Homework Set #1
MIMO-OFDM concepts and implementation

The goal of this project is to implement an end-to-end MIMO-OFDM system. Let's define the following notation

- N_l is the number of layer of information sent by the users (a.k.a. Transmission/information layers)
- N_{TX} is the number of antennas at the transmitter.
- $\mathcal{M}$ is the modulation signal we use, such as QPSK (or 4QAM), 16QAM, 64 QAM, 256 QAM
- N_{RX} is number of antennas at the Receiver.

1. **MIMO-OFDM Block Diagram** Draw a block diagram of MIMO-OFDM with $N_{TX} \times N_{RX}$ antennas where N_l of information layers are sent. The block diagram should include, channel coding (LDPC or Turbo or Polar codes), Modulation, precoder, Mimo-Detection(Zero-Forcing, ML), OFDM system (with S/P, P/S, FFT, IFFT, Cyclic prefix,...) . Explain for each block the input and the output.
2. **Basic definitions** Define/explain the following expressions

SNR	Fading Channels	Selective channels
Tapped delay line channel	Doppler	Carrier frequency
Subcarrier	RB (Resource block)	RE (Resource Element)
Base Station	UE (user equipment)	Downlink
Uplink	Pilot/ Reference signal	LLR (Log Likelihood Ration)
BER (Bit Error Rate)	BLER (Block error rate)	EVM
PAPR	PAPR problem	IQ imbalance

3. **Basic concepts** Explain the following processes
   (a) Channel estimation in LTE and/or 5G

i. Least-Squares
ii. MMSE
iii. Linear MMSE

(b) MIMO detetcion

i. Zero-Forcing
ii. Maximum Likelihood
iii. V-blast
iv. Sphere decoding

(c) Channel coding

i. Convolutional codes
ii. Turbo codes
iii. LDPC codes
iv. Polar Codes

(d) PAPR reduction

4. **SISO Implementation** Implement the OFDM without the channel coding and with $N_{TX} = N_{RX} = 1$. Draw BER as a function of SNR. Draw for different channels, SNR, Dopler, modulation. Use the following guidelines:

(a) FFT size of 1024

(b) Guard interval 1/8 of the FFT length

(c) Send 20 symbols: 1^{st} preamble symbol (known to the receiver) and rest data symbols (use QPSK for start, then move to 16QAM 64QAM)

(d) Use the following channels:

i. $h(n) = \delta(n)$
ii. $h(n) = \delta(n-1) + 0.7j\delta(n-10)$
iii. $h(n) = \delta(n-1) - 0.4j\delta(n-10) + 0.9\delta(n-13)$

(e) Perform channel estimation based on the known preamble symbol and plot it for all channels. with and without added noise.

(f) Add noise at various SNR level, detect the data using (ML) criterion and the estimated channel and plot BER curves.

5. **MIMO Implementation** Implement the MIMO-OFDM without the channel coding and with $N_{TX} = n, N_{RX} = n$ Draw BER as a function of SNR. Draw for different MIMO-demodulations.

6. **MIMO with channel coding Implementation** Implement the MIMO-OFDM with the LDPC or Turbo-coding and with $N_{TX} = nN_{RX} = n$ Draw BER and BLER as a function of SNR. Draw for different parameters of the setting.

7. **Impairments.** It is often the case that there exists some mismatch in the communication model due to error estimation, imperfect synchronization and noise that were not taken into account. Please provide a list of impairments in MIMO-OFDM communication system and implement 2 of them in your simulation. Investigate their influence.