MIMO Precoding Performance for Correlated and Estimated Rician Fading

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Outline

1. Section 1: Introduction
2. Section 2: Channel fading model
3. Section 3: Precoded MIMO system model
4. Section 4: Numerical results
5. Section 5: Summary and conclusion

Motivation

- Multiple-input multiple-output (MIMO) attracts research interests for next generation wireless communication systems because of its potential high capacity and reliability
- Theoretical evaluations suffer from limited practical relevance
- Important issue to exploit channel state information at transmitter (CSIT) to improve link performance

Exploit Channel State Information at Transmitter (CSIT)

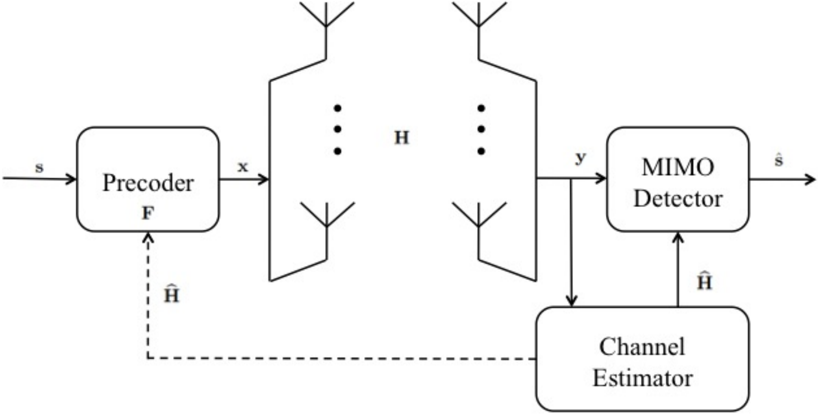
Benefits

- Allows transmitter know full/partial channel state information
- Alleviates the interference when preprocessing the data before transmission
- Provides the extra gain by using CSIT.

Issues need to work

- Perfect CSIT is not available in wireless communications
- Estimated CSIT usually relies on only independent antenna assumptions
- Practical channel environment relates to both instantaneous and statistics channel state information (CSI).

Precoded MIMO Block Diagram

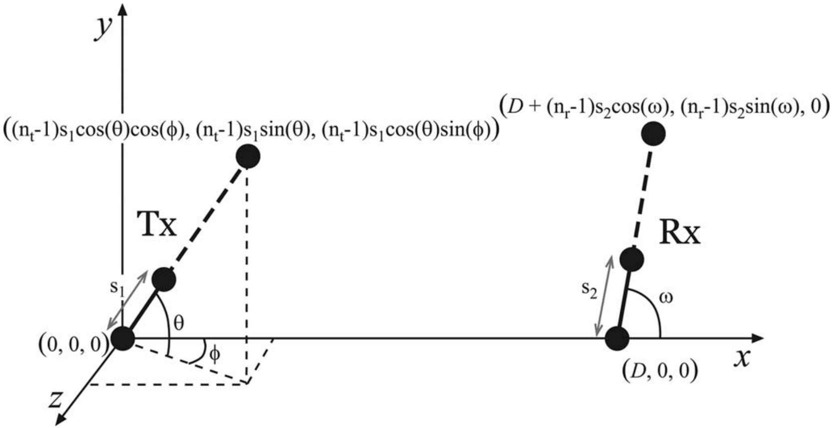


Channel Model

Channel matrix has complex-valued Gaussian-distributed elements with unit variance, and can be written as:

$$\mathbf{H} = \mathbf{H}_{\mathrm{d}} + \mathbf{H}_{\mathrm{r}} = \sqrt{\frac{K}{K+1}}\mathbf{H}_{\mathrm{d,n}} + \sqrt{\frac{1}{K+1}}\mathbf{H}_{\mathrm{r,n}}. \quad (1)$$

- $\mathbf{H}_{\mathrm{d,n}}$: normalized deterministic component, with $\mathrm{rank}(\mathbf{H}_{\mathrm{d,n}}) = 1 : N_{\mathrm{T}}$
- $\mathbf{H}_{\mathrm{r,n}}$: normalized random component, with $\mathbf{H}_{\mathrm{r,n}} = \mathbf{R}_{\mathrm{Rx}}^{\frac{1}{2}}\mathbf{H}_{w}\mathbf{R}_{\mathrm{Tx}}^{\frac{1}{2}}$
- Spatial correlation matrix for Tx correlated only is $\mathbf{R}_{\mathrm{H}} = \frac{1}{K+1}\mathbf{R}_{\mathrm{Tx}}$, in which $\mathbf{R}_{\mathrm{Tx}}$ is affected by azimuth spread (AS)
- $\mathbf{H}_{w}$: i.i.d. channel matrix
- K: Rician K-factor (Rician fading : $K \neq 0$, Rayleigh fading : $K = 0$)


y
((n_t-1)s_1cos(θ)cos(ϕ), (n_t-1)s_1sin(θ), (n_t-1)s_1cos(θ)sin(ϕ))
(D + (n_r-1)s_2cos(ω), (n_r-1)s_2sin(ω), 0)
Tx
Rx
s_1
θ
ϕ
(0, 0, 0)
s_2
ω
x
(D, 0, 0)
z

WINNER II Channel Model

- Most comprehensive available
- Measured radio channel extensively in a wide range of scenarios
- Developed statistical models for the fading based on thorough measurement (always Rician fading, never Rayleigh fading)
- Distinguished its models from other mostly theoretical models.

AS-K Statistical Distribution

Table: Base-station AS and K distribution

Scenario	AS [°]	K	$\rho_{\chi,\psi}$
A1: indoor office/residential	$10^{1.64+0.31\chi}$	$10^{0.1(7+6\psi)}$	-0.6
B1: typical urban microcell	$10^{0.40+0.37\chi}$	$10^{0.1(9+6\psi)}$	-0.3
B3: large indoor hall	$10^{1.22+0.18\chi}$	$10^{0.1(2+3\psi)}$	$+0.2$
C1: suburban	$10^{0.78+0.12\chi}$	$10^{0.1(9+7\psi)}$	$+0.2$
C2: typical urban macrocell	$10^{1.00+0.25\chi}$	$10^{0.1(7+3\psi)}$	$+0.1$
D1: rural macrocell	$10^{0.78+0.21\chi}$	$10^{0.1(7+6\psi)}$	$+0.0$
D2a: rural, high-speed	$10^{0.70+0.31\chi}$	$10^{0.1(7+6\psi)}$	$+0.0$

System Signal Model

The system has N_T transmit antennas and N_R receive antennas. The transmitter precodes a $N_\mathrm{T} \times 1$ source symbol vector **s** with a precoding matrix **F**, where the precoding matrix has a size of $N_\mathrm{T} \times N_\mathrm{T}$, i.e.,

$$\mathbf{x} = \mathbf{F}\mathbf{s}. \tag{2}$$

Then, received signals can be represented as the N_R-dimensional complex-valued vector:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \tag{3}$$

where **x** is the N_T-dimensional vector with the precoded complex-valued transmitted symbols, **H** is the channel matrix with complex-valued Gaussian distributed elements with unit variance, and the noise vector is complex-valued, zero-mean, spatially-uncorrelated, Gaussian distributed, i.e., $\mathbf{n} \sim \mathcal{N}_\mathrm{c}(0, N_0\,\mathbf{I})$.

Linear Precoding Approaches

Linear precoding is the most available for current advanced transmitter design.

Zero Forcing (ZF) Approach

- Suboptimal that less achievable in capacity
- Still can maximize the performance in some environments

Minimum Mean Square Error (MMSE) Approach

- Optimal approach that is available for precoding
- Simple to characterize the nose effect on the performance

Mismatched Zero Forcing (ZF) Precoding

The ZF approach cancels the inter-stream interference by the following matrix:

$$\mathbf{F}_{\text{ZF}} = (\widehat{\mathbf{H}}^H\widehat{\mathbf{H}})^{-1}\widehat{\mathbf{H}}^H, \tag{4}$$

where $(\cdot)^H$ denotes Hermitian transposition.

Mismatched Minimum Mean Square Error (MMSE) Precoding

In order to maximum precoding interference plus noise cancellation, MMSE precoding minimizes the minimum square error between the transmitted symbols and received symbols. The precoding matrix is given by:

$$\begin{aligned}\mathbf{F}_{\text{MMSE}} &= \arg\min_{\mathbf{F}} \mathbb{E}\{||(\mathbf{HFs}+\mathbf{n})-\mathbf{s}||_F^2 \mid \mathbf{H}\} \\ &= (\widehat{\mathbf{H}}^H\widehat{\mathbf{H}}+N_0\mathbf{I})^{-1}\widehat{\mathbf{H}}^H,\end{aligned} \tag{5}$$

where $||\cdot||_F^2$ represents the Frobenius spectral norm of a matrix.

New Approach

Given the estimated channel matrix, the true channel matrix can be rewritten as:

$$\mathbf{H} = \mathbf{H}_\mathrm{m} + \mathbf{H}_\mathrm{e}, \tag{6}$$

where $\mathbf{H}_\mathrm{m}$ is given by:

$$\mathbf{H}_\mathrm{m} = \mathbb{E}\{\mathbf{H} \mid \widehat{\mathbf{H}}\} = \mathbb{E}\{\mathbf{H}\} + \mathbf{R}_\mathrm{T}(\mathbf{R}_\mathrm{T} + N_0\mathbf{I})^{-1}(\widehat{\mathbf{H}} - \mathbb{E}\{\widehat{\mathbf{H}}\}). \tag{7}$$

The rows of $\mathbf{H}_\mathrm{e}$ follow the distribution of $\mathcal{N}_\mathrm{c}(0, \mathbf{R}_\mathrm{e})$, where

$$\mathbf{R}_\mathrm{e} = \mathbf{R}_\mathrm{T} - \mathbf{R}_\mathrm{T}(\mathbf{R}_\mathrm{T} + N_0\mathbf{I})^{-1}\mathbf{R}_\mathrm{T}^H. \tag{8}$$

Then we can rewrite the received signal as:

$$\mathbf{y} = \mathbf{H}_\mathrm{m}\mathbf{x} + \boldsymbol{\nu}, \tag{9}$$

where the new noise vector $\boldsymbol{\nu} = \mathbf{H}_\mathrm{e}\mathbf{x} + \mathbf{n}$ is zero-mean, complex-valued, Gaussian-distributed with correlation matrix:

$$\mathbf{R}_{\boldsymbol{\nu}} = \mathbb{E}\{\boldsymbol{\nu}\boldsymbol{\nu}^H\} = \mathrm{tr}(\mathbf{R}_\mathrm{e})\mathbf{I}_{N_\mathrm{T}} + N_0\mathbf{I}. \tag{10}$$

Chanel Statistics Estimation

Exploiting L instantaneous estimated channel state information (CSI) to average over fading, then the statistics CSI can be computed by:

$$\widehat{\mathbf{H}}_{\mathrm{d}} = \frac{1}{L}\sum_{i=1}^{L}\widehat{\mathbf{H}}_i \tag{11}$$

$$\widehat{K} = \frac{||\widehat{\mathbf{H}}_{\mathrm{d}}||_F^2}{\frac{1}{L}\sum_{i=1}^{L}||\widehat{\mathbf{H}}_i - \widehat{\mathbf{H}}_{\mathrm{d}}||_F^2} \tag{12}$$

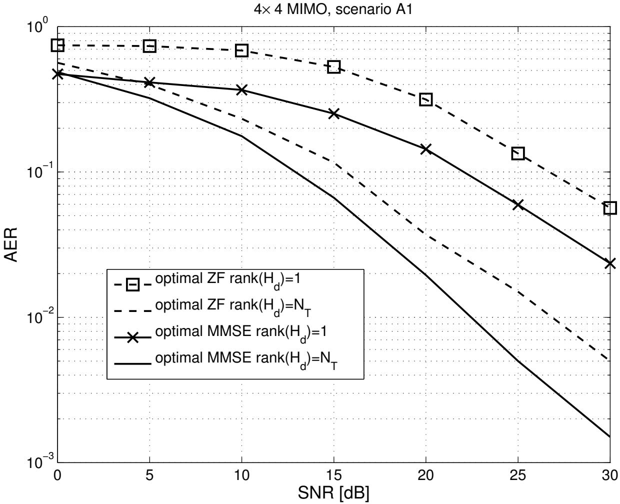
$$\beta = \frac{\widehat{K}+1}{L}\sum_{i=1}^{L}(||\widehat{\mathbf{H}}_i||_F^2 - ||\widehat{\mathbf{H}}_{\mathrm{d}}||_F^2) \tag{13}$$

$$\widehat{\mathbf{R}}_{\mathrm{T}} = \frac{\widehat{K}+1}{\sqrt{\beta}L}\sum_{i=1}^{L}(\widehat{\mathbf{H}}_i^H\widehat{\mathbf{H}}_i - \widehat{\mathbf{H}}_{\mathrm{d}}^H\widehat{\mathbf{H}}_{\mathrm{d}}). \tag{14}$$

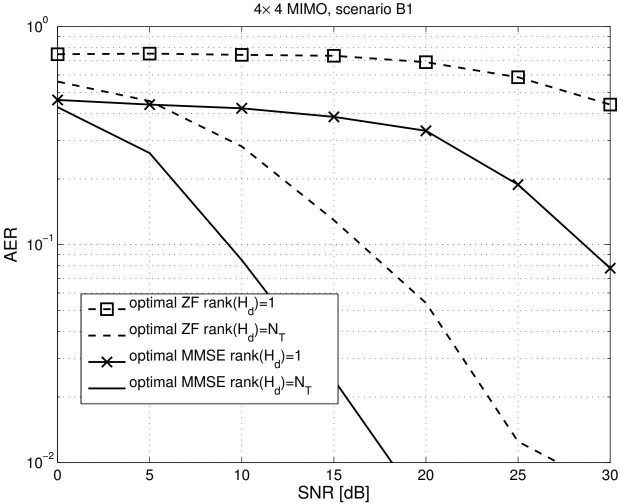
Simulation Parameter

Scenarios	A1, B1
Tx antennas	4
Rx antennas	4
Training symbols for each data slot	4×4
Training Length (L) for SCSI estimate	10
rank($\mathbf{H}_\mathrm{d}$)	1, N_T, random
Random (AS,K) samples	10000
Modulation	QPSK

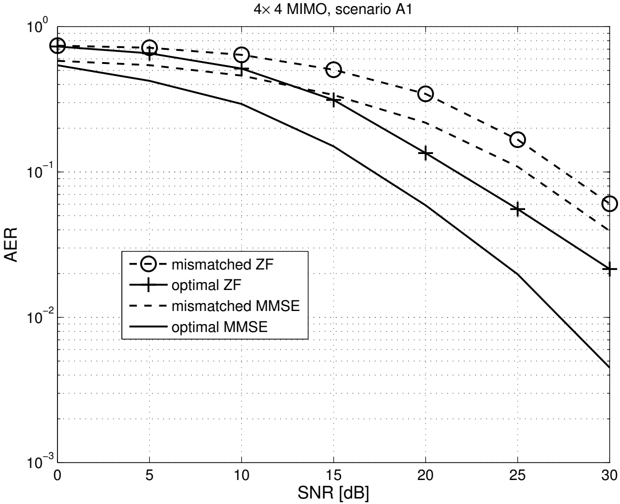
4 × 4 MIMO ZF vs. MMSE precoding for scenario A1, mean values



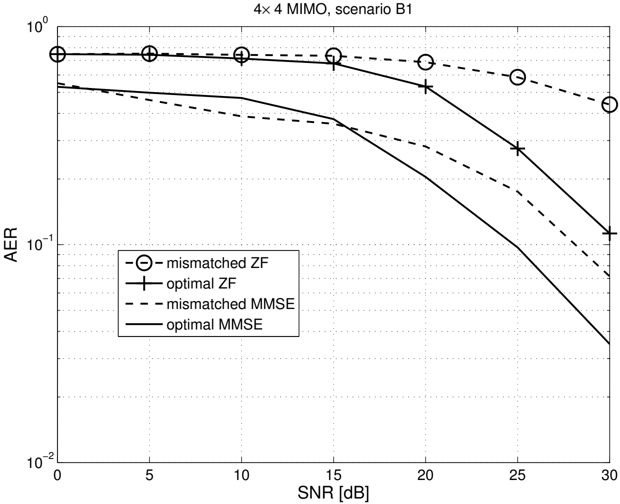
4×4 MIMO ZF vs. MMSE precoding for scenario B1, mean values



4 × 4 MIMO MMSE precoding for scenario A1, random values



4×4 MIMO MMSE precoding for scenario B1, random values



- Evaluated MIMO precoding performance for various assumptions about the channel fading and CSI realistically.
- The performance of precoding can be change significantly due to the different rank
- For the more realistic, i.e., Rician fading channel, the applicable optimal approach accounts for both ICSI and SCSI to transmitter can help improve the precoding performance, comparing with the mismatched approaches
- For less correlated channel, i.e., scenario A1, the optimal ZF precoding can obtain better performance than that of mismatched MMSE precoding.