Construction and capacity analysis of high-rank line-of-sight MIMO channels

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Introduction

• General MIMO transmission scheme

Example, $3 \times 3$

\[
H = \begin{bmatrix}
h_{11} & h_{12} & h_{13} \\
h_{21} & h_{22} & h_{23} \\
h_{31} & h_{32} & h_{33}
\end{bmatrix}
\]
Introduction

• General MIMO transmission scheme

\[
\begin{pmatrix}
\begin{array}{ccc}
   h_{11} & h_{12} & h_{13} \\
   h_{21} & h_{22} & h_{23} \\
   h_{31} & h_{32} & h_{33}
\end{array}
\end{pmatrix}
\]

Example, $3 \times 3$

- To achieve high MIMO gain we need the channel matrix to be high rank
- Usually high MIMO gain is depended on a high degree of multipath
- Best performance is obtained when the subchannels experiences uncorrelated fading
- One can not rely on this kind of MIMO gain when a strong LOS component is present
- Objective: Construct a MIMO system that gives a high rank channel matrix without the requirement of a high degree of multipath
MIMO channel matrix

• The MIMO transmission is modeled in complex baseband as

\[ r = Hs + n \]

• Slowly varying and frequency flat fading is assumed
• The channel matrix is modeled by a Ricean channel model

\[ H = \sqrt{\frac{K}{1 + K}} \cdot H_{\text{LOS}} + \sqrt{\frac{1}{1 + K}} \cdot H_{\text{NLOS}} \]

• The elements in \( H_{\text{NLOS}} \) is independent identical distributed complex Gaussian, i.e. Rayleigh distributed amplitudes
• The elements in \( H_{\text{LOS}} \) will be discussed in detail in the next slides
Geometrical model

• To find the elements of $H_{\text{LOS}}$ we use a ray tracing technique
• We restrict our investigation to uniform linear antenna arrays
• The geometrical model

The parameters in the figure is used to determine the path length, $r_{m,n}$

The normalized channel response vector from transmit antenna $n$

$$h_n = \left[ \exp\left(\frac{j2\pi}{\lambda} r_{0,n}\right), \ldots, \exp\left(\frac{j2\pi}{\lambda} r_{N-1,n}\right) \right]^T$$
Optimal antenna separation

• It can be shown that we maximize the capacity when the channel response vectors are orthogonal

\[
\langle h_k, h_l \rangle = \sum_{m=0}^{M-1} \exp \left( j \frac{2\pi}{\lambda} (r_{m,k} - r_{m,l}) \right) = 0
\]

\[\vdots\]

\[\Rightarrow d_td_r = \frac{\lambda R}{N \cos \theta}\]

• Transmission scheme best suited for fixed systems
• To keep \(d_td_r\) at practical values \(\lambda R\) must be small
  • high frequencies
  • short distance
Performance evaluation

• To evaluate the performance we use different versions of Shannons capacity formula

• It is assumed that the branch sources are uncorrelated and equal power is used on each branch (optimal when channel not known at the transmitter)

• The capacity of such a MIMO system is

$$C = \sum_{i=1}^{N} \log_2 \left(1 + \frac{\bar{\gamma}}{N} \lambda_i \right) \text{ bit/s/Hz}$$

where $\lambda_i$ is the i’th eigenvalue of $\mathbf{H} \mathbf{H}^H$

• Outage capacity, $P_{out}(C_{th}) = P_r[C \leq C_{th}]$.

• Effective degrees of freedom (EDOF), quantifies how many equivalent SISO channels that gives an increase of 1 bit/s/Hz when SNR is doubled
Simulations

- A $3 \times 3$ MIMO system is used to demonstrate the performance.
- To investigate how sensitive the MIMO system is in regards of optimal values we introduce a mismatch factor, $\eta$

\[
d_t d_r \eta = \frac{\lambda R}{N \cos \theta}
\]

- $\eta$ greater than 1 (0 dB) implies that the interantenna-distance product is too small.
• Eigenvalues as a function of mismatch factor for a $3 \times 3$ MIMO system (pure LOS, $K \to \infty$)
Results

- Outage capacity for a $3 \times 3$ MIMO system with average SNR $= 20$ dB
Results

- Effective degrees of freedom for a $3 \times 3$ MIMO system with average SNR = 5 dB
Conclusions

- By designing the antenna arrays correctly a high rank channel matrix is achieved for a pure LOS transmission
- We still get good performance even if we have some deviation from the optimal values
- This transmission scheme is well suited for systems that have a strong LOS component
  - High frequency FWA systems that require LOS transmission (short wavelength)
  - Near the BS for other FWA systems where a strong LOS component often is present (short distance)