Gigantic MU-MIMO: Toward Channel Statistics Independence in ML Receivers

1. Introduction

1.1. In this final project, we explored, extended, and implemented Viterbi-model-based approaches and DNN architectures for learning the underlying statistics of wireless fading channel communication which obeys a Markovian stochastic input-output relationship.
Based on the main paper **"ViterbiNet: A Deep Learning Based Viterbi Algorithm for Symbol Detection"** by Nir Shlezinger, Nariman Farsad, Yonina C. Eldar, and Andrea J. Goldsmith

2. Files Structure and Uses

2.1. **Code** folder contains all code subdirectories and files implemented in python

- 2.1.1. **channel** folder contains data generation code
  - 2.1.1.1. **channel.py –** contains ISI AWG transmit function
  - 2.1.1.2. **channel_dataset.py** – contains the channel data generation class
  - 2.1.1.3. **channel_estimation.py** – contains the channel method and costs
  - 2.1.1.4. modulator.py – contains the BPSK modulation function
- 2.1.2. **ecc** folder contains the error correction, encoding, decoding files which based on Reed-Solomon algorithm https://en.wikiversity.org/wiki/Reed%E2%80%93Solomon_codes_for_coders
- 2.1.3. **dir_definitions.py** – includes all project directories and sub-directories
- 2.1.4. **detector.py** – contains the Detector class which responsible for the DNN/Statistical models and methods (ModelBased / EndToEnd / Statistical) including the Viterbi algorithm
- 2.1.5. **models.py** – contains all the project models ADNN / Sionna / SionnaPlus / Transformer / LSTM' / ViterbiNet / ClassicViterbi additional to experimental models, implemented using PyTorch.
- 2.1.6. **trainer.py** – contains the Trainer class which responsible for all training and evaluation flow for a given model including save/load model, configurate loss and optimizer, initialize channel parameters and data, run train loop and backprop, training evaluation, and online evaluation.
- 2.1.7. **plotter.py** – contains the plot functions which creates graphs based on the models results such as "ser by block index" or "ser by snr' and summary table by SNR function
- 2.1.8. **configuration.yaml** – includes configurable project parameters such as channel parameters / train and validation hyper-parameters / loss type and available optimizers.

2.1.9. **main.py** – responsible for running the project, by looping over SNR list from 7 to 15 cross all models and controls all phases of training, evaluation, and graphs using the “execute_and_plot” function.
In addition, it contains “HYPERPARAMS_DICT” with configurable parameters and main flags.

2.1.9.1. **Important “HYPERPARAMS_DICT” configurable keys:**

2.1.9.1.1. **HYPERPARAMS_DICT [‘val_frames’]**
HYPERPARAMS_DICT [‘subframes_in_frame’]
Their multiplication result determines the Minibatch size during training.

2.1.9.1.2. **HYPERPARAMS_DICT [‘self_supervised_iterations]**
determine the number of self (online) training iterations on the correctly detected block during online evaluation

2.1.9.1.3. **HYPERPARAMS_DICT [‘train_minibatch_num’]**
determines the number of Minibatches during training

2.1.9.2. **Important main flags:**

2.1.9.2.1. **run_over** – value = 0 load plots from previous runs, else value = 1 load trained weights and start online evaluation, else value = 2 clear all and start training from scratch.

2.1.9.2.2. **plot_by_block** – once set to **True** the project will generate “ser by bock index” plot else set to **False** the project will generate “ser by snr” plot.

2.1.9.2.3. **block_lenght** – determine the transmission length of each block i.e. the number of bits.

2.1.9.2.4. **channel_coefficients** - 'time_decay' / 'cost2100' determine the channel cost type.

2.1.9.2.5. **snr_start, snr_end** – determine the range of SNRs

2.1.9.2.6. **models_list** – contains list of DNN models which will be part of the detector

2.1.9.2.7. **detector_method** – determine the detector methodology ‘ModelBased’ for Viterbi based and llr learning / ‘EndToEnd’ for bit to bit learning without Viterbi / Statistical used only for the ‘ClassicViterbi’ model which is the statistical Viterbi algorithm with perfect CSI.

2.1.9.2.8. **self_supervised** - True/False for online evaluation enable

**** Note -- every parameter configured in the main.py**
**** is the last that counts and overwrites configuration.yaml**
**** file values**

2.2. **Resources** folder contains the channel coefficients vectors for cost2100 (4 taps, each with 300 blocks).

2.3. **Results** folder

 2.3.1. **figures** folder – contains all the saved graphs images

 2.3.2. **plots** folder – contains all the saved plots data

 2.3.3. **weights** folder – contains all the trained models' weights per channel cost and each by SNR and gamma.

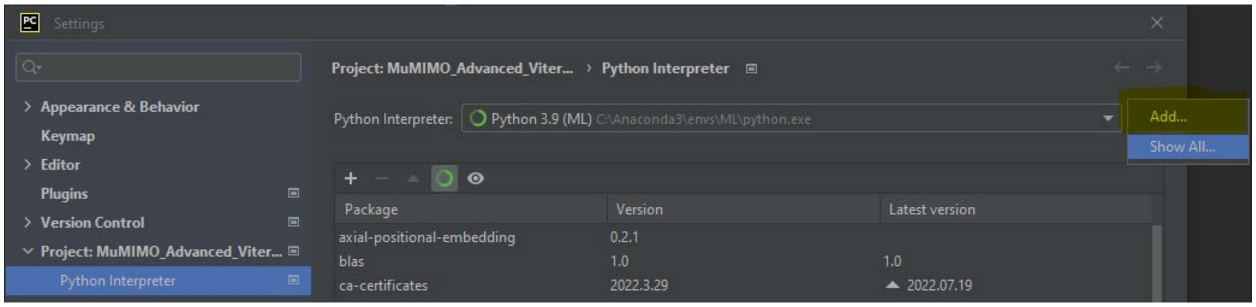
2.4. **project_env.yml** – conda environment with all related packages and modules run the command "conda env create -f project_env.yml " to create the project env

3. Execution

3.1. In order to execute the project first make sure you have Anaconda and PyCharm (IDE) installed, then install the project_env.yml
# --- console command "conda env create -f project_env.yml " --- #
Next follow instructions:

 3.1.1. Open **PyCharm** in the project root directory

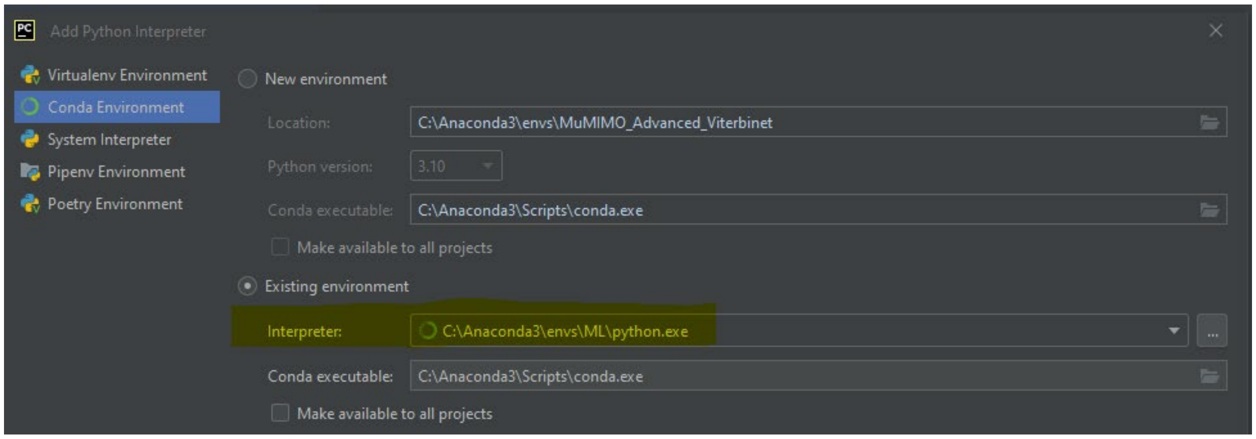
 3.1.2. Go to, File → Settings → Python Interpreter → Add



Python Interpreter: Python 3.9 (ML) C:\Anaconda3\envs\ML\python.exe

Package	Version	Latest version
axial-positional-embedding	0.2.1	
blas	1.0	1.0
ca-certificates	2022.3.29	2022.07.19

 3.1.3. Select the **Conda Environment** that created from the project_env.yml file



New environment
Location: C:\Anaconda3\envs\MuMIMO_Advanced_Viterbinet
Python version: 3.10
Conda executable: C:\Anaconda3\Scripts\conda.exe

Existing environment
Interpreter: C:\Anaconda3\envs\ML\python.exe
Conda executable: C:\Anaconda3\Scripts\conda.exe

 3.1.4. For windows the conda env usually found at C:\Anaconda3\envs\<env_name>\python.exe

3.2. Now you can run the **Code\main.py** file to execute the project.

4. Run and Modify Project

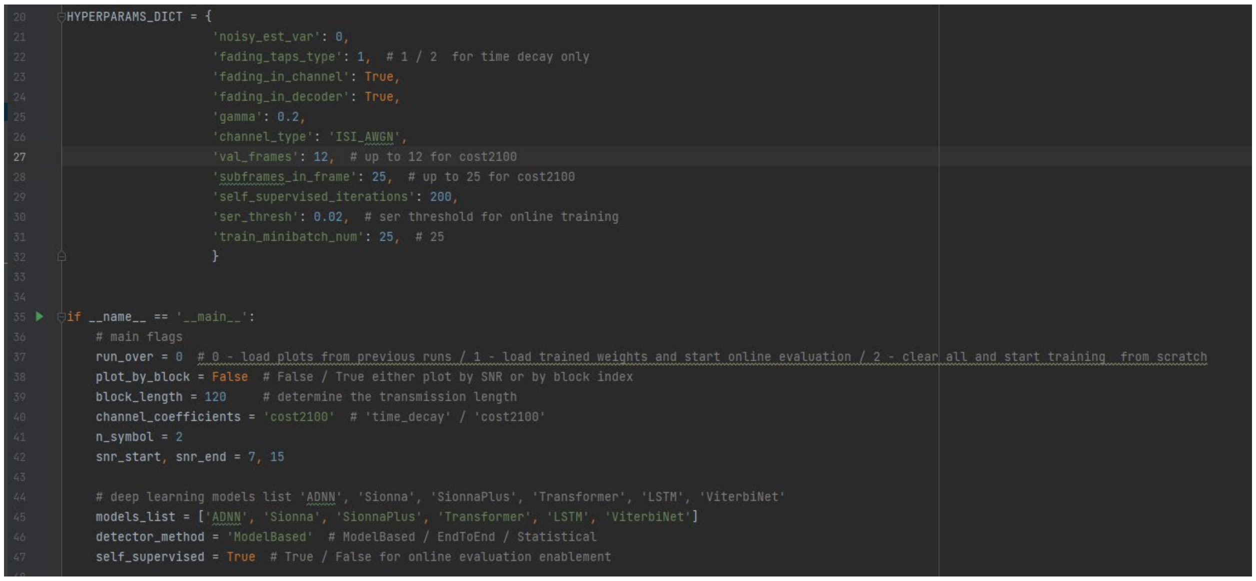
4.1. As described above at the “**Files Structure and Uses”** section, the **Code/main.py** file runs and controls all the project aspects, therefore, most of the running, plotting, training, evaluation and data configuration in it. So please look on the **main.py** sub-section, including all the relevant flags and parameters. **** All the most important running configuration described there** **

4.2. Use the “**run_over”** flag to:

4.2.1. **run_over** = 0 → **load all plots** from previous results

4.2.2. **run_over** = 1 → **load trained weight** and start **online evaluation**

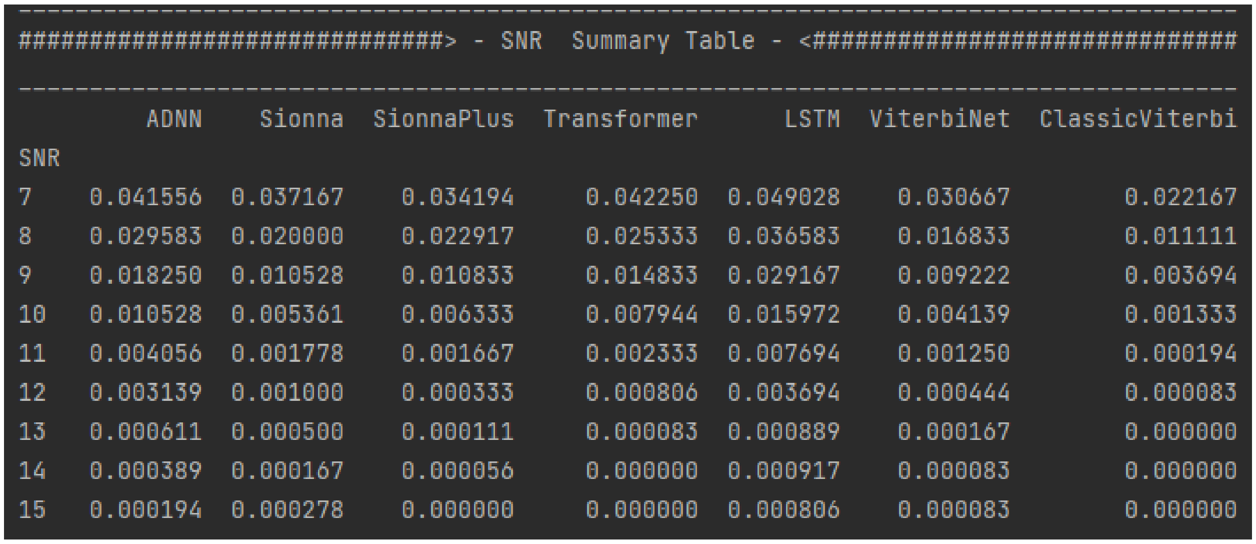
4.2.3. **run_over** = 2 → **clear all** results and **train** from scratch



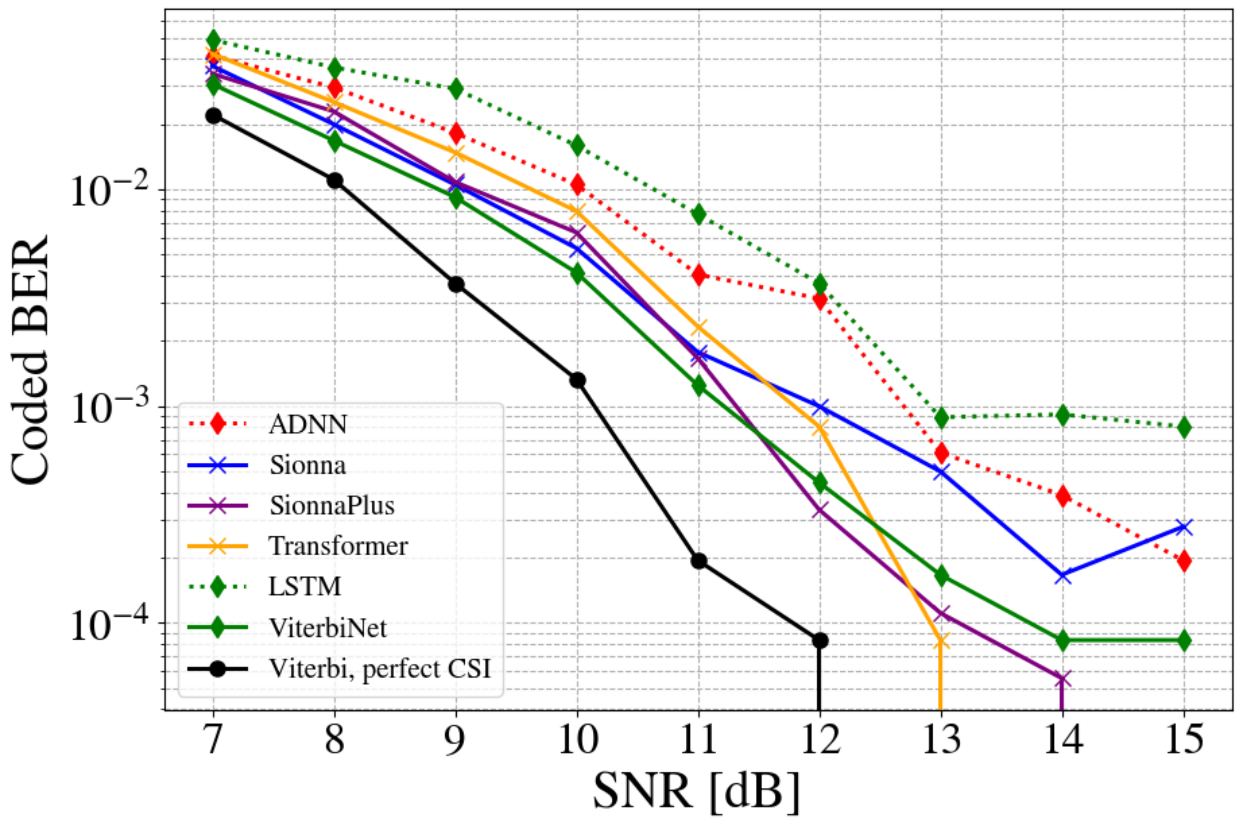
```python
HYPERPARAMS_DICT = {
                    'noisy_est_var': 0,
                    'fading_taps_type': 1,  # 1 / 2  for time decay only
                    'fading_in_channel': True,
                    'fading_in_decoder': True,
                    'gamma': 0.2,
                    'channel_type': 'ISI_AWGN',
                    'val_frames': 12,  # up to 12 for cost2100
                    'subframes_in_frame': 25,  # up to 25 for cost2100
                    'self_supervised_iterations': 200,
                    'ser_thresh': 0.02,  # ser threshold for online training
                    'train_minibatch_num': 25,  # 25
                    }


if __name__ == '__main__':
    # main flags
    run_over = 0  # 0 - load plots from previous runs / 1 - load trained weights and start online evaluation / 2 - clear all and start training  from scratch
    plot_by_block = False  # False / True either plot by SNR or by block index
    block_length = 120     # determine the transmission length
    channel_coefficients = 'cost2100'  # 'time_decay' / 'cost2100'
    n_symbol = 2
    snr_start, snr_end = 7, 15

    # deep learning models list 'ADNN', 'Sionna', 'SionnaPlus', 'Transformer', 'LSTM', 'ViterbiNet'
    models_list = ['ADNN', 'Sionna', 'SionnaPlus', 'Transformer', 'LSTM', 'ViterbiNet']
    detector_method = 'ModelBased'  # ModelBased / EndToEnd / Statistical
    self_supervised = True  # True / False for online evaluation enablement
```

5. Benchmark Results

All models' SER results cross SNR's using Viterbi Model-Based method on cost2100



```
-----------------------------------------------------------------------------------
###############################> - SNR  Summary Table - <###############################
-----------------------------------------------------------------------------------
         ADNN    Sionna  SionnaPlus  Transformer      LSTM  ViterbiNet  ClassicViterbi
SNR
7    0.041556  0.037167    0.034194     0.042250  0.049028    0.030667        0.022167
8    0.029583  0.020000    0.022917     0.025333  0.036583    0.016833        0.011111
9    0.018250  0.010528    0.010833     0.014833  0.029167    0.009222        0.003694
10   0.010528  0.005361    0.006333     0.007944  0.015972    0.004139        0.001333
11   0.004056  0.001778    0.001667     0.002333  0.007694    0.001250        0.000194
12   0.003139  0.001000    0.000333     0.000806  0.003694    0.000444        0.000083
13   0.000611  0.000500    0.000111     0.000083  0.000889    0.000167        0.000000
14   0.000389  0.000167    0.000056     0.000000  0.000917    0.000083        0.000000
15   0.000194  0.000278    0.000000     0.000000  0.000806    0.000083        0.000000
```



Enjoy!