SSPD 2015

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Performance Analysis of Polynomial Matrix SVD-based Broadband MIMO Systems

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Motivation

<u>General benefits of MIMO:</u>

- Diversity gain → increase in reliability in data transmission
- Multiplexing gain → increased bit-rate without increasing the bandwidth (Bit/s)/Hz

<u>Defense relevance of MIMO:</u>

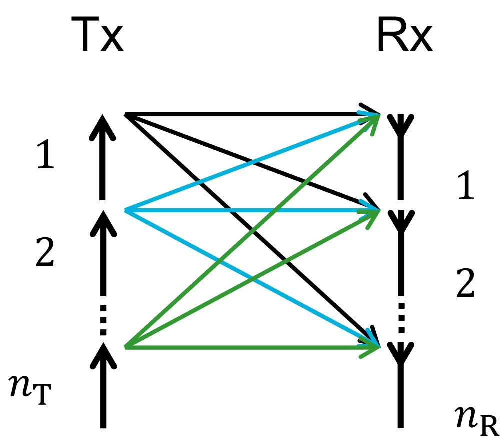
- MIMO radar application
    - Improved target detection performance
    - Improved angle estimation accuracy
    - Decreased minimum detectible velocity

Performance of an alternative MIMO orthogonalization approach for frequency-selective channels is analyzed: Polynomial Matrix Singular Value Decomposition (PMSVD)

Outline

1. Broadband MIMO System Model
   - Orthogonalization
   - Power Allocation
2. Bit-error rate analysis
3. Spectral efficiency analysis
4. Conclusion

Broadband MIMO System Model



frequency-selective links between all receive and transmit antennas are described by the sampled **channel impulse responses**

$$h_{\nu,\mu}(k) = (h_0\,, h_1\,, \dots\,, h_{L_c})$$

ν ..output index
μ ..input index

Two different Broadband MIMO system descriptions

basis:

$$h_{\nu,\mu}(k) = (h_0\,, h_1\,, \dots\,, h_{L_c})$$

convolution matrix → time-domain description

z-transform → description in z-domain

time-domain description

$$\boldsymbol{H}_{\nu\mu} = \begin{bmatrix} h_0 & 0 & 0 & \cdots & 0 \\ h_1 & h_0 & 0 & \cdots & \vdots \\ h_2 & h_1 & h_0 & \cdots & 0 \\ \vdots & h_2 & h_1 & \cdots & h_0 \\ h_{L_c} & \vdots & h_2 & \cdots & h_1 \\ 0 & h_{L_c} & \vdots & \cdots & h_2 \\ 0 & 0 & h_{L_c} & \cdots & \vdots \\ 0 & 0 & 0 & \cdots & h_{L_c} \end{bmatrix}$$

description in z-domain

$$\underline{h}_{\nu,\mu}(z) = h_0 + h_1 z^{-1} + \cdots + h_{L_c} z^{-L_c}$$

channel matrix

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{H}_{11} & \cdots & \boldsymbol{H}_{1n_\mathrm{T}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{H}_{n_\mathrm{R}1} & \cdots & \boldsymbol{H}_{n_\mathrm{R}n_\mathrm{T}} \end{bmatrix}$$

$$\boldsymbol{u} = \boldsymbol{H} \cdot \boldsymbol{c} + \boldsymbol{n}$$

spatio-temporal vector coding

polynomial channel matrix

$$\underline{\boldsymbol{H}}(z) = \begin{bmatrix} \underline{h}_{11}(z) & \cdots & \underline{h}_{1n_\mathrm{T}}(z) \\ \vdots & \ddots & \vdots \\ \underline{h}_{n_\mathrm{R}1}(z) & \cdots & \underline{h}_{n_\mathrm{R}n_\mathrm{T}}(z) \end{bmatrix}$$

$$\underline{\boldsymbol{u}}(z) = \underline{\boldsymbol{H}}(z) \cdot \underline{\boldsymbol{c}}(z) + \underline{\boldsymbol{n}}(z)$$

z-domain description

Broadband MIMO system description

How to eliminate the inter-channel interference?

Factorize the channel matrix for orthogonalization by applying

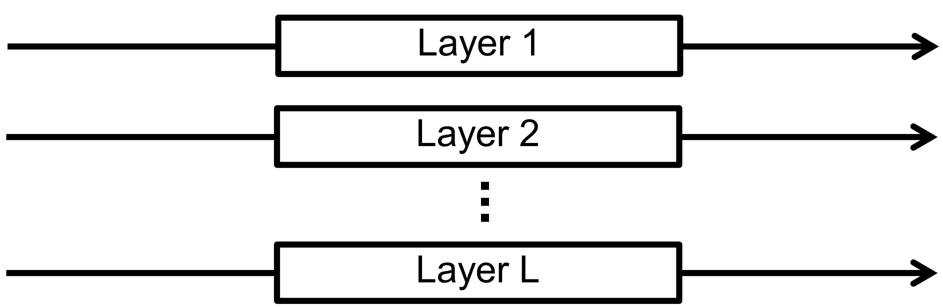
singular value decomposition (SVD)

$$\boldsymbol{H} = \boldsymbol{S} \cdot \boldsymbol{V} \cdot \boldsymbol{D}^{\mathrm{H}}$$

polynomial matrix SVD (PMSVD) using the SBR2 algorithm

$$\underline{\boldsymbol{H}}(z) = \underline{\boldsymbol{S}}(z) \cdot \underline{\boldsymbol{V}}(z) \cdot \underline{\tilde{\boldsymbol{D}}}(z)$$

- By utilizing this factorization and appropriately doing signal pre- and post-processing at the transmitter and receiver only the diagonal matrices $\boldsymbol{V}$ and $\underline{\boldsymbol{V}}(z)$ remain



✓ System is transformed into independent non-interfering layers

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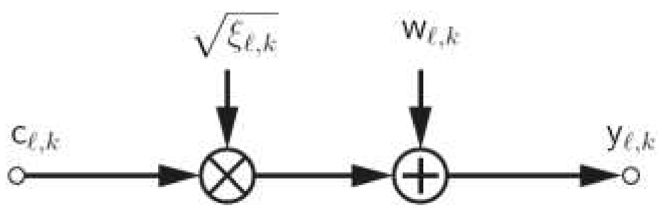
SVD-based MIMO layer model

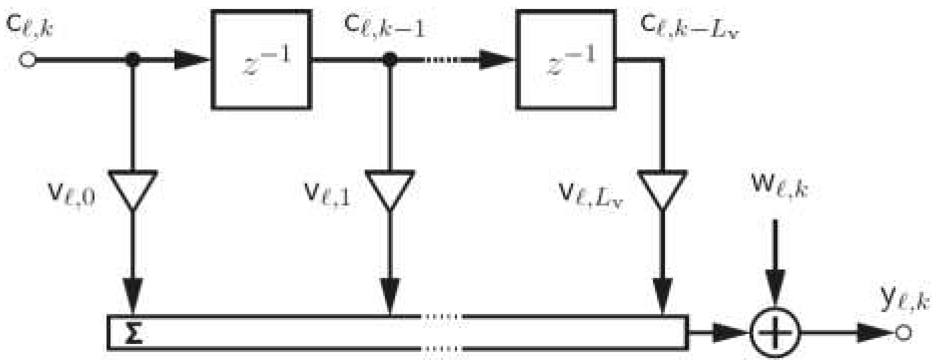
$$\boldsymbol{y} = \boldsymbol{V} \cdot \boldsymbol{c} + \boldsymbol{w}$$



Activated layer index $\ell = 1,2,\ldots,L$

PMSVD-based MIMO layer model

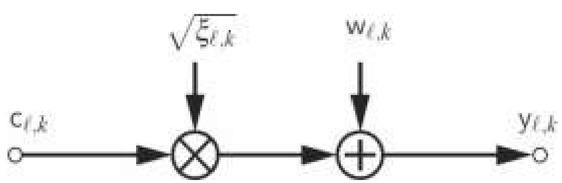
$$y_\ell(k) = v_\ell(k) * c_\ell(k) + w_\ell(k)$$



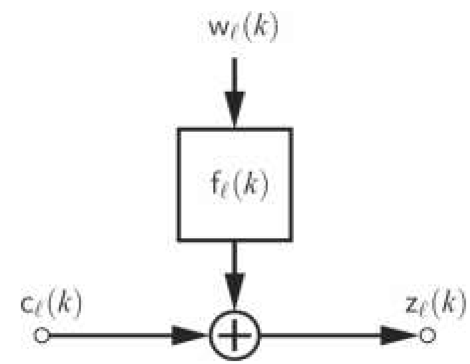
Layer-specific PMSVD-model is similar to a finite impulse response filter

- ➢ inter-symbol-interference (ISI) occurs
- ✓ T-spaced zero forcing equalizers are applied for eliminating the ISI

non-interfering and ISI-free broadband layer-based MIMO models



Resulting SVD system model

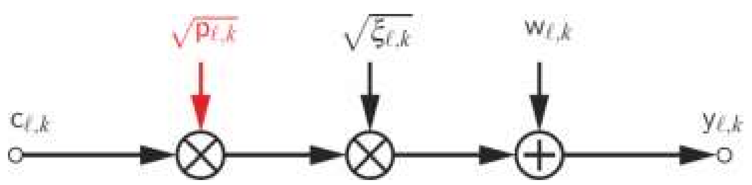


Resulting T-PMSVD system model

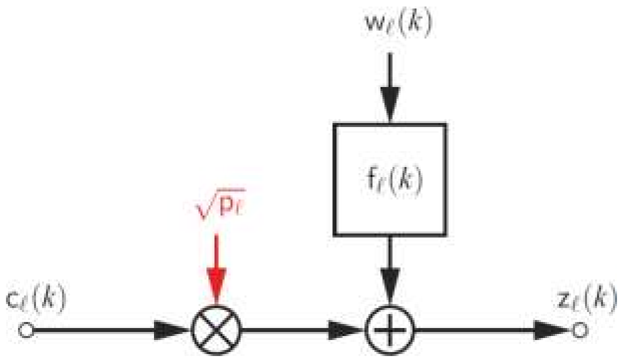
- half vertical eye opening is influenced by the singular values
- noise power is weighted by the equalizer

→ different qualities on all layers

Power Allocation (PA) Strategies



Resulting SVD system model



Resulting T-PMSVD system model

- Intuitively the transmit power is uniformly distributed over all layers

<u>equal SNR PA:</u>

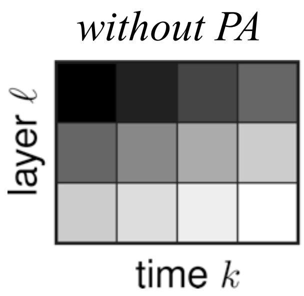
- The Layer with the highest BER limits the overall BER performance
  - ➢BERs of all layers are nearly balanced by equalizing the SNR values

Power Allocation Strategies

<u>SVD-based equal SNR PA</u>

Resulting SNRs:

- black → high SNR
- white → low SNR



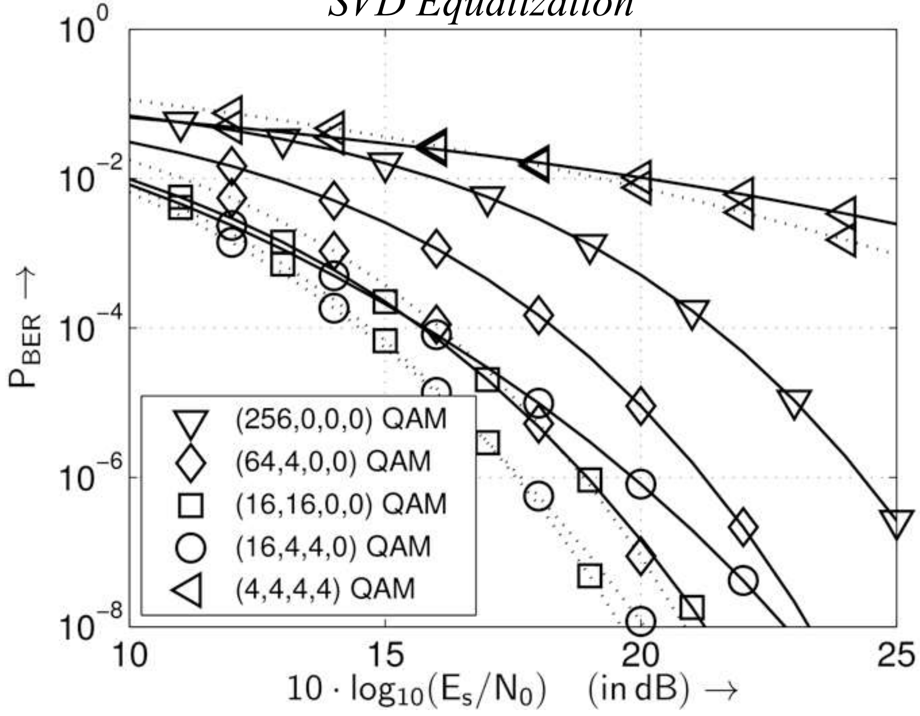
<u>T-PMSVD equal SNR PA</u>

BER Analysis

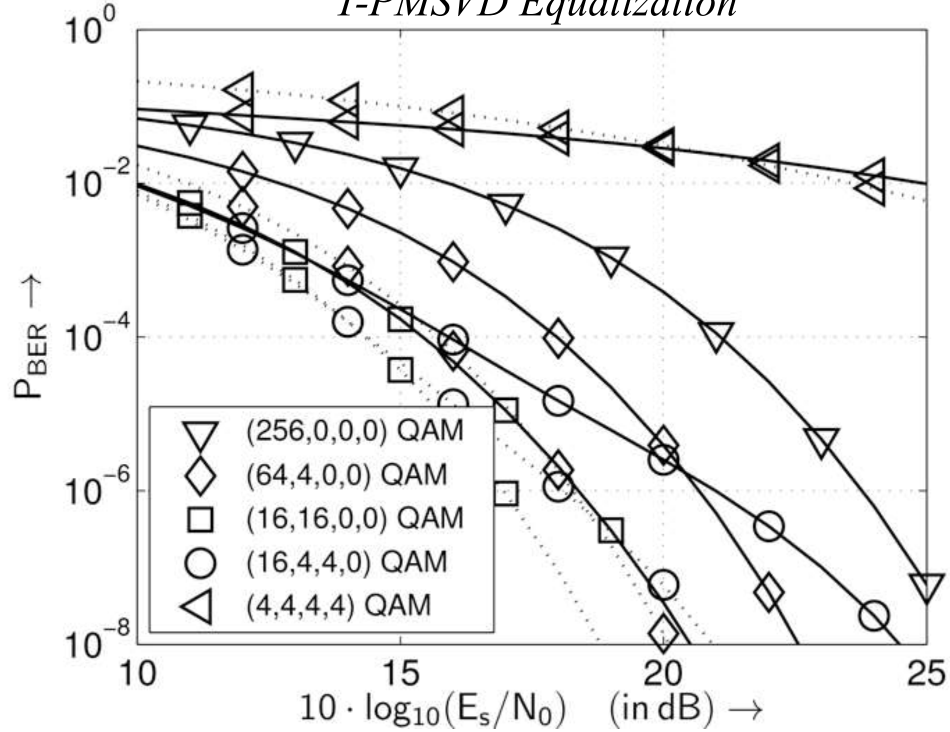
<u>4x4 Rayleigh Channel:</u>

- BER with PA (dotted lines) and without PA (solid lines) using fixed QAM constellations

SVD Equalization



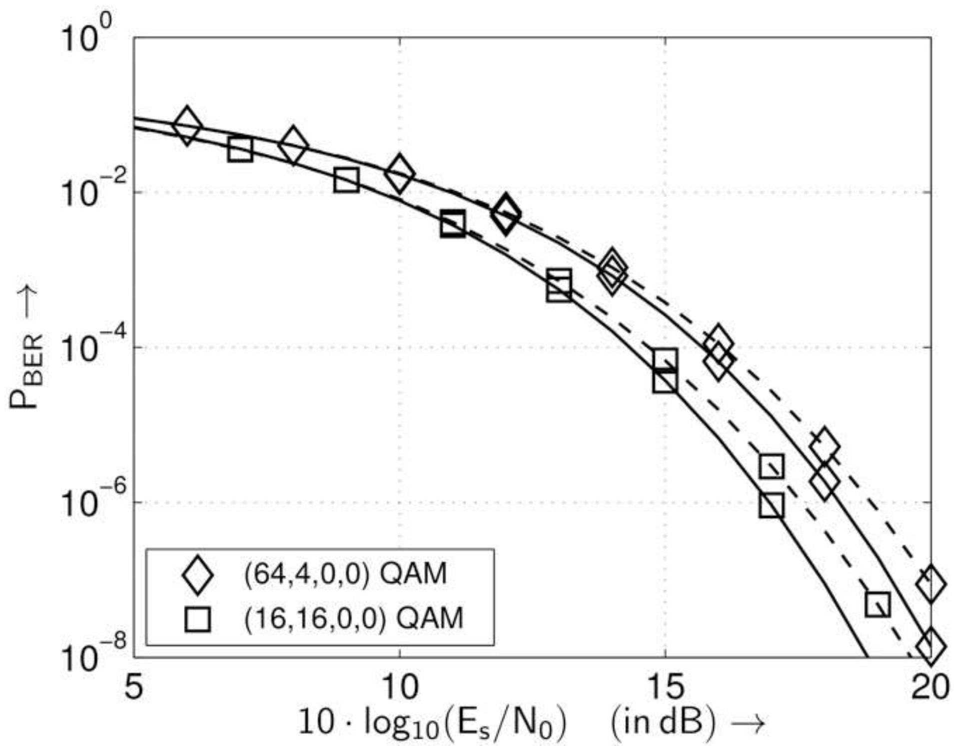
T-PMSVD Equalization



BER Comparison

<u>4x4 Rayleigh Channel:</u>

- SVD-equalization (dashed lines) and T-PMSVD equalization (solid lines)



Spectral Efficiency Analysis

Achievable Spectral Efficiencies

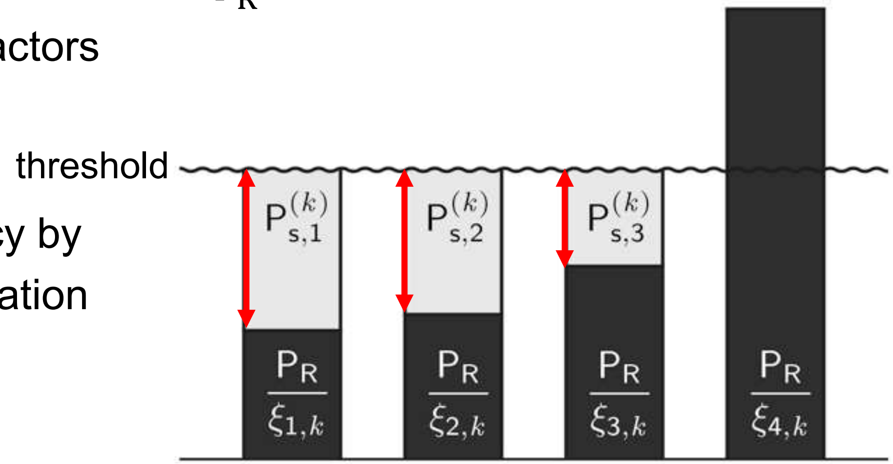
$$\eta_k = \sum_{\ell=1}^{L_\mathrm{W}} \log_2\left(1 + \rho^{(\ell,k)}\right)$$

with the SNRs:

$$\rho^{(\ell,k)} = \frac{P_{\mathrm{s},\ell}^{(k)}}{P_\mathrm{R}} \xi_{\ell,k}$$

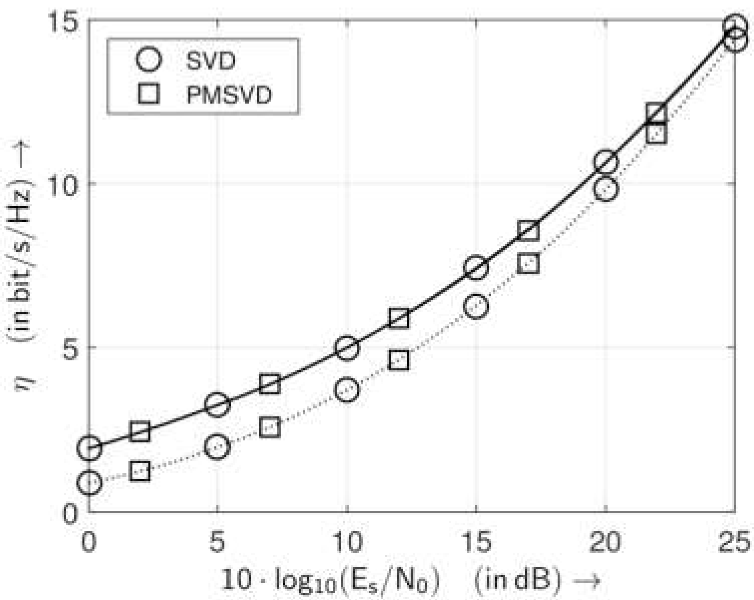
$\xi_{\ell,k}$ … layer specific weighting factors

Maximizing the Spectral efficiency by applying water-filling power allocation

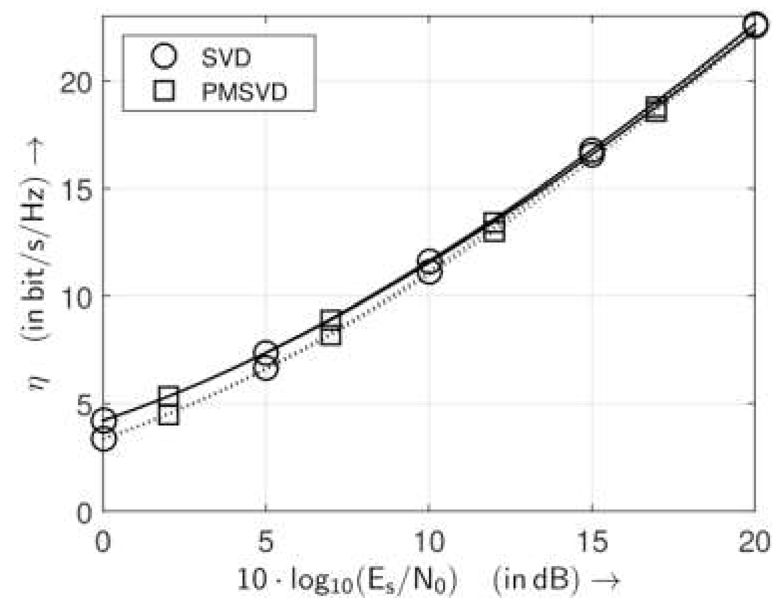


Spectral Efficiency Analysis

4x4 time-invariant channel



4x4 Rayleigh channel



- Spectral efficiency with water-filling PA (solid lines) and without PA (dotted lines)

  - Achievable spectral efficiency using PMSVD is nearly identical to applying SVD processing
  - Information-theoretically no drawback using PMSVD

Conclusion

- Information-theoretically the same spectral efficiency can be achieved in PMSVD systems comparing to conventional SVD-based systems

- BER performance using PMSVD processing in combination with a T-spaced ZF equalizer is slightly superior to the SVD BER performance within the analyzed channels and parameters

  - PMSVD processing seems to be an alternative to the classical SVD

Outlook

Options for increasing the BER performance:

- Viterbi detection instead of T-spaced zero forcing equalization in PMSVD-based systems
- Combined time and layer-based equal SNR power allocation in SVD systems
- Applying Optimal Power allocation

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Thank you

Any questions?

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