MIMO Performance of a Planar Logarithmically-Periodic Antenna


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Outline

1. Introduction
2. Antenna influence on channel capacity
3. Model verification in a simple LOS scenario
4. Performance measurement in office environment
5. Consequence for MIMO antenna design
Introduction

• Channel capacity can be increased using polarization diversity
• Log. per. antenna provides a high pol. diversity and will be used for the measurement
• The property will be shown by measured channel matrices in a well defined LOS channel
• To prove the performance in a realistic environment results taken in an office environment will be demonstrated
• The measurements were take by two different hardware setups
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**Introduction**

The MIMO channel

- non-stationary impulse response in baseband domain
- stationarity for a short time period
- \( t_c \approx 18 \text{ms} \) @ \( v_d = 5 \text{ km/h}, 5.2 \text{ GHz} \) for indoor environment
- impulse response is a complex value during one coherence time interval
- high SNR and high rank lead to a high channel capacity!

What can we do on antenna side to increase the channel capacity?

\[
\tilde{H} = \begin{bmatrix}
\tilde{h}_{11} & \tilde{h}_{12} & \cdots & \tilde{h}_{1N} \\
\tilde{h}_{21} & \ddots & \ddots & \vdots \\
\vdots & & \ddots & \ddots \\
\tilde{h}_{M1} & \cdots & \cdots & \tilde{h}_{MN}
\end{bmatrix}
\]

\[
C_{\text{MIMO}} = \log_2 \det \left( \bar{E} + \frac{P_T}{\sigma_N^2 M} \tilde{H} \tilde{H}^H \right) = \sum \log_2 \left( 1 + \frac{P_T}{\sigma_N^2 M} \lambda_i \right)
\]
\[ \tilde{H} = \sqrt{P} \left( \sqrt{\frac{K}{K+1}} H_{\text{LOS}} + \sqrt{\frac{1}{K+1}} H_{\text{NLOS}} \right) \]

**Rice-Matrix**

- fixed channel coefficients
- High rank of \( H_{\text{LOS}} \) can be achieved by:
- **Polarization diversity**
  (high polarization decoupling \( \text{AR} \) (Axial Ratio) of the involved antennas)

\[
\text{AR} = \frac{|E_{p_{\text{max}}}|}{|E_{p_{\text{min}}}|}
\]

\[
|H_{\text{LOS}}| = \begin{bmatrix} \left| h_{bb} \right| & \left| h_{br} \right| \\ \left| h_{rb} \right| & \left| h_{rr} \right| \end{bmatrix} = \begin{bmatrix} 1 & \approx \frac{1}{\text{AR}} \\ \approx \frac{1}{\text{AR}} & 1 \end{bmatrix}
\]

Example:

- \( P_v = 1 \)
- \( P_H = 1 / \text{AR}^2 \)

\( C_{\text{MIMO}} \) grows as secondary diagonal elements vanish.
**Introduction**

\[
\tilde{H} = \sqrt{P} \left( \sqrt{\frac{K}{K+1}} H_{LOS} + \sqrt{\frac{1}{K+1}} H_{NLOS} \right)
\]

**Rayleigh-_matrix**

- iid channel coefficients with stamped on correlation
- High rank of \( H_{NLOS} \) can be achieved by minimizing antenna correlation:
  - Pattern diversity
  - Spatial diversity
  - Polarization diversity

**Envelope correlation coefficient:**

\[
\rho_r \approx \left| \rho_{ij} \right|^2 = \frac{|R_{ij}|^2}{\sigma_i^2 \cdot \sigma_j^2}
\]

Antenna patterns in
- \( \vartheta \)-polarization
- \( \phi \)-polarization

\[
R_{ij} = K \cdot \int_{0}^{2\pi} \int_{0}^{\pi} C_{\vartheta} (\vartheta, \phi) \cdot C_{\phi} (\vartheta, \phi) + XPR \cdot C_{\phi} (\vartheta, \phi) \cdot C_{\phi} \cdot (\vartheta, \phi)
\]

\[
\rho_{ij} = \int_{0}^{2\pi} \int_{0}^{\pi} p_{ij} (\vartheta, \phi) e^{i k d} \sin(\vartheta) d\vartheta d\phi
\]

Spatial separation

Cross polarization ratio (channel property)

Probability density function including AOA, AOD and angular spread
Properties of the logarithmically-periodic antenna

- **Trapezoidal**, self-complementary four-arm \((N = 4)\) antenna for \((1 – 6)\) GHz
  - **Dual-linear polarization**
  - Optimized cross-polarization decoupling

\[
\begin{bmatrix}
1 \\
0 \\
-1 \\
0
\end{bmatrix}, \quad \begin{bmatrix}
0 \\
1 \\
0 \\
-1
\end{bmatrix}
\]

Mode 1

Mode 2
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Model verification in a simple LOS scenario

LOS scenario
Model verification in a simple LOS scenario

Transmitter

CW source
R&S SM300

Balun
Log.-Per. antenna

2,45045 GHz

2,4503 GHz

CW source
Anritzu MG3695A

Receiver

Log.-Per. antenna

R&S FS 300

Spectrum analyzer

R&S FS 300

150 cm

95 cm
Model verification in a simple LOS scenario

- Measurement of channel matrix at 2.4 GHz
- Separation by using two nearby frequencies (Δf = 150 kHz)
- Valid because of $B_{C,90\%} = 200$ kHz @ $\sigma_t=100$ ns
- Sweep time for spectrum analyzers $t \approx 1$ ms
- Valid because $t_c \approx 18$ ms

- Channel capacity is calculated in dependence of the rotation angle between the two antennas in 10° steps
Model verification in a simple LOS scenario

Comparison between measurement and simulation

$C_{\text{total}}$, $C_{\text{sub1}}$, $C_{\text{sub2}}$

$C_{\text{total}}$ measured
$C_{\text{sub1}}$ simulated
$C_{\text{sub2}}$

$\varphi$ / deg

$C / \text{bit/s/Hz}$

$2 \cdot \varphi_{\text{pol}} = 90^\circ$

$\varphi / \text{deg}$

$2 \cdot \varphi_{\text{pol}}$

$\varphi_{\text{pol}} \approx 8^\circ @ 2.4 \text{ GHz}$

Model verification in a simple LOS scenario

Comparison between measurement and simulation

$2 \cdot \varphi_{\text{pol}} = 90^\circ$

$\varphi / \text{deg}$

$2 \cdot \varphi_{\text{pol}}$

$\varphi_{\text{pol}} = 8^\circ @ 2.4 \text{ GHz}$

$\varphi_{\text{pol}}$
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Performance measurement in office environment

Wireless prototyping system HaLo 220 for 2x2 MIMO at WLAN frequencies

- 2 CW signals are used for determining the channel matrix
- Signals are being coherently sampled at the two receivers (5 MSa/s)
- Acquisition time for 1 channel matrix = 10 ms
- 1000 channel matrices for different channel scenarios
Performance measurement in office environment

Office environment for LOS and NLOS measurement

NLOS
LOS 2.4 GHz results

- **Red curve**
  - LOS component dominates (high slope)
  - Subchannel capacity is almost equal
  - Highest sum capacity

- **Blue curve**
  - Strongest subchannel equals that of the red case
  - Vertical polarization of monopoles suppresses the horizontal polarized wave from TA

- **Black curve**
  - Comparable to blue case, but more influence of NLOS components (different slope)
Red curve
• LOS component still dominates

Black curve
• Again more NLOS components, outage rate lowered in the weaker subchannel
NLOS 5.4 GHz results

Red curve
• NLOS components decrease slope
• SNR decreases (curve moves left)
• Capacity of weak subchannel decreases but is still better than black case

Black curve
• Capacity of strong subchannel is just slightly altered
• Capacity of weak subchannel decreases
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Consequence for MIMO antenna design

- Polarization diversity of adjacent antenna elements in a MIMO array leads to a good MIMO performance
- Planar antennas with high AR enable high decorrelation at little space
- Combination of spatial and polarization decoupling is useful for antenna switching