# Spatial Modulation with Finite Rate Channel State Feedback

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January 25, 2014

# Overview

# MIMO

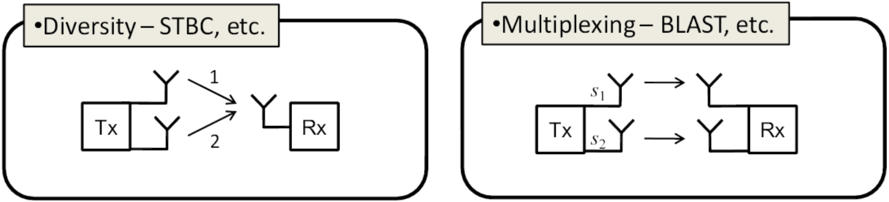


Figure: MIMO Classification

# Multiple Antenna Transmission Schemes

- V-BLAST transmission scheme
- Diversity Techniques
- Antenna Selection in MIMO

# Problems faced in multiple antenna transmission schemes

- BLAST transmission contains inherent Inter Channel Interference (ICI)
- Complex receiver required due to ICI
- STCs due to orthogonal design, can overcome these, but spectral efficiency is reduced
- When transmit antennas more than receive antennas, not possible to decode in one symbol duration

# Spatial Modulation

- Fundamentally different from above MIMO schemes
- Activates only one antenna at the transmitter at a time
- $\log_2 n_t$ bits used to select the antenna
- Extra information incorporated in the selection of antennas

# Spatial Modulation

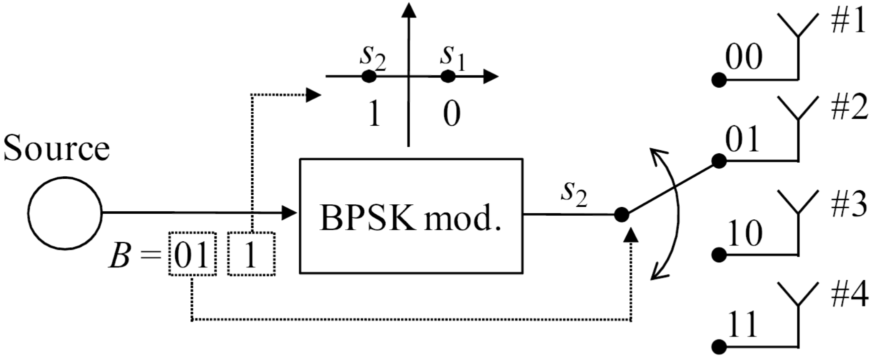


Figure: MIMO Classification

- Total spectral efficiency = $\log_2 n_t + \log_2 \mathcal{L}$
  $\mathcal{L}$ : Size of the constellation

## Advantages

- No Inter Channel Interference (ICI)
- No Inter Antenna Synchronization (IAS) required
- Spectral efficiency increased when compared to STCs

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## Disadvantage

- Spectral efficiency scales logarithmically with transmit antennas
- $n_t$ must be a power of 2

# Receiver

- ML Decoding

$$(\hat{i}, \hat{q}) = \arg\min_{i,q} ||\mathbf{y} - \mathbf{Hx}||^2 \quad (1)$$

Assume $l^{th}$ antenna is transmitting the symbol $s_l$

- Then, symbol error happens when

$$||\mathbf{y} - \mathbf{h}_l s_l||^2 > \min_{i,q;(i,q)\neq(l,s_l)} ||\mathbf{y} - \mathbf{h}_i q_i||^2 \quad (2)$$

State of the Art Adaptive Techniques in SM

# Adaptive Spatial Modulation (ASM)

## Yang et.al., June,2011

- Exhaustive search over different modulation orders for different antennas to reduce error performance
- Receiver feeds back modulation order prior to transmission
- Transmitter transmits based on that modulation order

# Adaptive Spatial Modulation (contd..)

Yang et.al., June,2011

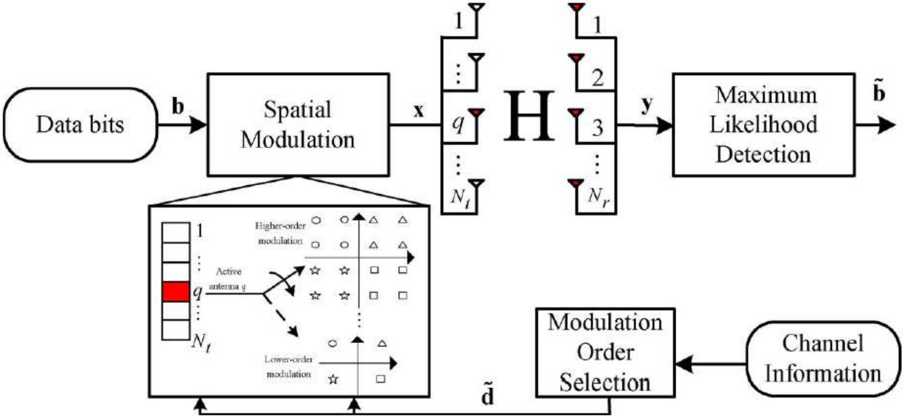


Figure:

# Adaptive Spatial Modulation (contd..)

Yang et.al., June 2011

- Performance metric used, probability of error,

$$p_e \approx \lambda . Q\left(\sqrt{\frac{1}{2N_0} d^2_{min}(\mathbf{H})}\right)$$

where

$$d^2_{min}(\mathbf{H}) = \min_{\mathbf{x_i},\mathbf{x_j} \epsilon \phi; \mathbf{x_i} \neq \mathbf{x_j}} \parallel \mathbf{H}(\mathbf{x_i} - \mathbf{x_j}) \parallel^2_{\mathbf{F}}$$

$\lambda$ represents average number of neighbour points with min distance $d_{min}(\mathbf{H})$

$\phi$ is the set of all possible transmit symbol vectors

# Link Adaptation for SM with limited FB

Yang et.al., Oct 2012

- Extended ASM to accommodate antenna selection also
- Exhaustive search over transmit mode also
- Search space and feedback load more

# Simplified Adaptive Spatial Modulation

Yang et.al., July 2013

- Exploits candidate selection probability to reduce the search space
- Feedback load reduced
- Still complexity high

# Proposed schemes

- Aim : To increase the minimum distance at the receiver
- Proposed 2 schemes assuming perfect CSIT available
  - SM with Beamforming and Constellation Rotation
  - Above scheme with Power Scaling
- Performance in the presence of partial CSIT

# Channel Model

$$y = \mathbf{hx} + z, \quad \mathbf{h} = [h_1, \ldots, h_{n_t}] \tag{3}$$

$$\mathbf{x} = \mathbf{Ws}, \ \mathbf{W} = \text{diag}(\mathbf{w})$$

$$\mathbf{s} \ \in \ \mathcal{C}^{n_t}, \text{ where } \mathbf{s} = [0, \ldots, 0, s_l, 0, \ldots, 0]^T$$

$s_l$ : symbol transmitting from the $l$th antenna at the transmitter
$z$ : $\mathcal{CN}(0, \sigma^2)$

# Channel Model (contd...)

The beamforming vector **w** is designed as

- Without power scaling

$$\mathbf{w} = [\exp(-j\phi_1), \exp(-j\phi_2), \ldots, \exp(-j\phi_{n_t})]^T \quad (4)$$

$$\phi_i = \angle h_i, 0 \leq i \leq n_t$$

$$||\mathbf{w}||_\infty \leq 1 \quad (5)$$

- With power scaling at the transmitter

$$\mathbf{w} = [\hat{\alpha_1} \exp(-j\phi_1), \hat{\alpha_2} \exp(-j\phi_2), \ldots, \hat{\alpha_{n_t}} \exp(-j\phi_{n_t})]^T \quad (6)$$

$$||\mathbf{w}||_2^2 \leq n_t \quad (7)$$

# Channel Model (contd...)

- ML Decoding
$$(\hat{i}, \hat{q}) = \arg\min_{i,q} |y - \mathbf{hx}|^2 \quad (8)$$
Assume $l^{th}$ antenna is transmitting the symbol $s_l$
- Then, symbol error happens when
$$|y - h_l s_l|^2 > \min_{i,q;(i,q)\neq(l,s_l)} |y - h_i q_i|^2 \quad (9)$$

# Beamforming

With beamforming, phase compensation of the channel is provided

$$
\begin{aligned}
||\mathbf{w}||_\infty &\leq 1 \quad (10)\\
\mathbf{x} &= \mathbf{Ws} \quad (11)\\
&= [0, ..., 0, s_l \exp(-j\phi_l), 0, ..., 0]^T \quad (12)\\
\Rightarrow y &= h_l s_l \exp\left(-j\phi_l\right) + z \quad (13)
\end{aligned}
$$

Effectively

$$
y = |h_l| s_l + z \quad (14)
$$

# Without Beamforming (conventional SM)

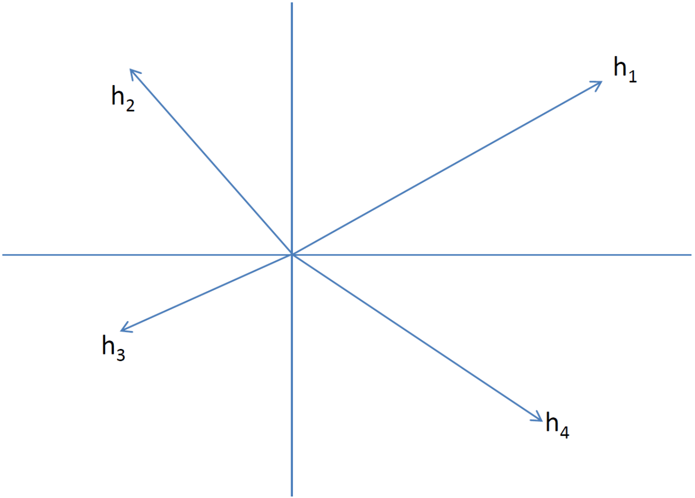


Figure: Effective channel gains in conventional SM

# With Beamforming without Constellation Rotation

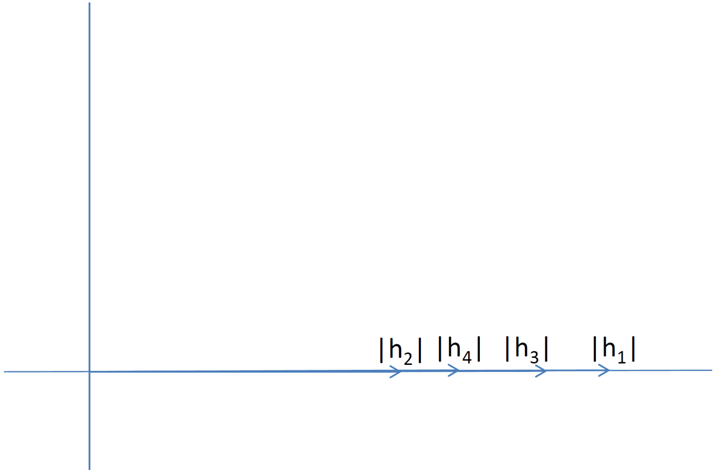


Figure: Effective channel gains with phase compensation and without constellation rotation

# Constellation Rotation

- Each antenna selects the symbol from the same constellation, but a rotated version
- Rotation angle different for each antenna.
- For antenna $i$, rotation angle $\theta_i = (i-1)\theta_0$

$$\theta_0 = \frac{\pi}{n_t} \text{ for BPSK}$$

$$\theta_0 = \frac{\pi}{2n_t} \text{ for QPSK}$$

# Constellations

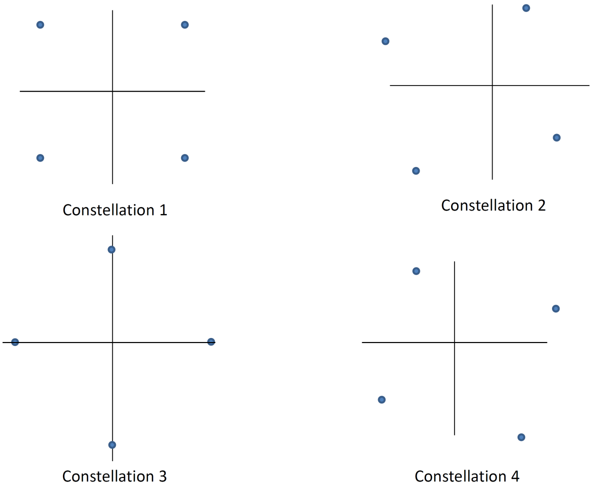


Figure: 4 rotated constellations of QPSK

# With Beamforming and Constellation Rotation

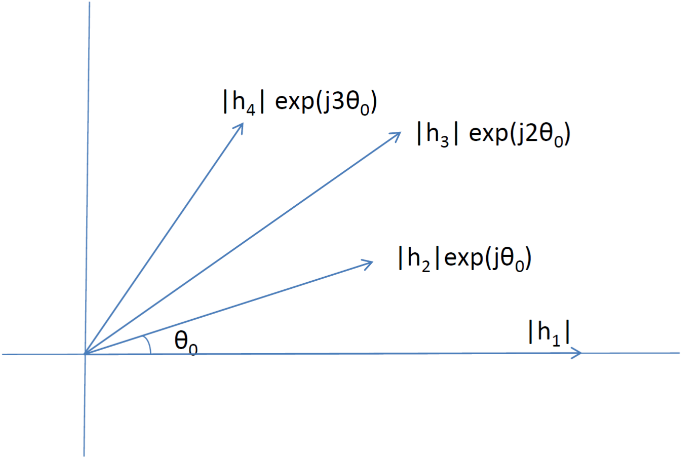


Figure: Effective channel gains with beamforming and constellation rotation at the transmitter

# With Beamforming and Constellation Rotation

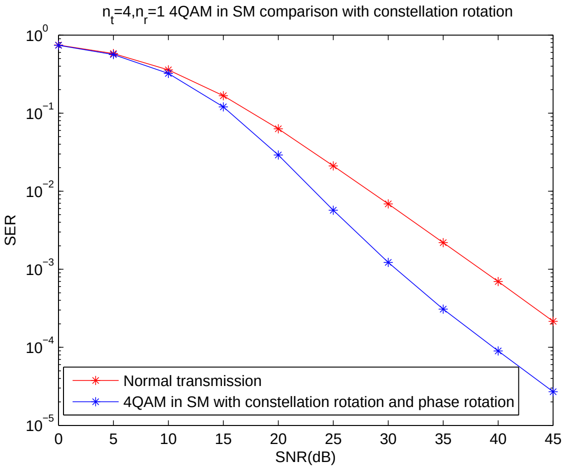


Figure: SM with constellation rotation

# Power Scaling

- For a generic setting with $n_t$ transmit antennas,
- $||\mathbf{w}||_2^2 \leq n_t$
- $\mathbf{w} = [\hat{\alpha_1} \exp(-j\phi_1), \hat{\alpha_2} \exp(-j\phi_2), \ldots, \hat{\alpha_{n_t}} \exp(-j\phi_{n_t})]$
- $\underline{\alpha} \triangleq [\alpha_1, ..., \alpha_{n_t}]$
- $\underline{\hat{\alpha}} =$

  $\arg\max_{\underline{\alpha}} (\min\{2\alpha_1^2|h_1|^2, \ldots, 2\alpha_{n_t}^2|h_{n_t}|^2, |\hat{\alpha_1}|h_1| - \alpha_2|h_2|\exp(j\theta_0)|^2, ...\}$
- subject to $\alpha_1^2 + {\alpha_2}^2 + \cdots + {\alpha_{n_t}}^2 \leq n_t$

# Power Scaling (contd...)

- Example: For $n_t = 2$, $\mathbf{w} = [\hat{\alpha_1} \exp(-j\phi_1), \hat{\alpha_2} \exp(-j\phi_2)]$

$$\hat{\alpha} = \arg\max_{\underline{\alpha}} \left( \min \left\{ 2\alpha_1^2|h_1|^2, 2\alpha_2^2|h_2|^2, |\alpha_1|h_1| - \alpha|h_2|\exp(j\theta_0)|^2 \right\} \right)$$

- subject to $\alpha_1^2 + {\alpha_2}^2 \leq 2$

# Power Scaling (contd...)

- Maximizing the difference between the two channel gains
- Transmitting power too low $\Rightarrow$ symbol will be decoded as another symbol from the same antenna

# Power Scaling (contd...)

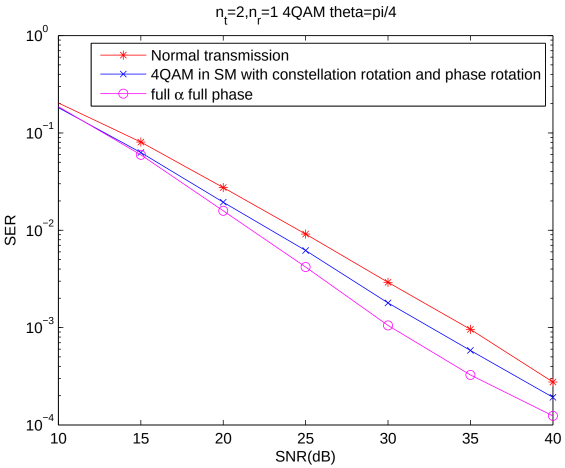


Figure: SM with Power Scaling

# Finite Rate Feedback

- Perfect CSIT not practical!
- CSIT obtained via a finite rate feedback channel
- CSI quantized at the receiver prior to FB

# Finite Rate Feedback

- $\phi_i \triangleq \angle h_i - \angle h_1$, for $1 \leq i \leq n_t$
- $\underline{\phi} \triangleq [\phi_2, ..., \phi_{n_t}]$
- Quantize $n_t - 1$ phase angles only
- Quantized version of $(\underline{\phi}) \Rightarrow \hat{\underline{\phi}} \triangleq [\hat{\phi_2}, ..., \hat{\phi_{n_t}}]$

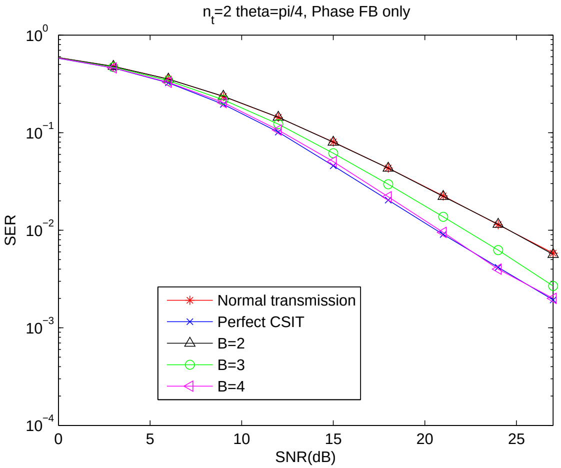


Figure: Comparison of SER for different FB rates

# Finite Rate Feedback

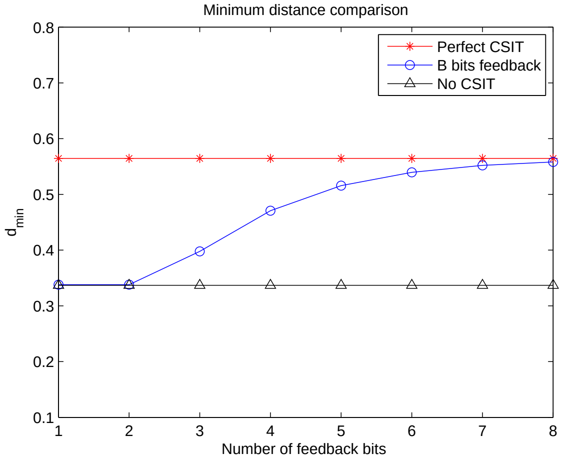


Figure: Comparison of minimum distance with number of FB bits

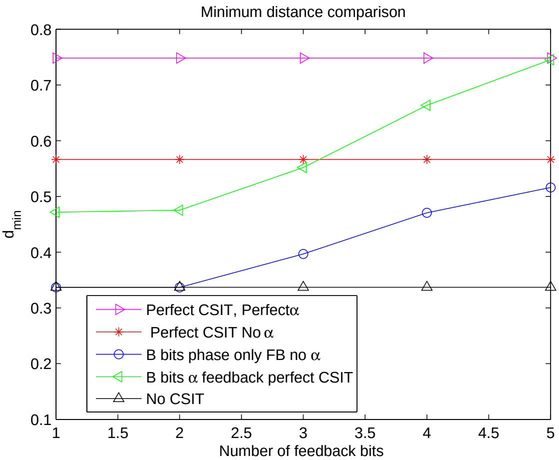


Figure: Comparison of minimum distance with number of FB bits with power scaling

# Summary

- Proposed 2 low complexity schemes to increase the minimum distance at the receiver
- Simulated the performance in the presence of partial CSIT

# Future work

- Design of quantizers
- Performance analysis with quantized CSIT