Deep Learning Assisted Rate Adaptation in Spatial Modulation Links

Anxo Tato, Carlos Mosquera

atlanTTic Research Center, University of Vigo

Galicia (SPAIN)

August 28, 2019

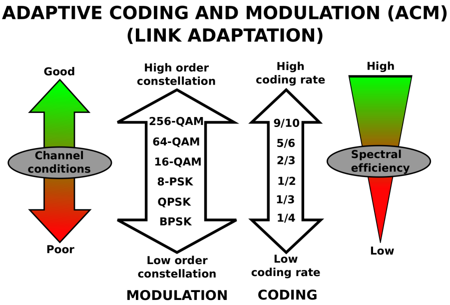
Motivation

- Increment of mobile data traffic (7x in 2017-2022)
- Mobile networks represented 0.2 % of global carbon emissions in 2017 (3x in 2020)
- Increment of M2M connections (4x in 2017-2022)
- Spectrum saturation

- **Spatial Modulation**
  - New modulation scheme for 5G and beyond 5G
  - Multi-antenna: high spectral efficiency
  - Low complexity: single RF chain
  - Better energy efficiency

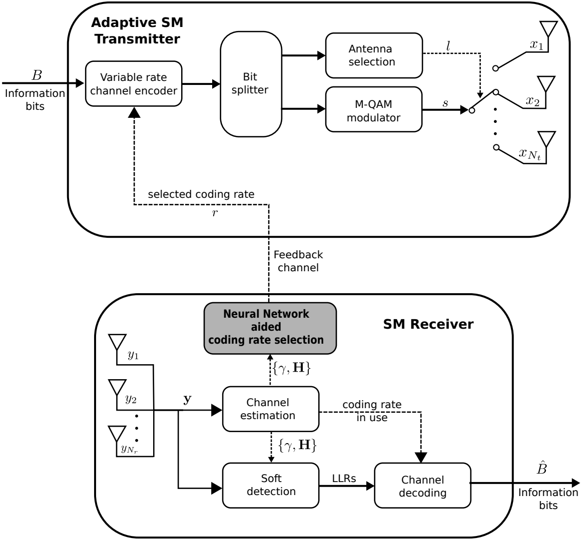
Introduction

- Link adaptation



- Coding rate adaptation mechanism for adaptive SM systems
  - Supervised learning
  - Deep neural network
  - Domain knowledge: Input features extracted from the channel matrix and the SNR

Block diagram adaptive SM system



System model

- Signal model:

$$\mathbf{y} = \sqrt{\gamma}\mathbf{H}\mathbf{x} + \mathbf{w} = \sqrt{\gamma}\mathbf{h}_l s + \mathbf{w} \tag{1}$$

- SM rate adaptation problem:

$$\begin{aligned} \underset{r}{\text{maximize}} \quad & r \log_2(N_t M) \\ \text{subject to} \quad & r \in \{r_1, r_2, \ldots, r_K\} \\ & \text{BER}(\gamma; r, \mathbf{H}) \le p_0. \end{aligned} \tag{2}$$

- Variables:

γ	SNR	$\mathbf{H}$	Chanel matrix
$\mathbf{x}$	Transmitted signal	$\mathbf{w}$	Noise
l	Selected antenna	s	Modulation symbol
r	Coding rate	M	Constellation order
K	Number of coding rate options	p_0	Target BER

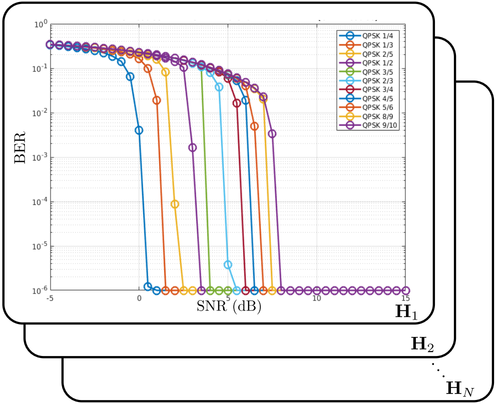
DL based coding rate selection

1. **Design phase**
    1. Evaluation of the performance of the channel codes
    2. Extraction of the SNR thresholds
    3. Building the dataset for Machine Learning
    4. Neural network training
    5. Performance evaluation
2. **Operation phase**
    1. Neural network assisted coding rate selection by the receivers in real time.

DL based coding rate selection

1. **Evaluation of the performance of the channel codes**
   System level simulations

$$\mathrm{BER}(\gamma;\ r, \mathbf{H})$$



DL based coding rate selection

2. **Extraction of the SNR thresholds**

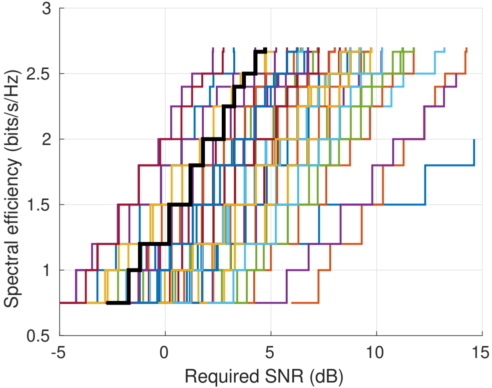


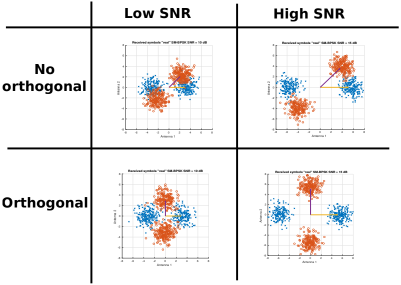
Figure 1: The minimum required SNR to guarantee a given BER p_0 with each coding rate for a set of 20 different channel matrices.

DL based coding rate selection

3. **Building the dataset for Machine Learning**
    - Dataset $\mathbb{X} = \{(\mathsf{x}_i, \mathsf{y}_i), i = 1, 2, \ldots, m\}$
    - Neural network input features:

      $$\mathbf{x} = g(\gamma, \mathbf{H}) = \left[\text{sort}\left(\gamma\|\mathbf{h}_1\|^2,\ \gamma\|\mathbf{h}_2\|^2\right),\ \ \Theta_H,\ \ \varphi\right]^t$$

        - **Columns norms scaled by the SNR**
        - **Hermitian angle** Θ_H and **Kasner's pseudoangle** φ between matrix columns: $\mathbf{h}_1^H \mathbf{h}_2 = \|\mathbf{h}_1\| \cdot \|\mathbf{h}_2\| \cdot \cos\Theta_H \cdot e^{i\varphi}$



    - Neural network output variable: $\mathsf{y} = r_k$ (target coding rate)

DL based coding rate selection

4. **Neural network training**
   - Training (70 %) and validation (15 %) datasets
   - Neural network configuration
     - Three hidden layers: 20+15+10 neurons
     - Activation function: tangent hyperbolic
     - Output layer: linear
   - Levenberg-Marquardt (LM) backpropagation algorithm
   - Cost function: MSE
5. **Performance evaluation**
   - Testing dataset (15 %)
   - Coding rate selection
     - $r = Q\left(\hat{\mathrm{y}}\right) = \arg\min_{r_k} \left|\hat{\mathrm{y}} - r_k\right|$
   - Confussion matrix: accuracy, rate of under-selection, outage probability
6. **Operation phase**
   - Coding rate selection with fixed neural network parameters $\boldsymbol{\theta}$

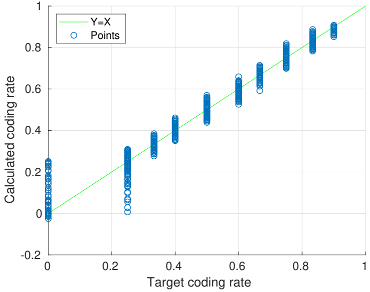
Simulated system parameters

- SM 2×2 with QPSK constellation and 9 coding rate options

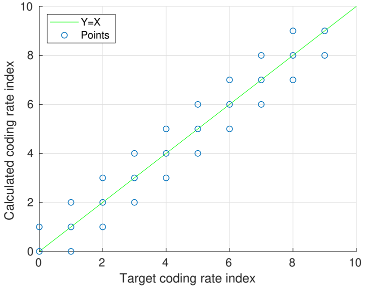
Paramter	**Value**
Transmit and receive antennas	$N_t = 2$, $N_r = 2$
Constellation	QPSK ($M = 4$)
Channel coding	DVB-S2 codes (BCH + LDPC)
Coding rate options	1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 5/6, 9/10
Target BER	$p_0 = 10^{-4}$
Channel matrices	1000 Rayleigh ditributed
SNR range	-5 to 15 dB (0.5 dB steps)

Raw classification performance (I)

- $r = Q(\hat{y}) = \arg\min_{r_k} |\hat{y} - r_k|$



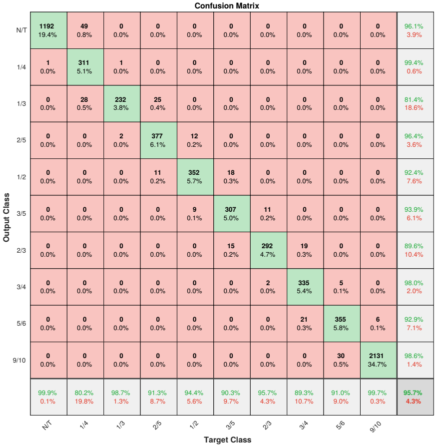
(a) Neural network ouput



(b) Selected coding rate index, $\Delta = 0$

- **Accuracy:** 96.2 %
- **Outage probability:** 2.1 %
- **Rate of under-selection:** 1.7 %

Raw classification performance (II)



Target coding rate	N/T	1/4	1/3	2/5	1/2	3/5	2/3	3/4	5/6	9/10
Accuracy (%)	98.7	95.9	91.9	94.2	93.8	91.8	94.4	89.3	89.7	99.5
Outage (%)	1.3	2.3	4.3	1.5	2.1	4.4	1.6	6.9	8.5	-
Underselection (%)	-	1.8	3.8	4.4	4.0	3.8	3.9	3.7	1.8	0.5

Table 1: Classification performance (no margin is applied, $\Delta = 0$).

Margin for reducing the outage

- Coding rate r selection with margin Δ:

$$r = Q(\hat{y} - \Delta) = \arg\min_{r_k} |\hat{y} - \Delta - r_k|, \tag{3}$$

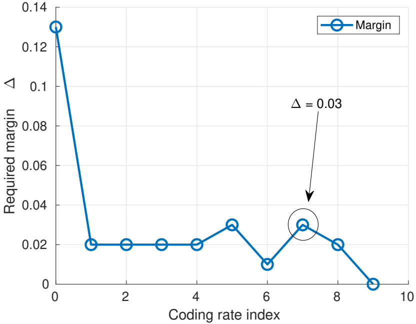


Figure 2: Required margin Δ per each target coding rate for having a zero outage probability in the testing dataset.

Classification performance with margin

	Margin		
	$\mathbf{\Delta = 0}$	$\mathbf{\Delta = 0.03}$	$\mathbf{\Delta = 0.13}$
Accuracy	96.2 %	80.0 %	21.6 %
Mean accuracy[1]	92.6 %	68.1 %	4.4 %
Outage	2.0 %	0.21 %[2]	0 %
Underselection	1.7 %	19.8 %	78.4 %

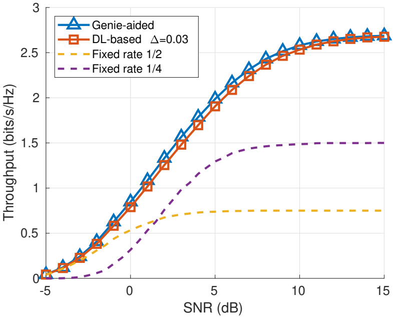
[1] Without taking into account N/T and 9/10.

[2] It already corresponds to zero outage if N/T is disregarded.

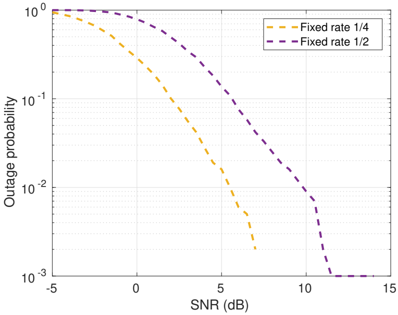
Table 2: Classification performance with and without a margin Δ.

System level performance (I)

- SM 2×2 system with a QPSK constellation and Rayleigh distributed channel matrices:



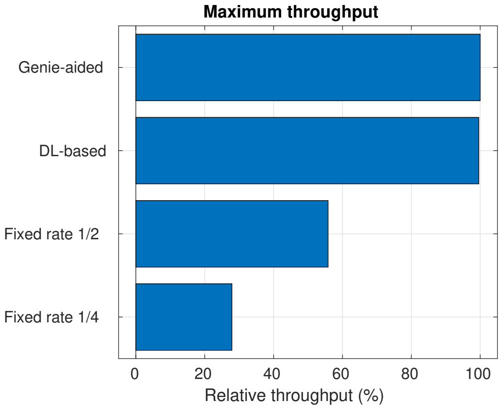
(a) Average throughput



(b) Average outage probability

System level performance (II)

- SM 2×2 system with a QPSK constellation and Rayleigh distributed channel matrices:



Conclusions and future work

CONCLUSIONS

- Coding rate selection for adaptive SM systems
  - Throughput near maximum achievable
  - Outage probability reduced with a margin Δ
- Remarkable gain compared with fixed coding rate allocation

FUTURE WORK

- Extension to higher number of antennas ($N_t = 2,\ 4,\ 8$)
- Several constellations (QPSK, 8PSK, 16QAM, 64QAM)
- Selection of codebook (subset of active antennas and constellation per antenna)

Thanks for your attention!

atlanTTic
research center
for Telecommunication Technologies

Universidade Vigo

Deep Learning Assisted Rate Adaptation in Spatial Modulation Links