The Andrew and Erna Viterbi Faculty of ELECTRICAL & COMPUTER ENGINEERING

SIPL
Signal and Image Processing Lab

TECHNION Israel Institute of Technology

Optimizing a Binary Intelligent Reflecting Surface for OFDM Communications

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IEEE SP Cup

- The most prestigious competition in signal processing for undergraduate students
- Solving real-world problems with signal processing methods
- The competition finals take place at the ICASSP conference

Goals

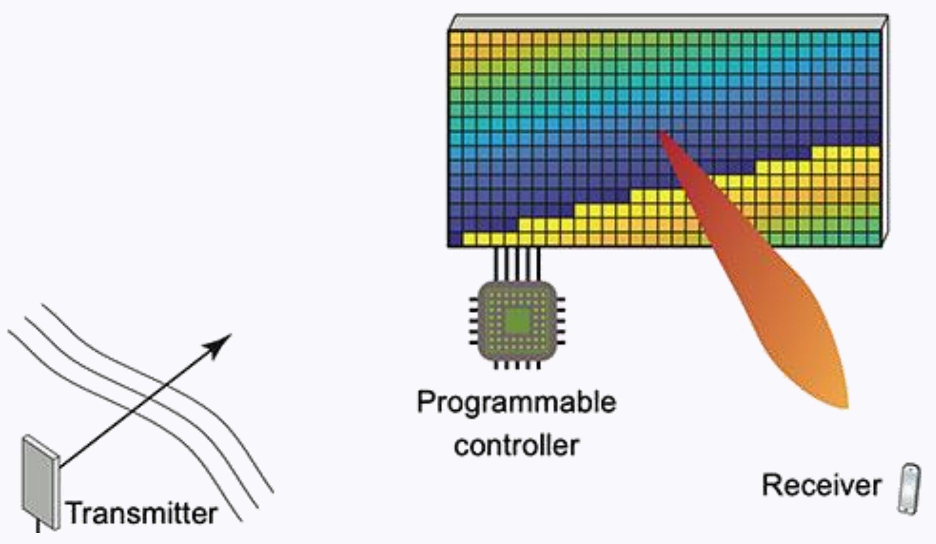
- Characterize the behavior of an intelligent reflecting surface
- Develop a control algorithm to configure the surface
- For each user, find a configuration that gives the highest data transmission rate
- Obtain highest score among all the competitors

Challenges

- Finding best configurations out of 2^{4096}
- No data provided on the IRS spatial shape
- Insufficient small dataset
- Limited number of papers on IRS discrete optimization

Intelligent Reflective Surface

- An Intelligent Reflecting Surface (IRS) is a two-dimensional array of metamaterial
- Consists of an array of controllable passive elements
- Can alter the amplitude and/or phase of the reflected signal
- Helps to overcome the problem of signal attenuation in 6G communication



$$z[k] = \sum_{\ell=0}^{M-1} \left(h_d[\ell] + \boldsymbol{v}_\ell^T \boldsymbol{\omega_\theta}\right) x[k-\ell] + w[k]$$

- $z[k]$ - Received signal
- $x[k]$ - Transmitted signal
- h_d - Direct channel BS⇒Receiver
- $\boldsymbol{v}_\ell$ - Cascaded channel BS⇒IRS⇒Receiver
- $\boldsymbol{\omega_\theta} \in \{\pm 1\}^{1\times 4096}$ - IRS configuration
- $w[k]$ - AWGN

Data Set

- A novel synthetic dataset, divided to two:
  - Dataset1 includes 4×4096 configurations, and their received signals for a certain user
  - Dataset2 includes 4096 configurations, and their received signals for 50 users
- The transmitted pilot signal is $x[k] \equiv \alpha$
- The pilot configurations create a 4096×4096 Hadamard matrix

Channel Estimation

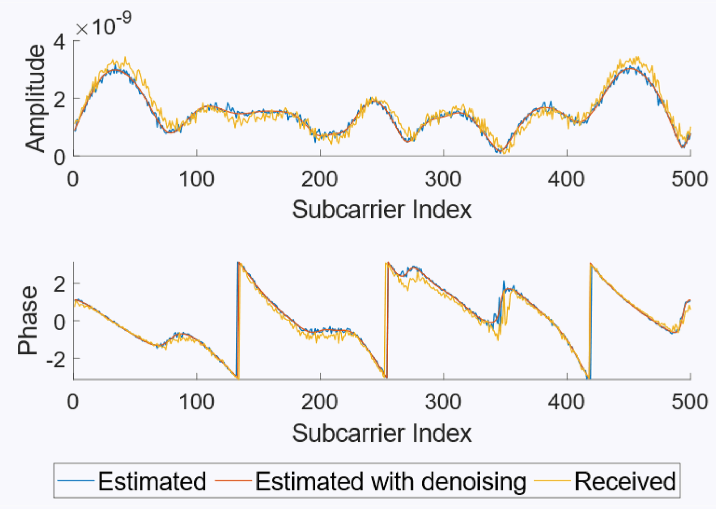
- Direct channel estimation using the pilot matrix Hadamard formation:

$$\hat{h}_d = \frac{\sum_{i=1}^{4096} z_i}{4096 \cdot \alpha}$$

  - z_i - The received pilot signal
- BS⇒IRS⇒Receiver cascaded channel estimation

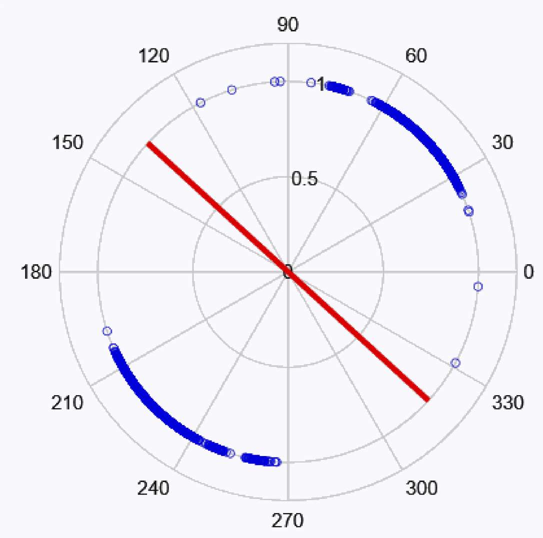
$$\widehat{V} = \frac{1}{\alpha}\left([\boldsymbol{z}_1^f \cdots \boldsymbol{z}_{4096}^f] - [\boldsymbol{h}_{d_1}^f \cdots \boldsymbol{h}_{d_{4096}}^f] \cdot \alpha\right)[\boldsymbol{\omega}_{\boldsymbol{\theta_1}} \cdots \boldsymbol{\omega}_{\boldsymbol{\theta}_{4096}}]^{-1}$$

- Estimated the spectral noise density using redundancy in dataset 1
- Deeper understanding of the IRS geometrical shape helped us to overcome the lack of data



Gradient-Quantization Algorithm

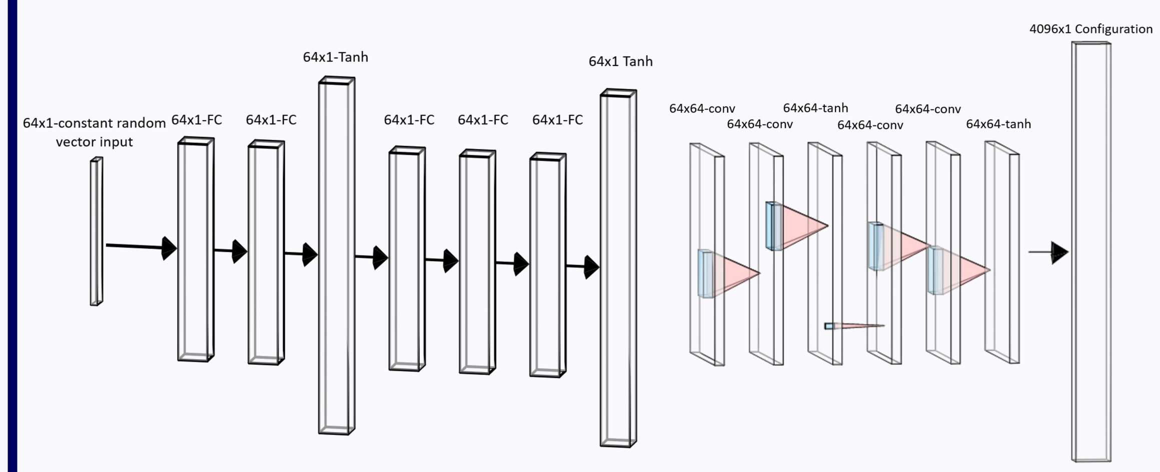
- Efficient heuristic solution exist for the continuous phase case – Strongest Tap Maximization (STM) [Zheng & Zhang, 2020]
- Initialize: STM continuous phase configuration
  - Find best separating line for the quantized phases



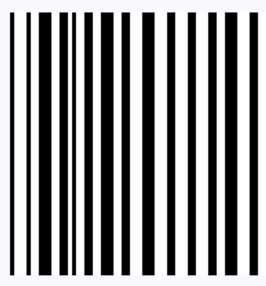
- Our novel algorithm consists of two steps that repeat until all IRS elements are fixed :
  - Quantize of the most ambiguous element
  - Optimize the unquantized element using gradient-descent

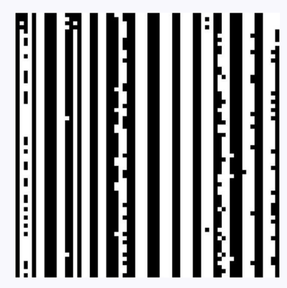
Generative Neural Network

- A novel method for configuration optimization
- Based on the known paper "Deep Image Prior" [Ulyanov et al., 2018],
- Use an untrained CNN as a regulator
- Optimize the weights to get maximal data transmission rate



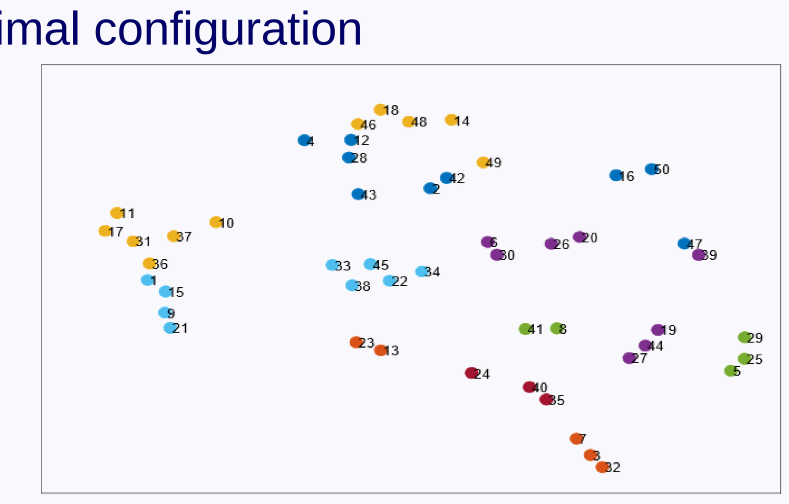
- The output of the first NN is a constant-columns steering configuration
- We used the second NN to fine tune the configuration


First NN output example


Second NN output example

Localization of users

- It is possible to locate the relative positions of the users based on the similarity between their optimal configuration



Results

- Finished in the 6^{th} place in the competition

Method	Mean Data Transmission Rate
Best configuration from the given dataset	103.55 $\left[\frac{Mb}{sec}\right]$
The competition instructor method	117.36 $\left[\frac{Mb}{sec}\right]$
Our method	117.73 $\left[\frac{Mb}{sec}\right]$