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

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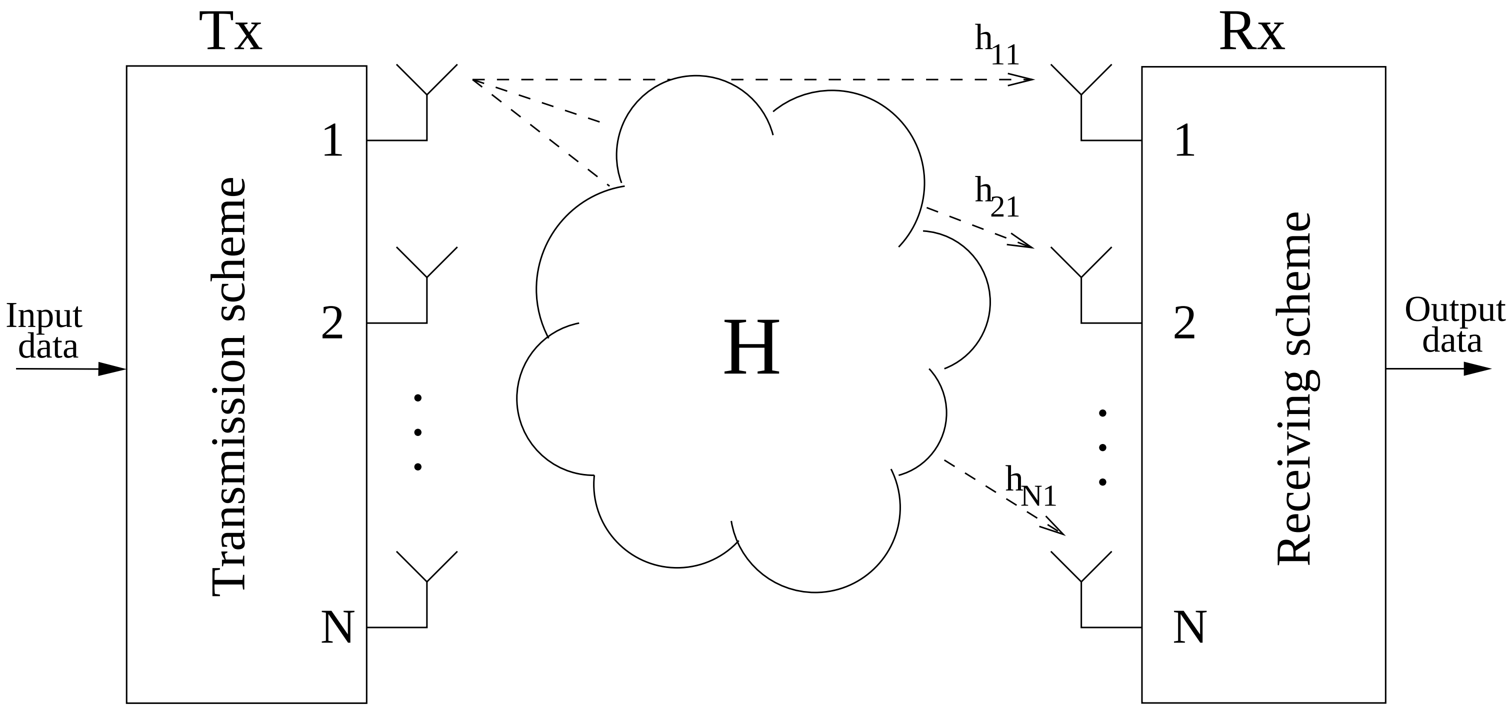
Introduction

- General MIMO transmission scheme



Example, 3×3

$$\mathsf{H} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$$

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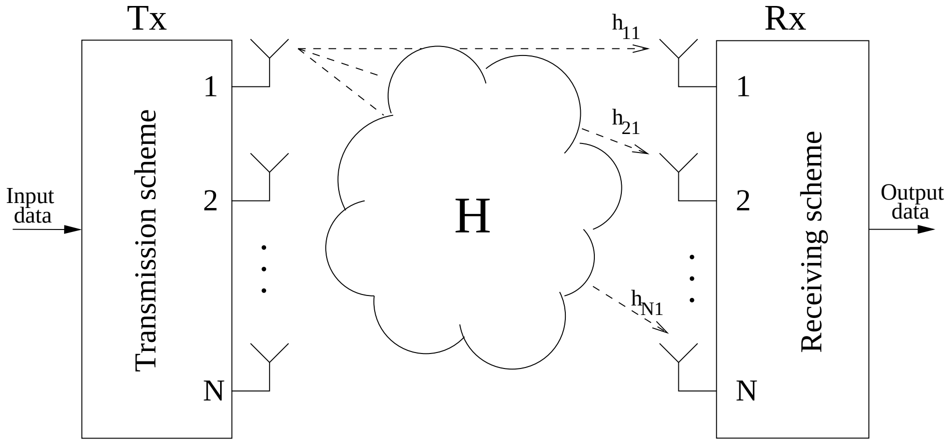


Example, 3×3

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

- 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

$$\mathbf{r} = \mathbf{H}\mathbf{s} + \mathbf{n}$$

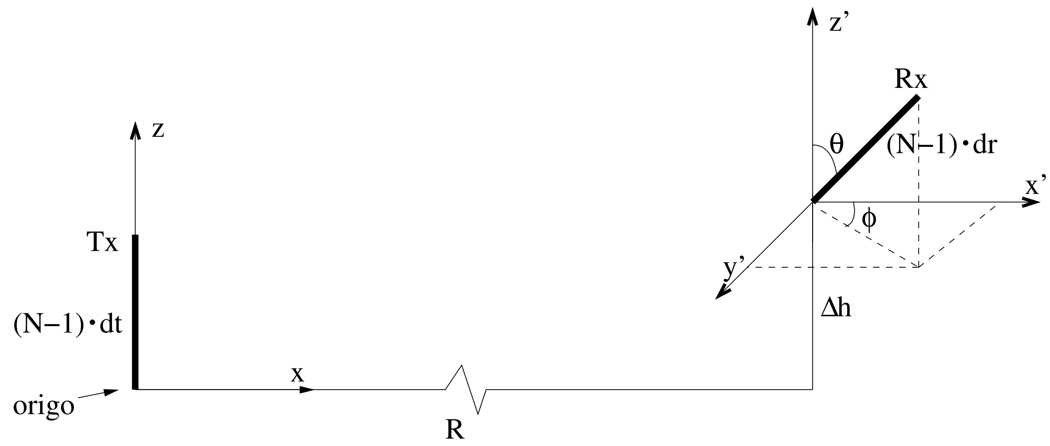
- Slowly varying and frequency flat fading is assumed
- The channel matrix is modeled by a Ricean channel model

$$\mathbf{H} = \sqrt{\frac{K}{1+K}} \cdot \mathbf{H_{LOS}} + \sqrt{\frac{1}{1+K}} \cdot \mathbf{H_{NLOS}}$$

- The elements in $\mathbf{H_{NLOS}}$ is independent identical distributed complex Gaussian, i.e. Rayleigh distributed amplitudes
- The elements in $\mathbf{H_{LOS}}$ will be discussed in detail in the next slides

Geometrical model

- To find the elements of $\mathbf{H}_{\mathbf{LOS}}$ 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

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

Optimal antenna separation

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

$$
\begin{aligned}
\langle \mathbf{h_k}, \mathbf{h_l} \rangle &= \sum_{m=0}^{M-1} \exp\left(j \frac{2\pi}{\lambda} \left(r_{m,k} - r_{m,l} \right) \right) = 0 \\
&\vdots \\
\Rightarrow d_t d_r &= \frac{\lambda R}{N \cos\theta}
\end{aligned}
$$

- Transmission scheme best suited for fixed systems
- To keep $d_t d_r$ at practical values λR 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

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

  where λ_i is the i'th eigenvalue of $\mathbf{HH^H}$
- Outage capacity, $P_{out}(C_{th}) = Pr[C \leq C_{th}]$.
- 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

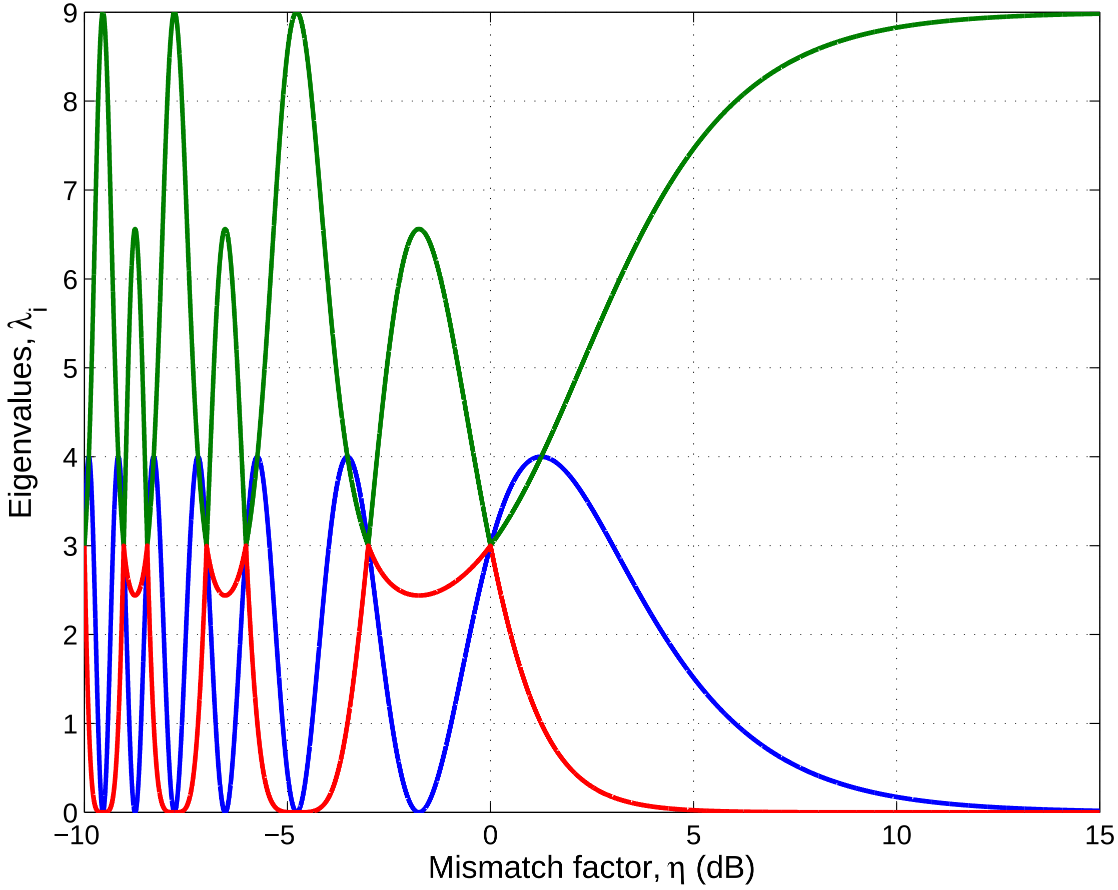
- A 3×3 MIMO system is used to demonstrate the performance
- To investigate how sensitive the MIMO system is in regards of optimal values we introduce a mismatch factor, η

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

- η greater than 1 (0 dB) implies that the interantenna-distance product is to small

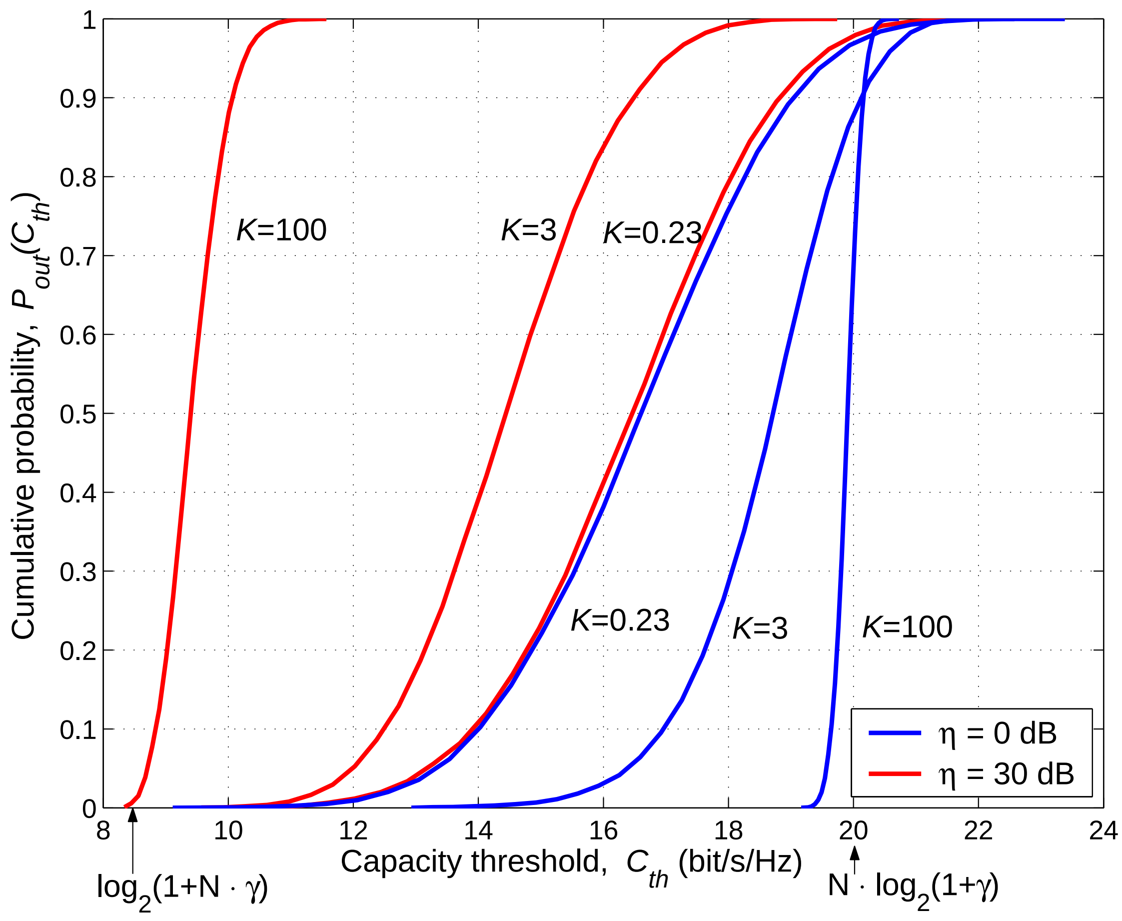
Results

- Eigenvalues as a function of mismatch factor for a 3×3 MIMO system (pure LOS, $K \to \infty$)



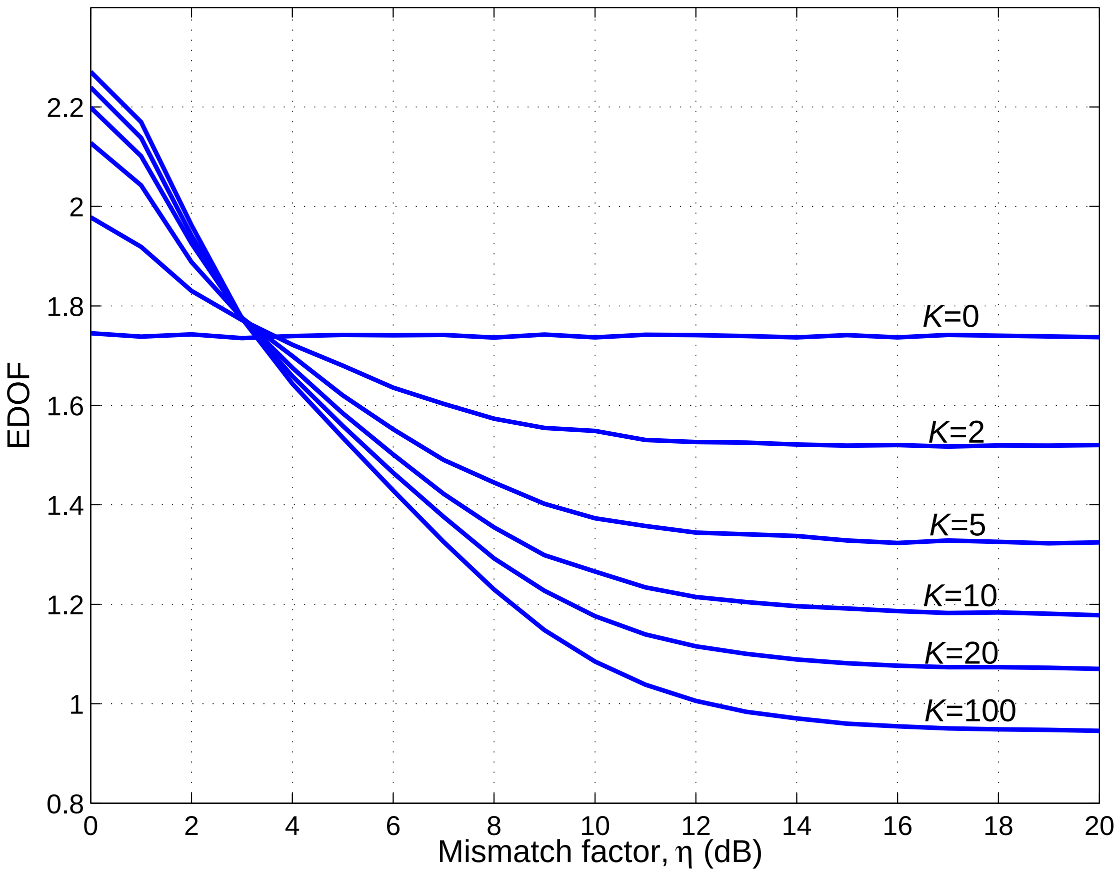
Results

- Outage capacity for a 3×3 MIMO system with average SNR = 20 dB



Results

- Effective degrees of freedom for a 3×3 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)

Questions

Frode Bøhagen, Pål Orten and Geir E. Øien, "Construction and Capacity analysis of high-rank line-of-sight MIMO channels," *Submitted to WCNC*, New Orleans, 2005.