A MIMO Optimization for Physical Layer Security

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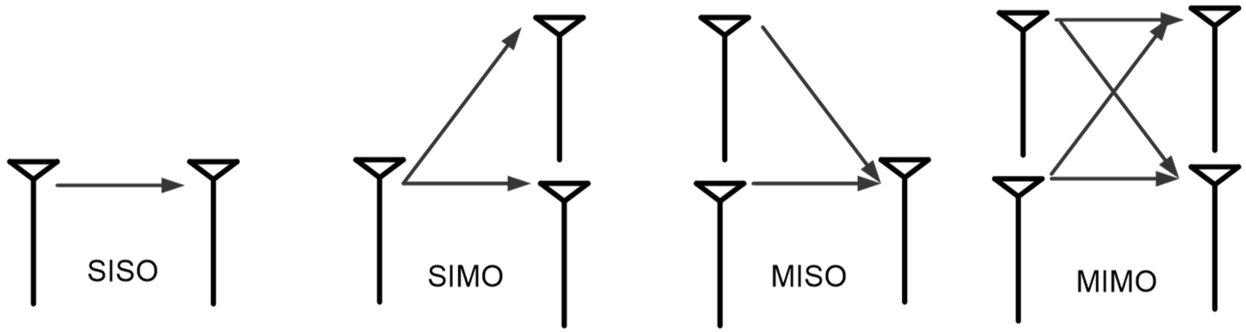
Outline

- Introduction
- System Characterization for MIMO types
- MISO System specified for Directivity
- Conclusions

Introduction

- 4G systems is demanding high data rates, improved performance and improved spectral efficiency
- Multi-antenna systems are used in order to push the **performance or capacity/throughput** limits as high as possible without an increase of the spectrum bandwidth, although at the cost of an obvious increase of complexity
- Multi-antenna systems are regarded as:
  - SISO (Single Input Single Output)
  - SIMO (Single Input Multiple Output)
  - MISO
  - MIMO



MISO System specified for Directivity

- Transmitters with **directivity introduced at information level** where the transmitted constellation is only optimized in the desired direction can be used for **security purposes**

- Severely time-dispersive channels in broadband wireless systems => Use MIMO to **improve spectral efficiency**

- The use of multilevel modulations in modern wireless standards leads to **high peak-to-average power ratios** and further drives the costs of **power amplifiers** while reducing their efficiency.

MISO System specified for Directivity

- **Power efficiency** on **Amplification** can be improved, due to the fact that **constellations are decomposed** into several BPSK (Bi Phase Shift Keying) or QPSK components (Quadri-Phase Shift Keying), being **each one separately amplified and transmitted independently by an antenna**

- Several users can coexist since **each user must know the configuration parameters associated to the constellation configuration**, i.e., the direction in which the constellation is optimized, **otherwise receives a degenerated constellation** with useless data

MISO System specified for Directivity

- FDE (Frequency-Domain Equalization) techniques are suitable for time-dispersive channels, namely the SC-FDE (Single Carrier – Frequency Domain Equalization) with multilevel modulations.
  - This leads to lower envelope fluctuations => efficient power amplification (OFDM signals present high envelope fluctuations)

- IB-DFE receiver (Iterative Block Decision Feedback Equalization) are suitable for SC-FDE with multilevel modulations

Multilevel constellations

- The constellation symbols can be expressed as a function of the corresponding bits as follows:

$$a_n = g_0 + g_1 b_n^{(1)} + g_2 b_n^{(2)} + g_3 b_n^{(1)} b_n^{(2)} + g_4 b_n^{(3)} + \ldots = \sum_{i=0}^{M-1} g_i \prod_{m=1}^{\mu} \left(b_n^{(m)}\right)^{\gamma_{m,i}}, \quad b_n^{(m)} = 2\beta_n^{(m)} - 1$$

for each $s_n \in \mathfrak{S}$

$(\gamma_{\mu,i}\ \gamma_{\mu-1,i} \ldots \gamma_{2,i}\ \gamma_{1,i})$ is the binary representation of *i*

In matrix format we have

$$\mathbf{s} = \mathbf{W}\mathbf{g},$$

where

$$\mathbf{s} = [s_1\ s_2\ \ldots\ s_M]^T \quad \mathbf{g} = [g_0\ g_1 \ldots g_{\mu-1}]^T$$

Multilevel constellations

- Examples:

  optimal 16-Voronoi constellation (linear)

$$g_0 = 0 \quad g_1 = -0.58 + j0.57 \quad g_2 = -0.712 + j0.545 \quad g_3 = -0.014 - j0.124 \quad g_4 = 0.028 + j0.248$$

$$g_5 = -0.186 + j0.273 \quad g_6 = -0.2 + j0.149 \quad g_7 = -0.014 - j0.124 \quad g_8 = -0.1 + j0.074$$

$$g_9 = 0.085 - j0.198 \quad g_{10} = 0.358 + j0.272 \quad g_{11} = 0.859 - j0.198 \quad g_{12} = -0.1 + j0.074$$

$$g_{13} = -0.085 - j0.198 \quad g_{14} = -0.1 + j0.074 \quad g_{15} = 0.085 - j0.198$$

- 16-OQAM can be decomposed as a sum of **four BPSK signals** with the mapping rule defined by the set of non null complex coefficients

$$g_2 = 2j \quad g_3 = j \quad g_8 = 2 \quad g_{12} = 1$$

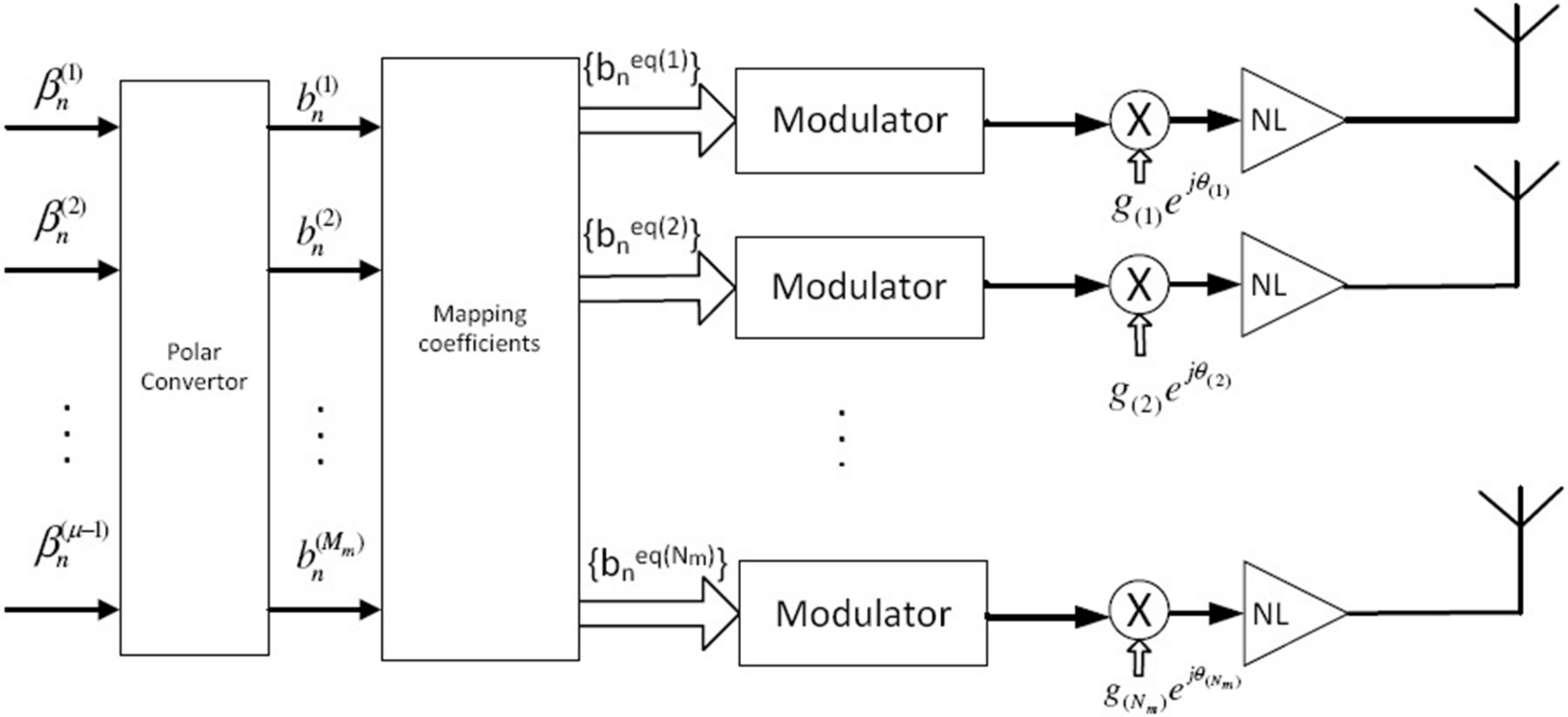
Transmitter

Sort=LINEAR			Sort=CENTER		
Gain	QAM	VORONOI	Gain	QAM	VORONOI
g_0	2j	0,717+j 0,546	g_0	0	-0,100+j 0,075
g_1	2	-0,588+j 0,572	g_1	0	-0,014-j 0,124
g_2	j	0,359+j 0,273	g_2	0	-0,014-j 0,124
g_3	1	-0,186+j 0,273	g_3	0	0,086-j 0,199
g_4	0	-0,201+j 0,149	g_4	0	0,086-j 0,199
g_5	0	0,029+j 0,248	g_5	0	-0,201+j 0,149
g_6	0	0,086-j 0,199	g_6	j	0,359+j 0,273
g_7	0	0,086-j 0,199	g_7	2j	0,717+j 0,546
g_8	0	0,086-j 0,199	g_8	2	-0,588+j 0,572
g_9	0	0,086-j 0,199	g_9	1	-0,186+j 0,273
g_{10}	0	-0,014-j 0,124	g_{10}	0	0,029+j 0,248
g_{11}	0	-0,100+j 0,075	g_{11}	0	0,086-j 0,199
g_{12}	0	-0,014-j 0,124	g_{12}	0	0,086-j 0,199
g_{13}	0	-0,100+j 0,075	g_{13}	0	-0,100+j 0,075
g_{14}	0	-0,100+j 0,075	g_{14}	0	-0,100+j 0,075
g_{15}	0	0,000	g_{15}	0	0,000

Linear and Centered arrangements of sub-constellations in transmitter's antennas for 16-QAM and 16 Voronoi

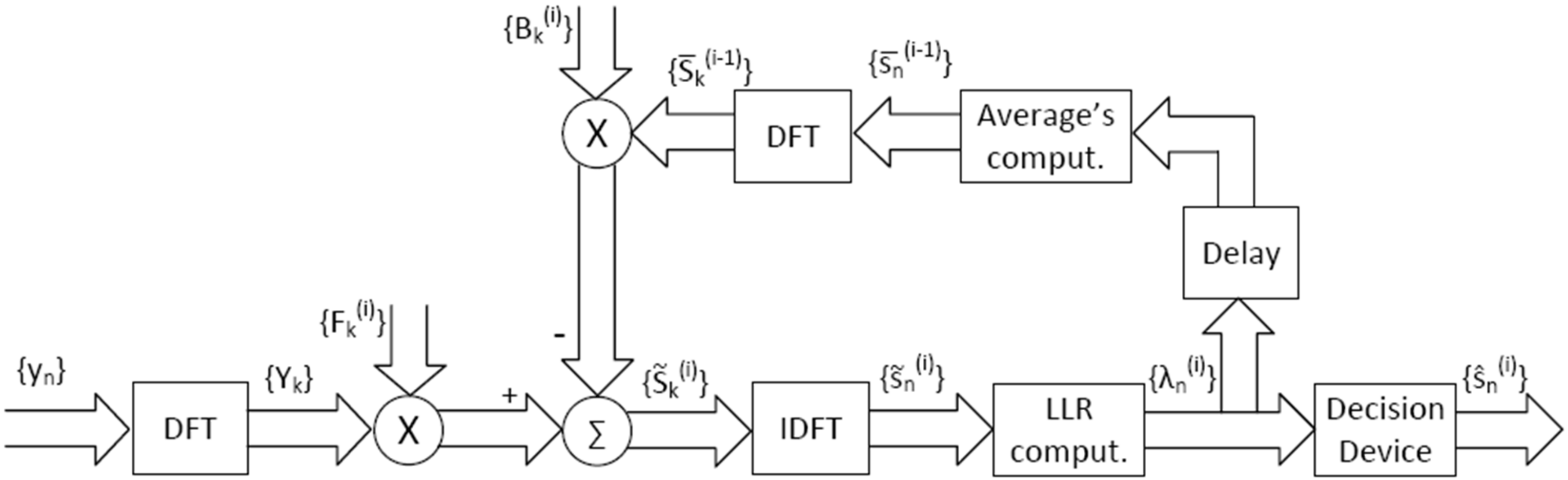
MISO System specified for Directivity

Transmitter



MISO System specified for Directivity

Receiver design



The receiver does not require any processing, as the multiple components of the modulation are summed over-the-air, and combined in terms of phase, as long as the receiver is in the desired DoA (alternatively, regular receive diversity can be employed).

MISO System specified for Directivity

Simulation Environment

- **SC-FDE systems with multilevel modulations.**

- **We considered 16-QAM, 64-QAM or Voronoi constellations, decomposed as as a sum of N_m BPSK components.**

- **Antennas are equally spaced by d=λ/4 and the constellations are optimized for θ=75º (under these conditions the directivity in the transmitted constellation is assured by phase rotations of the BPSK components).**

- **AWGN channel and a severely time-dispersive channel are considered**
  - **Channel is modeled as a frequency selective fading Rayleigh channel characterized by an uniform PDP (Power Delay Profile), with 32 equal-power taps, with uncorrelated Rayleigh fading on each tap.**

MISO System specified for Directivity

Simulation results

- The symbols s_n are selected with equal probability from a M-QAM constellation (dimensions of M=16 and M=64 are considered).

- The transmitter based on 16-QAM with gray mapping is characterized by the set of non null coefficients 2j, 1, 2 and j, associated to the antennas 1, 2, 3 and 4, respectively. 64-QAM uses 6 non-null coefficients with values 2j, 1, 2, j, 4 and 4j associated to the antennas 1, 2, 3, 4, 5 and 6, respectively.

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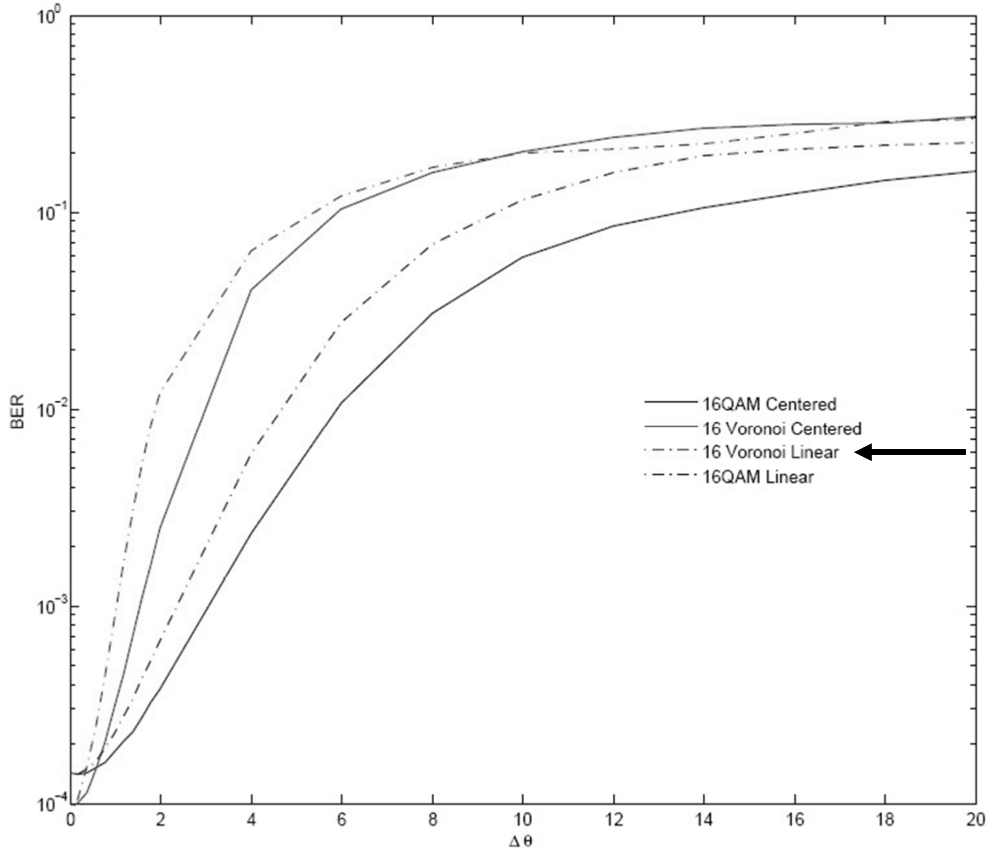
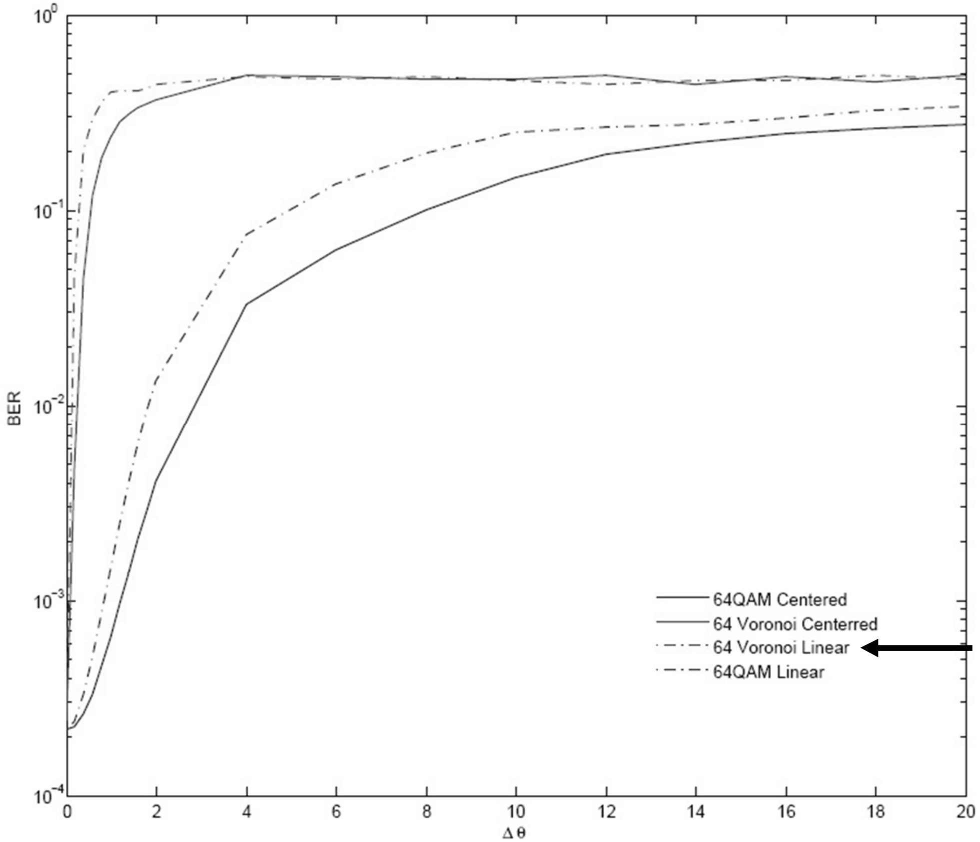


Impact of an angle error regarding the transmission direction θ in BER performance of size-16 constellations using linear and centered arrangements.

MISO System specified for Directivity



Impact of an angle error regarding the transmission direction θ in BER performance of size-64 constellations using linear and centered arrangements

MISO System specified for Directivity

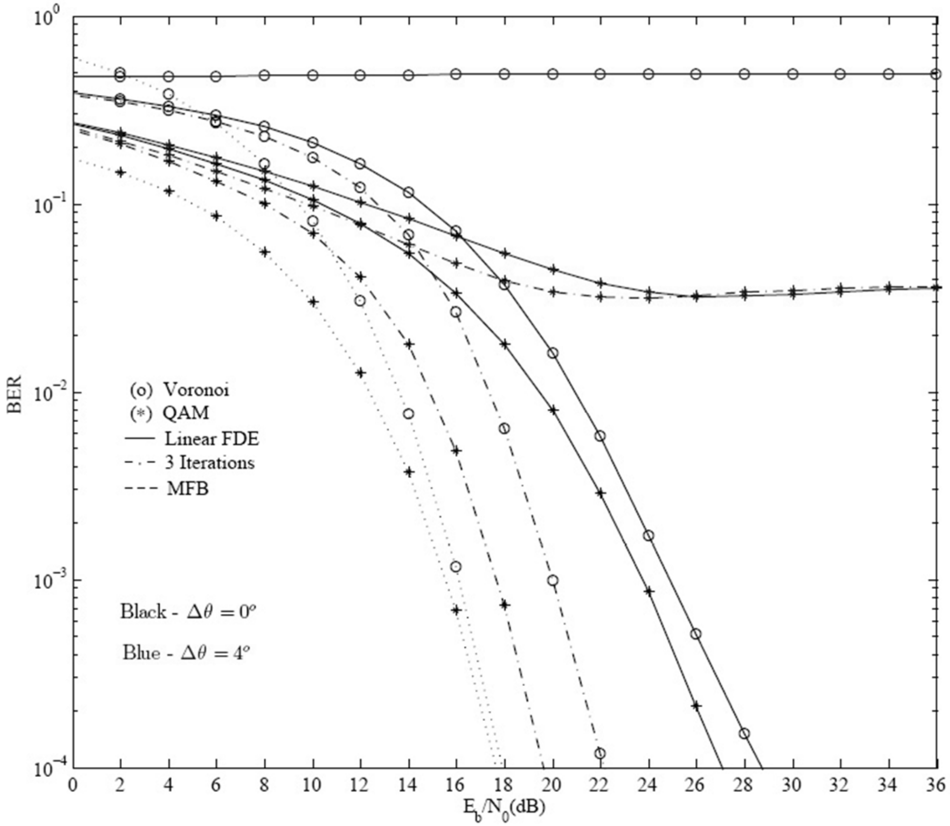
Analysis of Simulation Results

- **The impact of constellation's directivity on system's performance increases with the constellation's size.**

- **Higher directivity is assured by Voronoi constellations with a linear arrangement (uses 16 antennas, instead of 4 [16-QAM] or 6 [64-QAM]).**

- **Increasing system's spectral efficiency / higher modulation orders assures a better separation of the data streams transmitted for the different users.**
  - **Higher impact of angle errors for constellations that are decomposed in a higher number of sub-constellations (i.e. the case of Voronoi constellations).**

MISO System specified for Directivity



Linear array: BER performance for size-64 constellations with a frequency selective channel and an angle error against to transmission direction θ.

MISO System specified for Directivity

Analysis of Simulation Results

- **When the angle error is null for 3 iterations of IB-DFE the performance is close to the Matched Filter Bound (MFB).**

- **Due directivity errors (see 4º of error) other users are unable to decode efficiently the transmitted data (the constellation symbol is degenerated)**

- **Voronoi constellations are the best choice.**
  - **Voronoi constellations achieves higher directivity but worse performance.**

Conclusions

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- **Results show that the proposed MIMO / MISO system achieves directivity, while degenerating the constellation signals in the other directions.**

- **Directivity can increase with higher spectral efficiencies / higher order modulations.**

- **Constellation shaping implemented by a MISO transmission structure achieves physical layer security.**

- **Besides the aspects already mentioned, this approach also improves the power efficiency given the decomposition of multilevel constellations into constant envelope signals.**
    - **This facilitates the use of simplified non-linear amplifiers.**

Acknowledgements

- This work was supported by FCT project IT UID/EEA/50008/2013