Linear Transmit Signal Processing in 1-Bit Quantized Massive MIMO Systems

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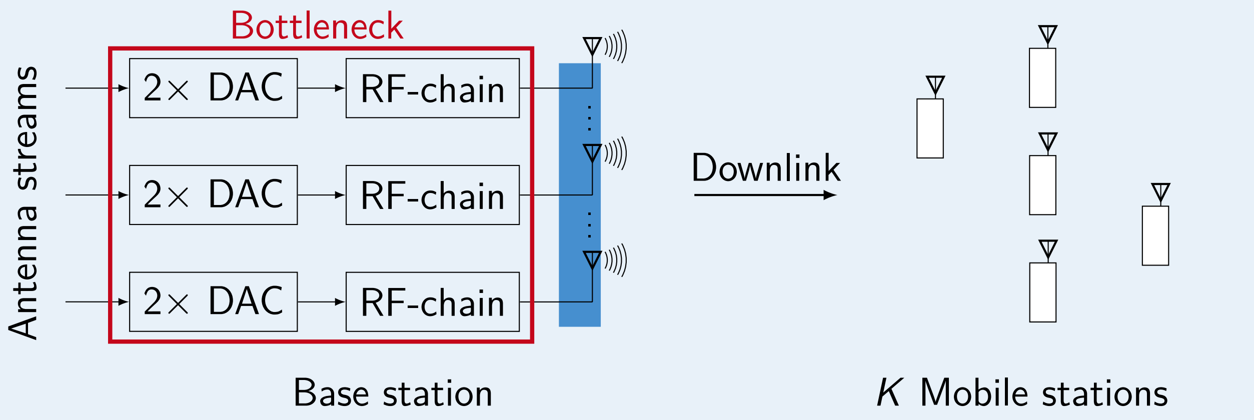
Motivation

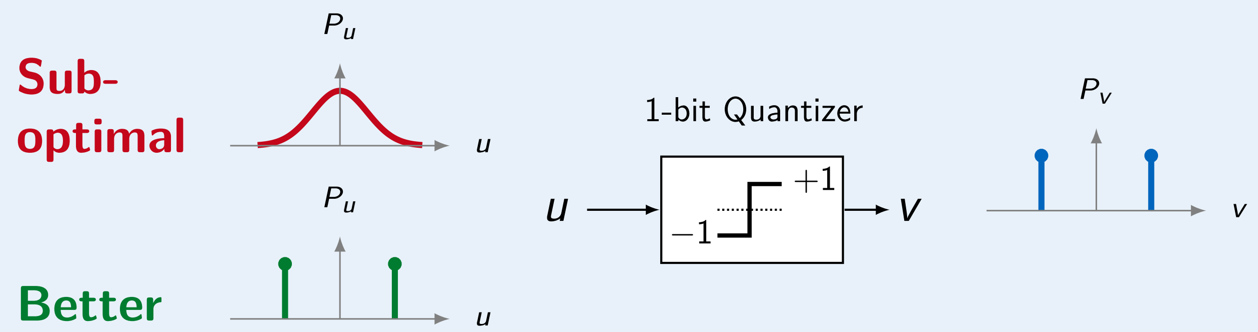
- **Goal**: Low-complexity and power-efficient **massive** MIMO system
- **Bottleneck**: Hardware complexity and power-consumption of RF-chains [1]
  - ⇔ Linearly operated Power Amplifiers (PAs)
  - ⇔ High-resolution Digital-to-Analog Converters (DACs)
- Does **not scale** for a **massive** MIMO system



- **Idea**:
  - 1-bit DACs ⇒ simplifies complexity and efficiency of RF-chains
  - Linear precoding ⇒ Find precoder **only** once per channel coherence time

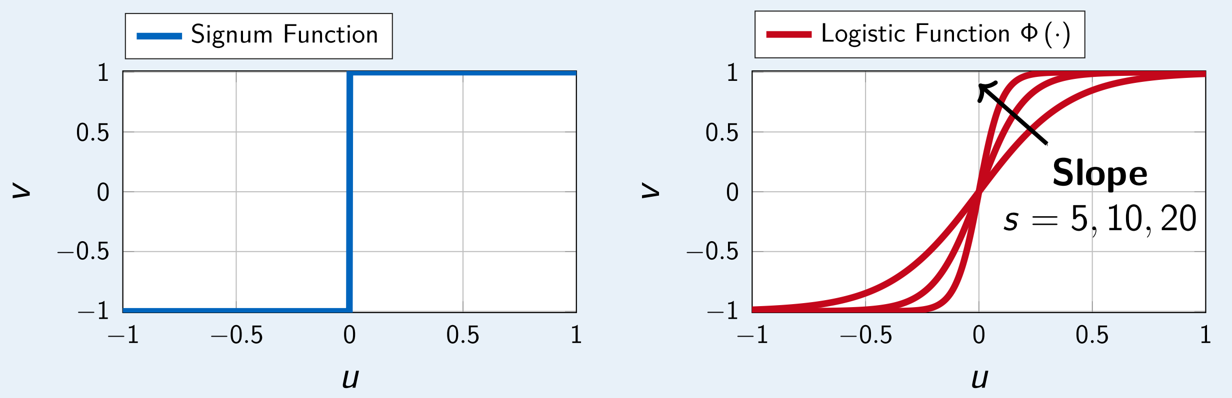
DAC Model (1-bit)

- **State-of-the-art**: Statistical model for quantizer ⇒ Assumes Gaussian u
- Our approach: Model quantizer by **Sigmoid** function

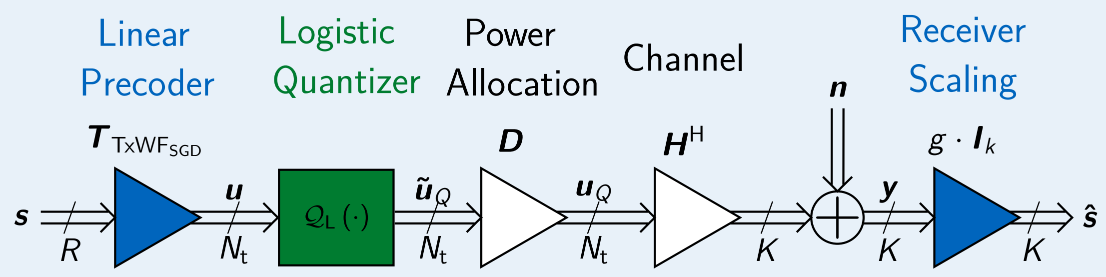


Smooth Approximation of 1-bit DAC

- Approximate Signum function by a Sigmoid function $\Phi(\cdot)$



System Model (flat fading)



- **Of interest**: $\boldsymbol{T}_{\mathrm{TxWF_{SGD}}}$, g
- **Logistic quantizer**: $\mathcal{Q}_{\mathrm{L}}(\cdot) = \Phi(\Re\{\cdot\}) + j \cdot \Phi(\Im\{\cdot\})$
- Power allocation: *Equal* ($\boldsymbol{D}_{\mathrm{EQ}} = c \cdot \mathbf{I}_{N_t \times N_t}$), *non-equal* ($\boldsymbol{D}_{\mathrm{NEQ}} = \mathrm{fct}(\boldsymbol{T})$)
- TX-Power constraint: $\mathrm{E}\left[\boldsymbol{u}_Q^{\mathrm{H}} \boldsymbol{u}_Q\right] \leq P_{\mathrm{tx}}$
- Noise: $\boldsymbol{n} \sim \mathcal{CN}(\mathbf{0}_K, \boldsymbol{C}_{\boldsymbol{nn}})$

Constrained Optimization Problem

$$\textbf{MSE:} \quad \epsilon = \frac{1}{N} \cdot \left\| \mathbf{\Pi} \boldsymbol{S} - \widehat{\boldsymbol{S}} \right\|_{\mathrm{F}}^2$$

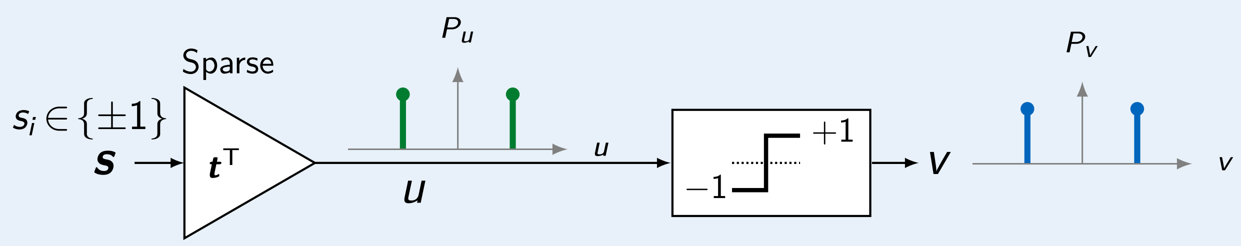
- Data symbols $\boldsymbol{s}$ from *QPSK*
- **Sample matrix** $\boldsymbol{S} \in \mathbb{C}^{R \times N}$: $[\boldsymbol{s}_1, \ldots, \boldsymbol{s}_N]$, all combinations of $\boldsymbol{s}$
- **Receive symbol matrix** $\widehat{\boldsymbol{S}} \in \mathbb{C}^{K \times N}$: $[\hat{\boldsymbol{s}}_1, \ldots, \hat{\boldsymbol{s}}_N]$
- Superposition matrix $\mathbf{\Pi} \in \mathbb{C}^{K \times R}$ ⇔ Higher-rank precoding [2]
- Normalization: $1/N$

Finding $\boldsymbol{T}_{\mathrm{TxWF_{SGD}}}$ and g

MSE smooth and nonlinear in $\boldsymbol{T}$ ⇒ (Stochastic) Gradient Algorithms

Complexity and Regularization

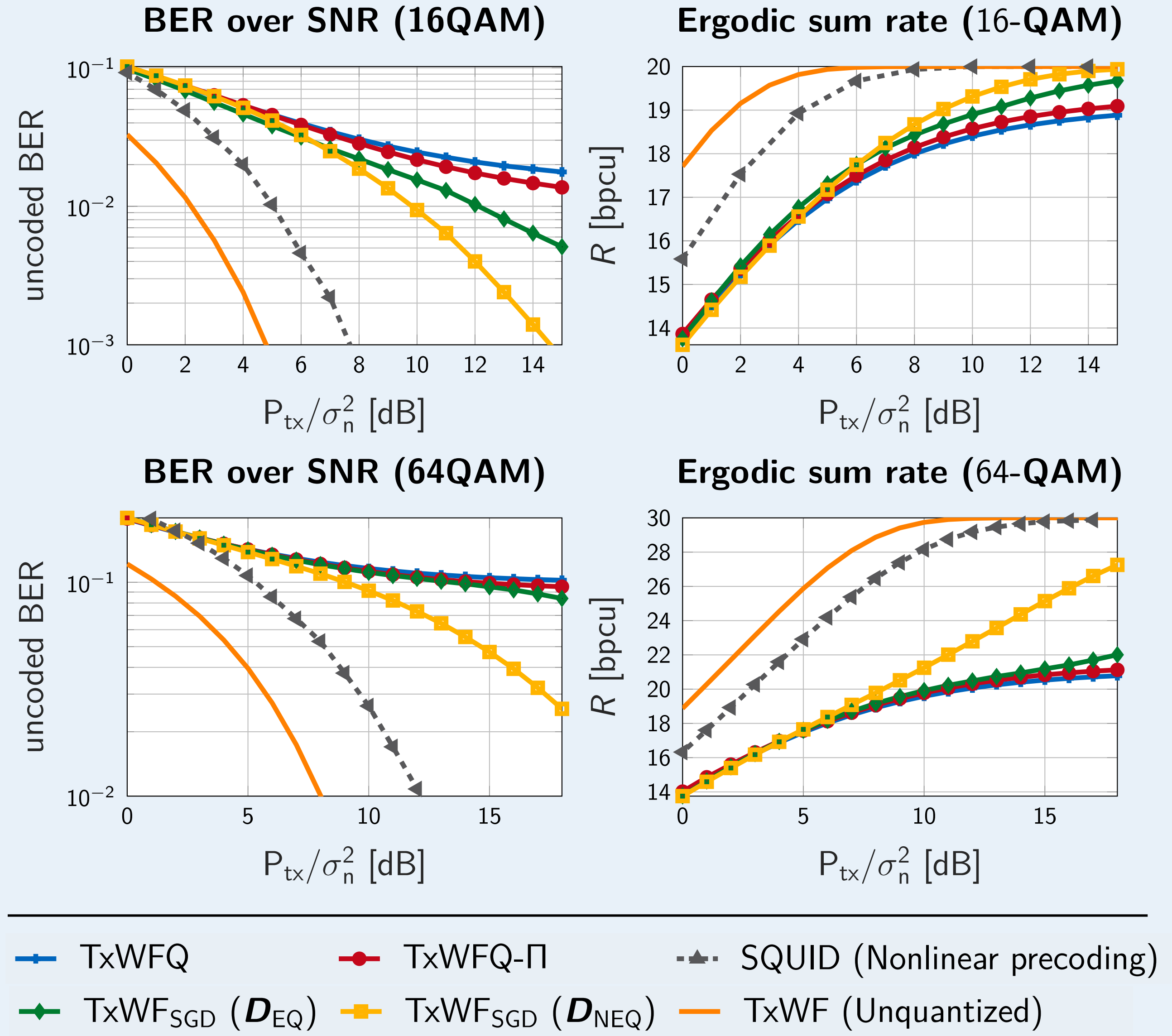
- **Complexity** per step $\mathcal{T} \propto N = |\mathcal{A}_{\mathrm{rx}}|^K$
- **Receiver alphabet** $|\mathcal{A}_{\mathrm{rx}}| = 4$ (QPSK), 16 (16-QAM), ...
  - ⇒ Reduce $\boldsymbol{S}$ and use regularization ⇏ **Overfitting**



Interpretation of Regularization

- **Sparsity**: l_1-regularization of $\boldsymbol{T}$ [3] ⇒ reduces quantization error
- **Quantization noise model**: l_2-regularization of $\boldsymbol{T}$ [4]

Numerical results (5 users, 80 TX-antennas, perfect CSI)



Conclusion

- **Improved rate and BER** compared to state-of-the-art linear precoders
- $\mathrm{TxWF_{SGD}}$ ($\boldsymbol{D}_{\mathrm{EQ}}$) **outperforms** TxWFQ and TxWFQ-Π
  - ⇒ Hardware simplification due to equal power allocation
- $\mathrm{TxWF_{SGD}}$ ($\boldsymbol{D}_{\mathrm{NEQ}}$) **reduces gap** to nonlinear precoding methods
- **Linear precoding** (once per channel coherence time) ⇔ **Nonlinear precoding** (for each transmit vector)
- **Further avenues:** Imperfect CSI and complexity comparison

References

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