Karlsruher Institut für Technologie

Development of a Single-Carrier SM-MIMO Transceiver

Detector Design
MIMO Implementation

Communications Engineering Lab
Prof. Dr.rer.nat. Friedrich K. Jondral

System Model SC-SM

SM with N_t=2, BPSK

Bits-to-Symbol Mapping		
Input bits	Active antenna	BPSK symbol
00	1	-1
01	1	+1
10	2	-1
11	2	+1

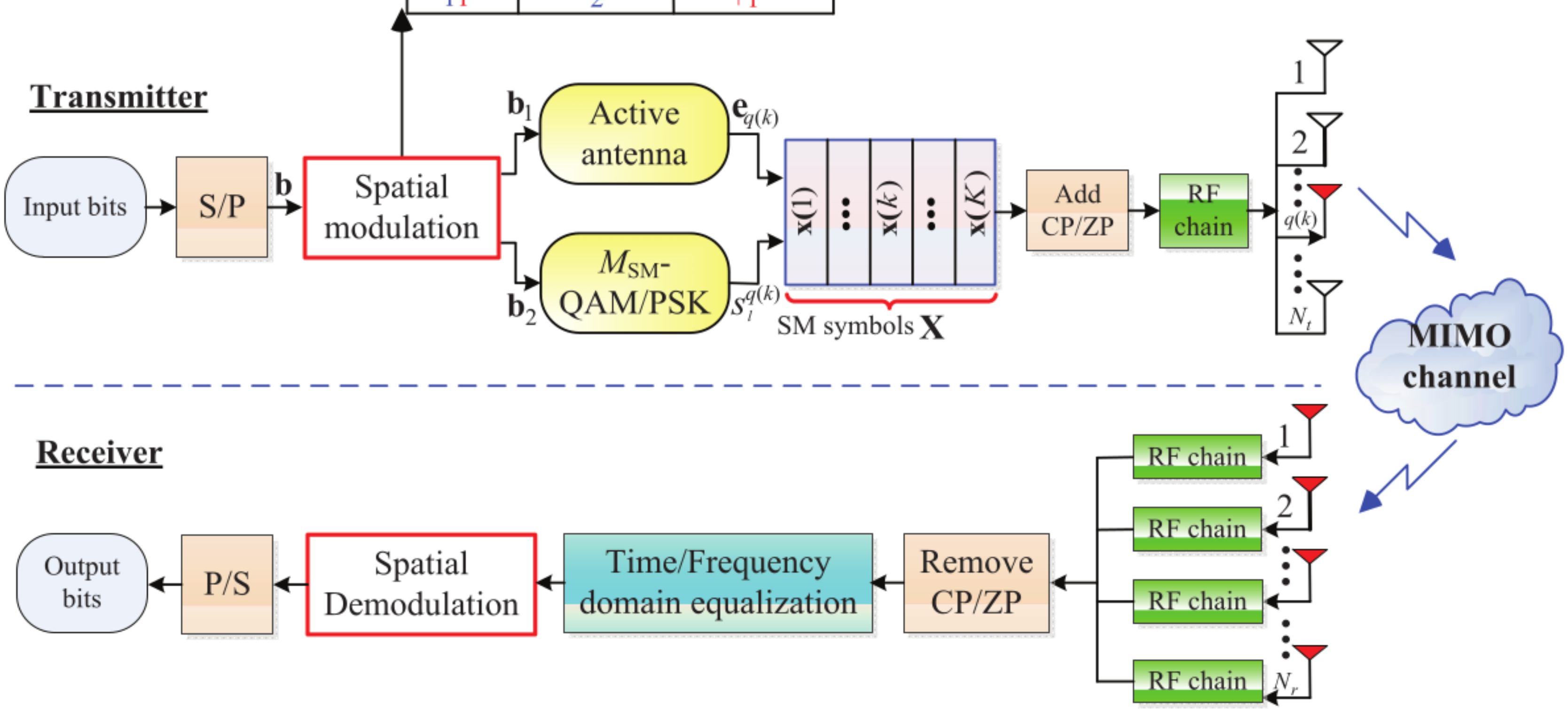

Figure 1: General transceiver structure of SC-SM systems [**1**]

Low-Complexity Detection Scheme for GSM-SC

- Based on M-algorithm
- Single stream ML detection
- Avoids QR-decomposition
- Balanced trade-off: performance & complexity
- Scheme approaches ML detector with increasing M
- Efficient operation even in rank-deficient channel scenarios

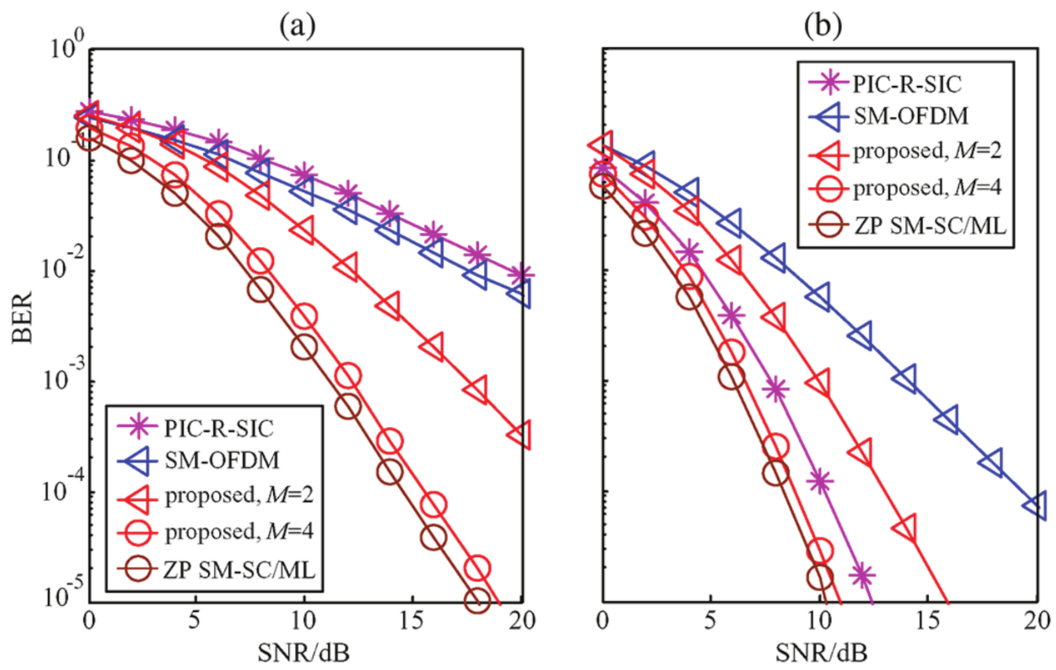

Figure 4: BER of ZP-aided SM-SC and SM-OFDM with different receiver antennas: (a) N_r = 1; (b) N_r = 2 [**1**]

Current Detector Design

- Transmission system fully implemented:

$$\underbrace{\begin{bmatrix} \mathbf{Y}_1 \\ \mathbf{Y}_2 \\ \vdots \\ \mathbf{Y}_{K+P-1} \end{bmatrix}}_{\mathbf{Y}\text{ of size}(K+P-1)N_r\times 1} = \underbrace{\begin{bmatrix} \mathbf{H}_0 & \mathbf{O} & \dots & \mathbf{O} & \mathbf{O} \\ \mathbf{H}_1 & \mathbf{H}_0 & \dots & \mathbf{O} & \mathbf{O} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \mathbf{H}_{P-1} & \mathbf{H}_{P-2} & \dots & \mathbf{H}_0 & \mathbf{O} \\ \mathbf{O} & \mathbf{H}_{P-1} & \dots & \mathbf{H}_1 & \mathbf{H}_0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \mathbf{O} & \mathbf{O} & \dots & \mathbf{H}_{P-1} & \mathbf{H}_{P-2} \\ \mathbf{O} & \mathbf{O} & \dots & \mathbf{O} & \mathbf{H}_{P-1} \end{bmatrix}}_{\mathbf{H}\text{ of size }(K+P-1)N_r\times KN_t} \underbrace{\begin{bmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_K \end{bmatrix}}_{\mathbf{x}\text{ of size }KN_t\times 1} + \underbrace{\begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \\ \vdots \\ \mathbf{n}_{K+P-1} \end{bmatrix}}_{\mathbf{n}\text{ of size }(K+P-1)N_r\times 1}$$

- Channel Matrix scales according to N_t, N_r:

```
[
 [-0.50745165-0.87831815j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 1.04248069-0.27567013j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 1.04583692-0.25768064j -0.50745165-0.87831815j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.14774513-0.92481899j  1.04248069-0.27567013j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.61323969-0.53632448j  1.04583692-0.25768064j -0.50745165-0.87831815j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [-0.24550281-0.42326164j  0.14774513-0.92481899j  1.04248069-0.27567013j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j          0.61323969-0.53632448j  1.04583692-0.25768064j  0.50745165-0.87831815j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j         -0.24550281-0.42326164j  0.14774513-0.92481899j  1.04248069-0.27567013j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j          0.61323969-0.53632448j  1.04583692-0.25768064j -0.50745165-0.87831815j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j         -0.24550281-0.42326164j  0.14774513-0.92481899j  1.04248069-0.27567013j  0.00000000+0.j          0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.61323969-0.53632448j  1.04583692-0.25768064j -0.50745165-0.87831815j  0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.24550281-0.42326164j  0.14774513-0.92481899j  1.04248069-0.27567013j  0.00000000+0.j          0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.61323969-0.53632448j  1.04583692-0.25768064j  0.50745165-0.87831815j  0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j         -0.24550281-0.42326164j  0.14774513-0.92481899j  1.04248069-0.27567013j  0.00000000+0.j        ]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.61323969-0.53632448j  1.04583692-0.25768064j -0.50745165-0.87831815j]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j         -0.24550281-0.42326164j  0.14774513-0.92481899j  1.04248069-0.27567013j]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.61323969-0.53632448j  1.04583692-0.25768064j]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.24550281-0.42326164j  0.14774513-0.92481899j]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.61323969-0.53632448j]
 [ 0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j          0.00000000+0.j         -0.24550281-0.42326164j]
]
```


Communications Engineering Lab
Prof. Dr.rer.nat. Friedrich K. Jondral

Current Detector Design

- Working MIMO implementation (N_t x N_r):
  - 1 x 2
  - 2 x 2

$$\mathbf{e}_2^m = \left\| \hat{\mathbf{Y}}_2 - \begin{pmatrix} \mathbf{H}_0 & 0 \\ \mathbf{H}_1 & \mathbf{H}_0 \end{pmatrix} \begin{pmatrix} \mathbf{x}_1^m \\ \mathbf{x}_2 \end{pmatrix} \right\|_F^2$$
$$= \tilde{\mathbf{e}}_1^m + \left\| \mathbf{Y}_2 - \begin{pmatrix} \mathbf{H}_1 & \mathbf{H}_0 \end{pmatrix} \begin{pmatrix} \mathbf{x}_1^m \\ \mathbf{x}_2 \end{pmatrix} \right\|_F^2, \mathbf{x}_2 \in C_{GSM}$$

- M smallest metrics are chosen by M-algorithm:
  - M = 1
  - No final detection yet: $\hat{\mathbf{x}}_{proposed} = \underset{m \in (1,2,\ldots,\hat{M})}{\arg\min} ||\mathbf{Y} - \mathbf{H}\mathbf{D}_K^m||_F^2$

- Script to test the detector:
  - If every sent symbol is correctly detected: True
  - ~45% of the time this is the case (SNR = 10 dB)

Prospects

Karlsruher Institut für Technologie

- Adjust sent symbols
- Generalize for M (starting with M = 2)
- Compare BER performance with results in paper
- MIMO schemes to implement:
  - 2 x 1
  - N_t x N_r
- Fuse scripts: class based SISO transmission and MIMO detector scheme
- Addition of synchronization, channel estimation, spatial modulation
- Proof of concept with GNU Radio

Any questions?

- Sources
  - [1] L. Xiao, D. Lilin, Y. Zhang, Y. Xiao, P. Yang and S. Li, “**A low-complexity detection scheme for generalized spatial modulation aided single carrier systems**,” *IEEE Commun. Lett.*, vol. 19, no. 6, pp. 1069-1072, Jun. 2015