=1}^{Q} \mathbb{E}_z \left[\log_2 \left(\sum_{k_2=1}^{Q} \exp\left(- \frac{\| h_{\max}(x_{\text{tas}}(k_1) - x_{\text{tas}}(k_2)) + z \|^2 - \|z\|^2}{\sigma^2} \right) \right) \right] \tag{6}$$

SM or TAS?

We compare spatial modulation and transmit antenna selection in terms of following metrics:

- Mutual Information
- Symbol Error Rate
- Outage Probability

We also investigated the behavior of mutual information with the increase in transmit antennas.

Performance Metrics

Symbol detection

ML is the optimal receiver, and is given by

$$\hat{x} = \arg\min_{a,d} \left\| y - h x_a x_d \right\|^2 \tag{7}$$

Outage Probability

Outage is reported if rate r is less than r_t:

$$P_{\text{out}} = \mathbf{P}(r < r_t \mid \mathbf{C}) \tag{8}$$

Simulation Results

Mutual Information:

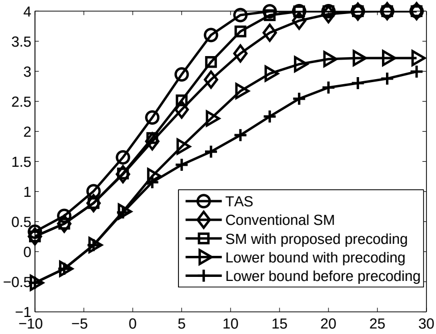


Figure: Mutual Information comparison between SM, and TAS with $N_t = 4$

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Symbol Error Rate:

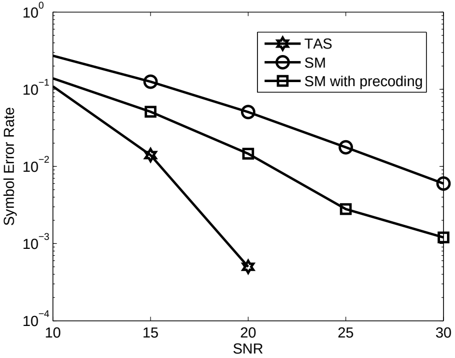

Figure: SER comparison between SM, and TAS with $N_t = 4$

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Mutual Informatiom with Number of Antennas:

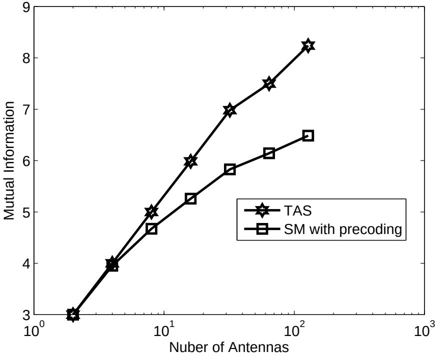

Figure: Mutual Information performance with Number of Antennas for SM, and TAS at SNR=18dB

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Outage Probability:

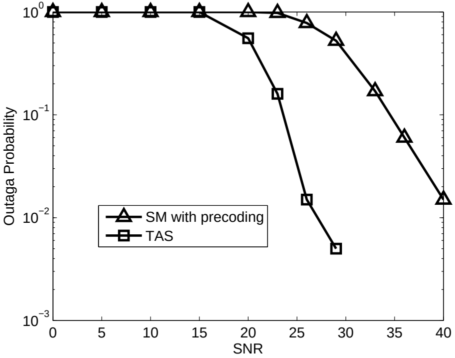

Figure: Comparison of Outage Probability between TAS and SM with $N_t = 4$

Now, what if the number of receive antennas increase? say $N_r = 8$

Will transmit antenna selection still outperform spatial modulation?

Let's see...

With Multiple Receive Antennas

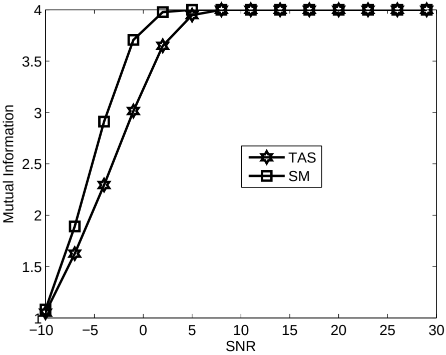

Figure: Mutual Information with 8 receive antennas

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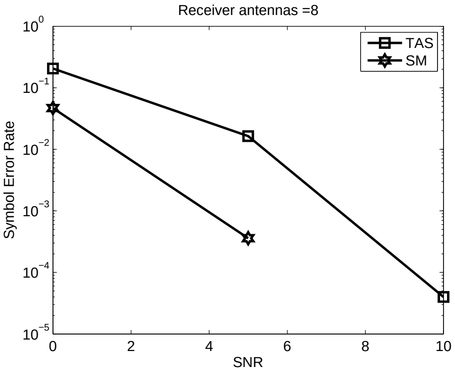

Figure: Symbol error rate with 8 receive antennas

This is something interesting! :)