A Learning Approach for Optimal Codebook Selection in Spatial Modulation Systems

Vidit Saxena[1,2], Baptiste Cavarec[1], Joakim Jaldén[1], Mats Bengtsson[1], and Hugo Tullberg[2]

[1]Department of Information Science and Engineering, KTH, Stockholm [2]Ericsson Research, Stockholm

Abstract

Problem Description

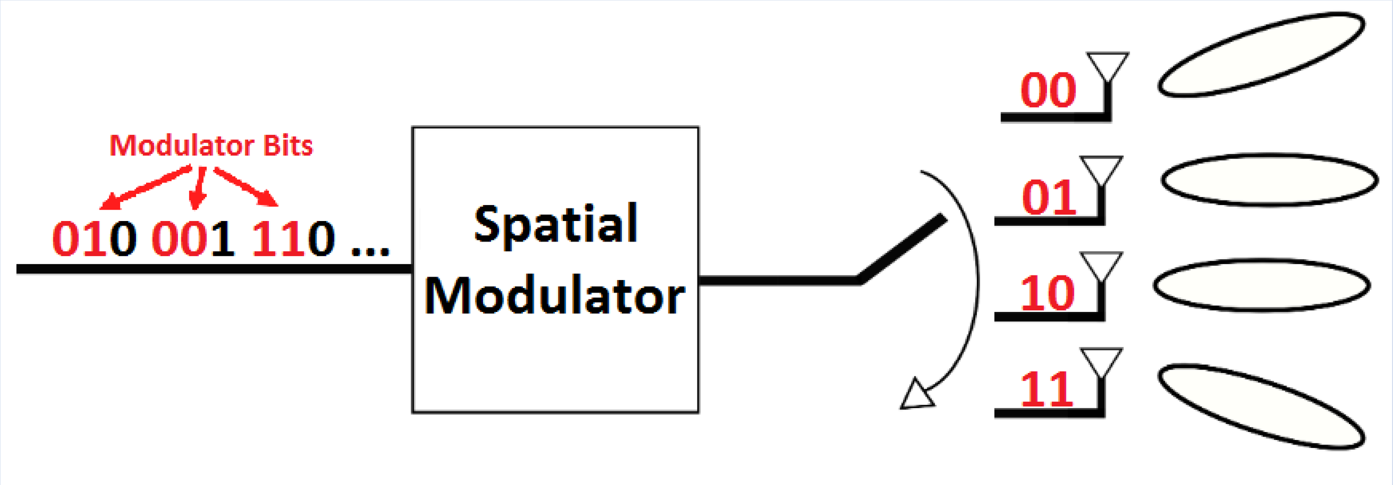
- Spatial modulation (SM) encodes information with the choice of one of out several available transmit antenna patterns.
- The optimal SM codebook depends on the dynamic channel state.
- For any arbitrary channel state, the problem of selecting the optimal codebook is analytically intractable in general [1].

Contributions

We propose a learning approach that selects the optimal SM codebook in each transmission instance for an optimality criteria defined in terms of

- Minimizing the symbol error rate (SER), or,
- Maximizing the average throughput.

Spatial Modulation



- The transmit SM signal is given by $\alpha\mathbf{x}_i$, where $\alpha \in \mathbf{\Omega}_i$ is the transmit symbol from the constellation $\mathbf{\Omega}_i$ for the i^{th} transmit antenna pattern and $\mathbf{x}_i$ is the pattern selection vector.
- The received SM signal is $\mathbf{y} = \sqrt{\rho}\mathbf{H}\,\alpha\mathbf{x}_i + \boldsymbol{w}$, where ρ is the average received signal-to-noise ratio, $\mathbf{H}$ is the $N_t \times N_r$ channel matrix and $\boldsymbol{w}$ is the noise.
- The SM receiver estimates the (pattern, symbol) combination $(\tilde{i}, \tilde{\alpha})$ that minimizes the Euclidean distance $||\mathbf{y} - \tilde{\alpha}\mathbf{H}\mathbf{x}_{\tilde{i}}||$.
- A successful symbol transmission occurs when $(\tilde{i}, \tilde{\alpha}) = (i, \alpha)$ and defines the binary success variable s.

Acknowledgements

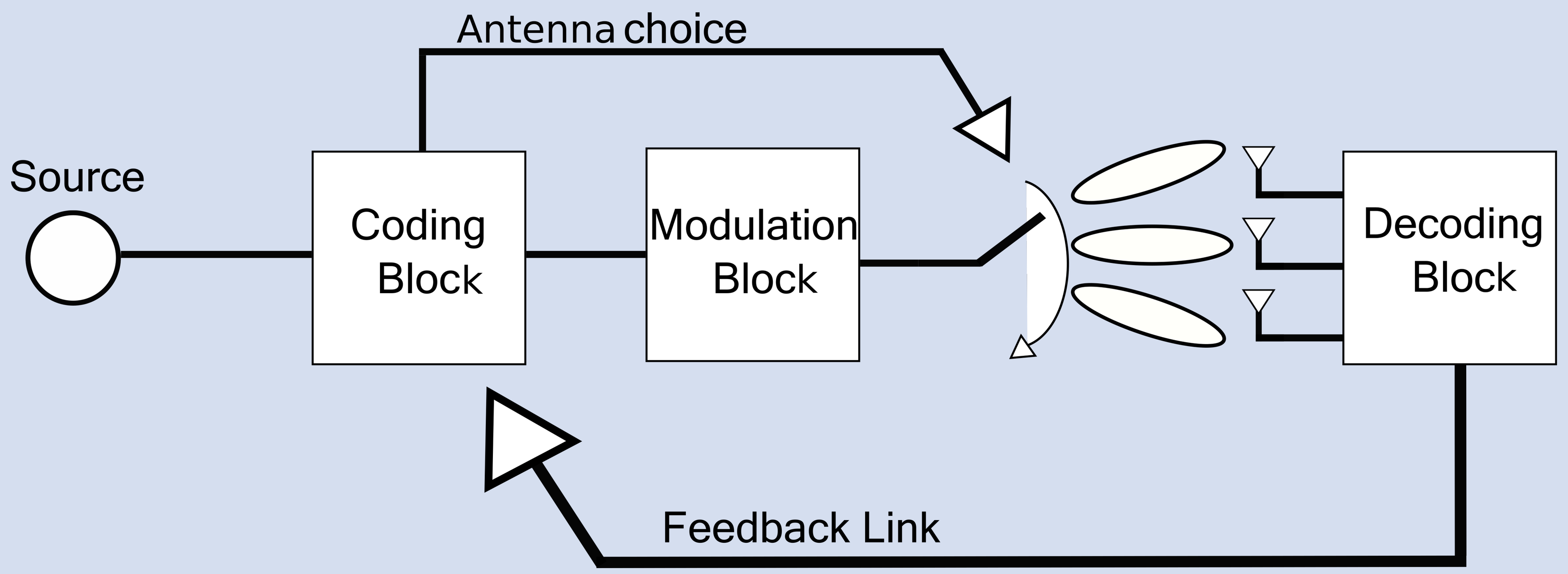
Vidit Saxena was partially supported by the Wallenberg AI, Autonomous Systems and Software Program (WASP) funded by the Knut and Alice Wallenberg Foundation.

Adaptive Spatial Modulation

In adaptive spatial modulation, the transmitter needs to select one out of several candidate SM codebook in each transmission instance to satisfy some optimality metric, typically defined in terms of the error rate or throughput [2].

1. The transmitter periodically transmits pilot signals that are known *a priori* to the receiver.
2. The receiver estimates the instantaneous channel state from pilot signals to determine the optimal SM codebook.
3. The receiver feeds back index of the optimal SM codebook to the transmitter.
4. The transmitter uses the the reported SM codebook for data transmission.

A SM codebook is defined as the set of constellations for each transmit antenna pattern, $\mathcal{C} = \{\mathbf{\Omega}_1, \ldots, \mathbf{\Omega}_{N_t}\}$. We assume that a fixed set of candidate SM codebooks are available and that this set is known to the transmitter as well as the receiver.



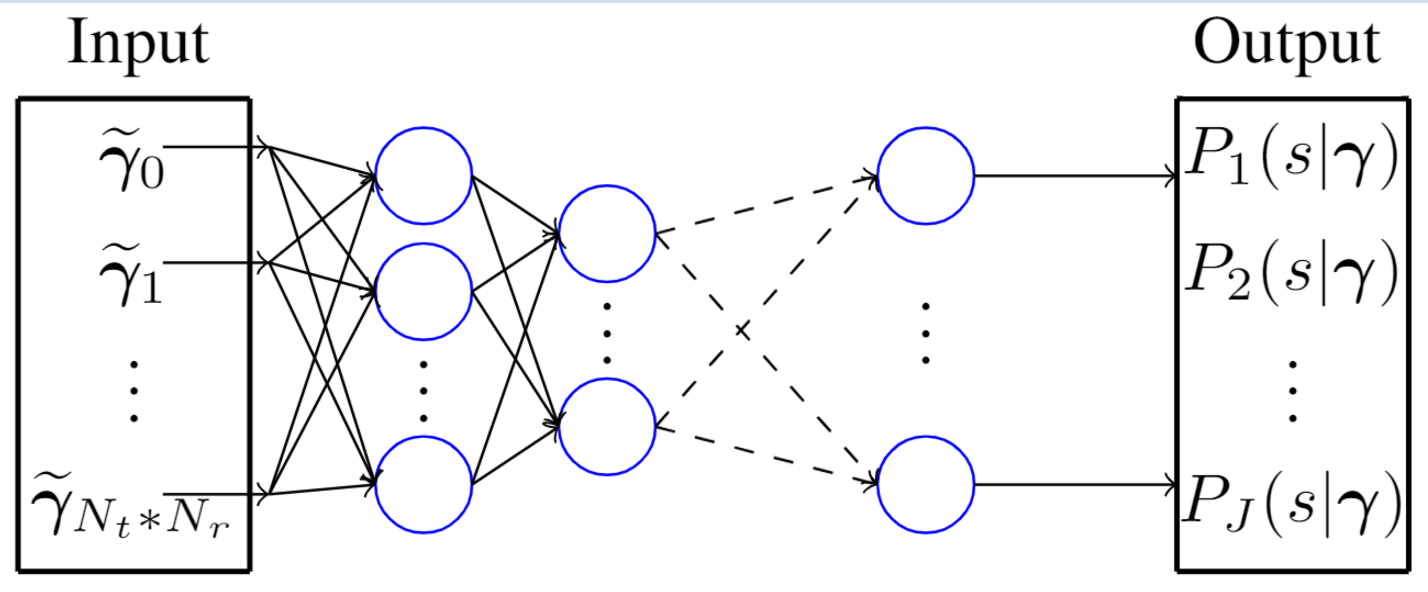
Optimal Codebook Selection

We train an artificial neural network (ANN) $f(\tilde{\boldsymbol{\gamma}}; \boldsymbol{\theta})$ to predict the conditional success probability $P(s|\tilde{\boldsymbol{\gamma}})$ for the channel SNR vector $\tilde{\boldsymbol{\gamma}}$ [3]. The ANN parameters are trained by minimizing the mean squared error loss function

$$\mathcal{L}(\boldsymbol{\theta}) = \frac{1}{N}\sum_{n=1}^{N}(s_n - f(\boldsymbol{\gamma}_n; \boldsymbol{\theta}))^2$$

$$\mathcal{L}(\boldsymbol{\theta}) \xrightarrow{N\to\infty} E\left\{\left(f(\boldsymbol{\gamma}; \boldsymbol{\theta}) - E\{s|\boldsymbol{\gamma}\}\right)^2\right\} + E\left\{\text{var}\{s|\boldsymbol{\gamma}\}\right\}$$

$$\boldsymbol{\theta}^{\text{opt}} = \arg\min_{\boldsymbol{\theta}} \mathcal{L}(\boldsymbol{\theta})$$



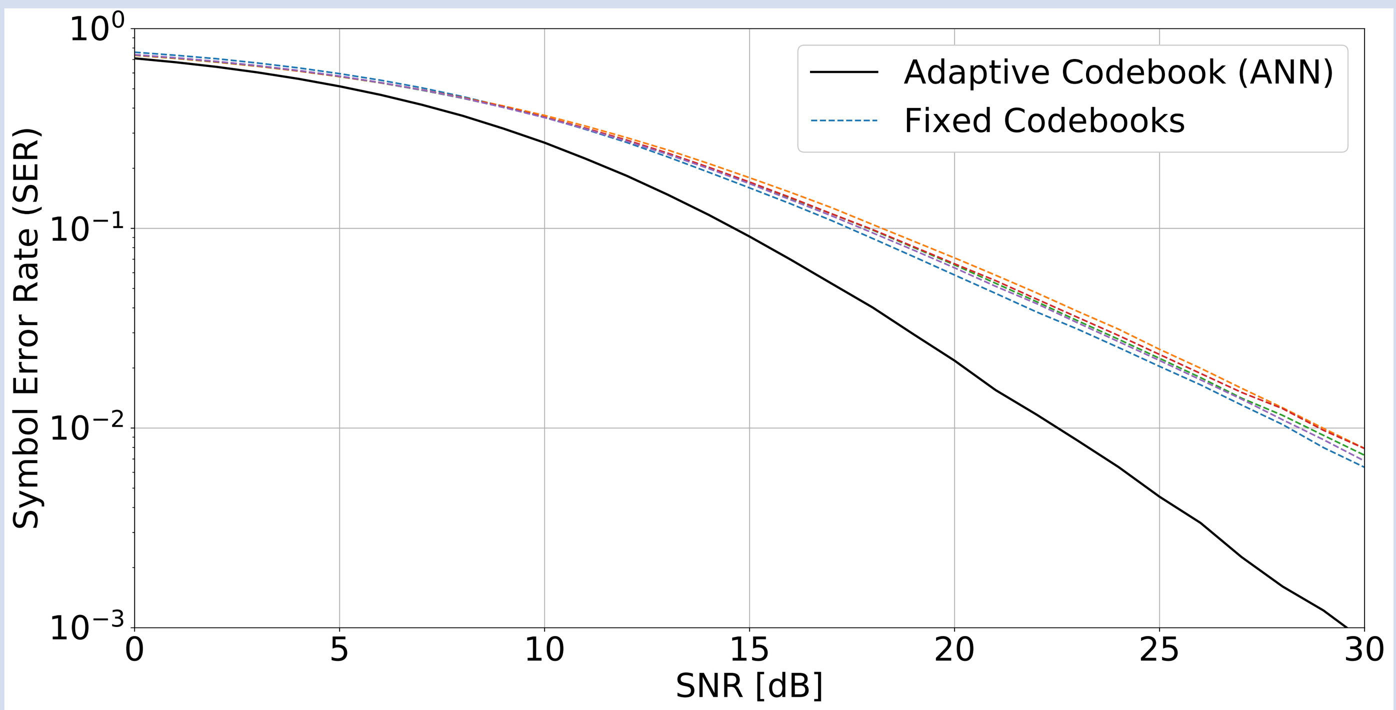
- We utilize a *fully connected, feedforward* ANN as illustrated in the figure to model the probability of success for each candidate codebook $j \in \{1, \ldots, J\}$ given the channel state $\tilde{\boldsymbol{\gamma}}$. Each layer of the ANN employs a rectified linear unit (ReLU) activation function. The output layer of the ANN is activated with a sigmoid to compress the network output between $[0, 1]$.
- The ANN parameters are trained offline through stochastic gradient descent and backpropagation. After training iteratively until convergence, the ANN predicts the success probability for each candidate codebook for a given channel state. We use these predictions to select the optimal codebook in each transmission instance.

Simulation Parameters	
Antenna config ($N_t \times N_r$)	4×1
Channel fading	I.i.d. Rayleigh
Bits per channel use	4

Codebook Index	Constellation Sizes $\{\lvert\mathbf{\Omega}_1\rvert, \ldots, \lvert\mathbf{\Omega}_{N_t}\rvert\}$
0	[16, 0, 0, 0]
1	[8, 8, 0, 0]
2	[8, 4, 4, 0]
3	[8, 4, 2, 2]
4	[4, 4, 4, 4]

Symbol Error Rate

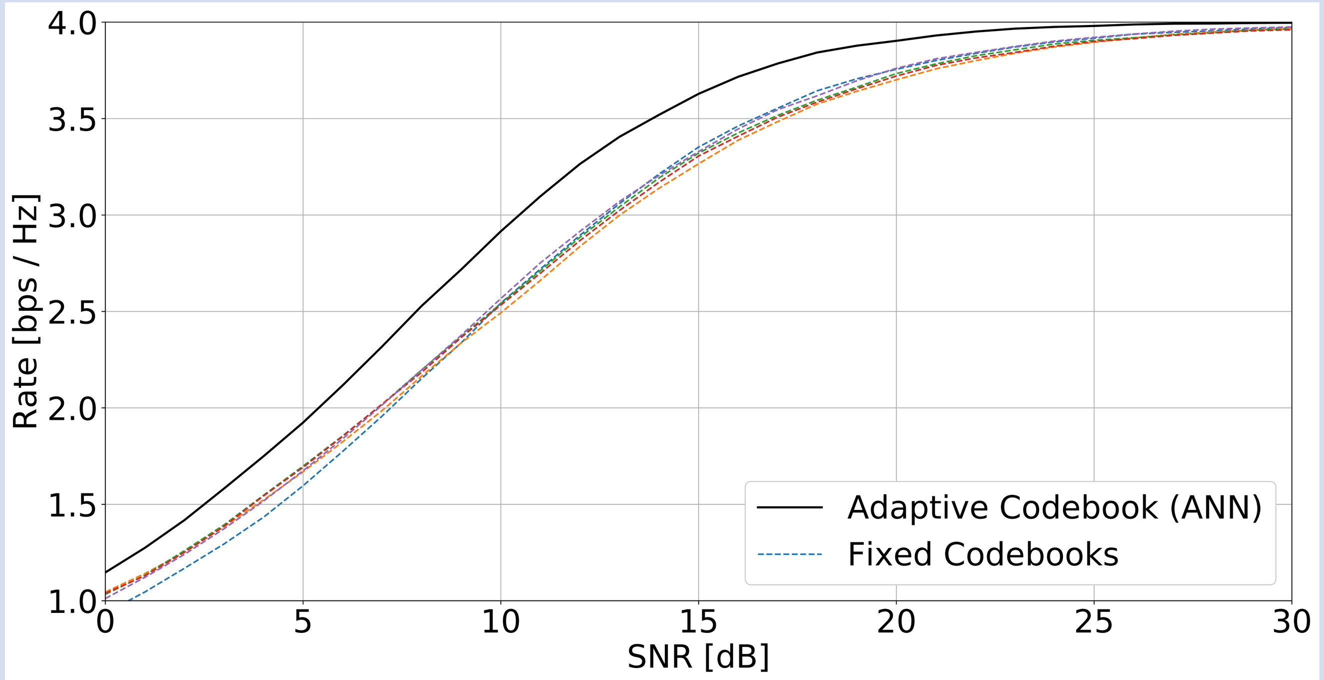
The optimal SM codebook is defined as the codebook with the minimum predicted SER in each transmission instance.



Optimal SM codebook selection lowers the spatial modulation SER by up to an order of magnitude.

Throughput

The optimal SM codebook is defined as the codebook with the maximum predicted throughput in each transmission instance.



Optimal SM codebook selection increases the spatial modulation throughput by up to 12%.

References

[1] P. Henarejos, A. Perez-Neira, A. Tato, and C. Mosquera, "Channel dependent mutual information in index modulations," *International Conference on Accoustics Speech and Signal Processing ICASSP 2018*.

[2] B. Cavarec and M. Bengtsson, "Channel dependent codebook design in spatial modulation," in *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 6413–6417, April 2018.

[3] V. Saxena, J. Jaldén, M. Bengtsson, and H. Tullberg, "Deep learning for frame error probability prediction in bicm-ofdm systems," in *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 6658–6662, April 2018.