Simulation of OFDM Transmission in 5G NR

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1 Objective

This project is a simulation of the downlink transmission scheme in 5G new Radio (NR). The NR specifications offer a range of bandwidth (BW) and sub-carrier spacing (SCS) configurations. The number of resource blocks(RBs) available for each of those configurations is shown in Figure 1. The fields with N/A are indicative of the fact that these configurations are not supported. This is not an exhaustive table as there are more values of SCS to choose form in the later releases but this simulation is based on this table. For the chosen BW and SCS, the transmit vector is generated for 100 frames and the peak to average power ratio (PAPR) is calculated and plotted for QPSK, 16-QAM and 64-QAM modulation schemes.

SCS (kHz)	5MHz	10MHz	15MHz	20 MHz	25 MHz	30 MHz	40 MHz	50MHz	60 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	217	245	273
60	N/A	11	18	24	31	38	51	65	79	107	121	135

Figure 1: Number of resource blocks for different configurations in NR (Source: TS 38.101-1)

2 Procedure

This section gives an overview of the steps employed in the implementation. The user is asked to choose a valid combination of BW and SCS. The user is also prompted to choose the modulation scheme. The number of RBs for the corresponding configuration is chosen. The number of QAM symbols which can be transmitted per OFDM symbol is calculated by multiplying the number of RBs with the number of orthogonal subcarriers per RB (=12).

A top-down approach is employed in this simulation in the sense that, the data bits are randomly generated based on the number of symbols which can be transmitted per frame in the chosen configuration. The PAPR plots for QPSK, 16-QAM and 64-QAM are desired.

For a given modulation scheme, the data bits generated are modulated to the corresponding complex QAM symbols using the formulas given in TS 38.221, sections 5.1.3, 5.1.4 and 5.1.5. The generated symbols are mapped onto the central region of a 4096 point IFFT block. A regular cyclic prefix is appended to the start of the output IFFT samples. This constitutes a single OFDM symbol. 14 such symbols form a slot. The duration of the slot is called the Transmit Time Interval (TTI). The PAPR (in dB) for each output of the IFFT block is calculated and tabulated in an array. The complementary cumulative distribution function (CCDF) is calculated for the PAPR vectors and plotted.

3 Calculations

This section provides the details of the formulas used for the calculations made in the simulation.
In 5G, $Nfft = 4096$. Let the chosen value of SCS be represented by Δf

$$T_s = \frac{1}{15\text{x}10^3\text{x}2048}; \qquad T_c = \frac{1}{\Delta f \text{x} Nfft}; \qquad \kappa = \frac{T_s}{T_c}$$

From κ, the value of μ is obtained as $\mu = \log_2 \kappa - 1$. In NR, each frame has 10 subframes. The number of slots per subframe depends on the value of μ. The number of slots is 10x2^μ. There are 14 OFDM symbols per slot.
The number of subcarriers which can be used is given by N_{RB}x12. These are mapped to the middle of the input of the IFFT block. The output of the IFFT block is a length 4096 vector of complex symmbols. The cyclic prefix length is calculated using the following formula where l represents the OFDM symbol number.

$$L_{cp} = \begin{cases} 144\kappa 2^{-\mu} & \text{, if } l = 0 \text{ or } l = 7\text{x}2^{\mu} \\ 144\kappa 2^{-\mu} + 16\kappa & \text{, otherwise} \end{cases}$$

Let for_papr represent the symbol sequence of one slot which is one TTI. The the peak to average power ratio is calculated for that vector as:

$$P_{peak} = \max(\text{for\_papr x conj(for\_papr)}^T); \;\; P_{avg} = \frac{(\text{for\_papr x conj(for\_papr)}^T)}{\text{L}_{for\_papr}}$$

$$papr = \frac{P_{peak}}{P_{avg}}$$

After iterating through the three modulation schemes, the CCDF for each row of the output PAPR matrix(in dB) is calculated. Vectors having values spaced 0.05 dB apart between the maximum and 0.5 dB lesser than the minimum PAPR values for each row of the PAPR matrix are generated. A loop is iterated over all values of the generated vectors and the number of PAPR values greater than each point of the vector in the corresponding PAPR row is entered into a vector. The latter vector is normalized to obtain the CCDF. The CCDFs of the three modulation schemes are plotted.

4 Result display

The calculations required for the output are made as follows:

- Sampling time = T_c
- Bandwidth used = N_{rb}*12*scs
- Sampling rate = $\frac{1}{T_c}$
- Average power per TTI = $\frac{\text{Total power}}{\text{number of slots}}$ (Repeated for each modulation scheme)
- Max PAPR = maximum value of papr in each row pf the papr matrix
- papr at probability 0.0001

- The mean and standard deviation of each of the papr vectors

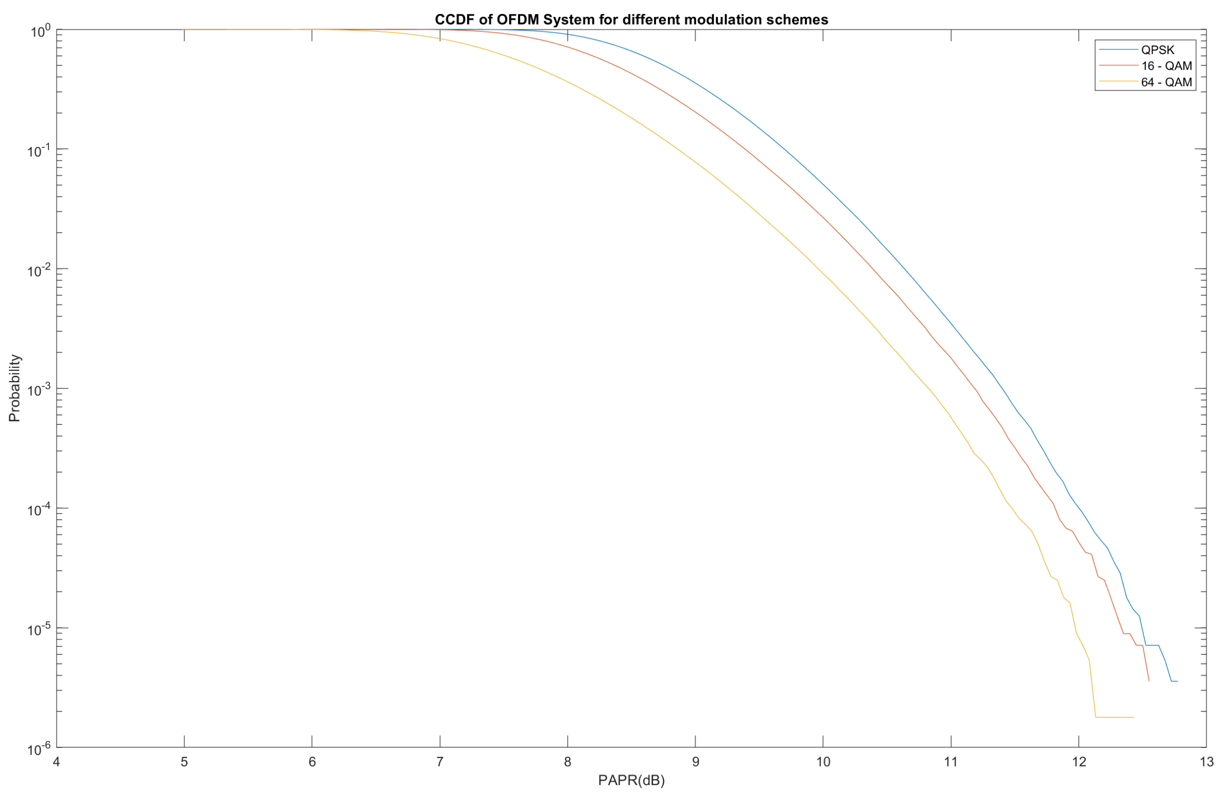
The CCDF which is a graph of the probability vs PAPR is plotted for each modulation scheme is plotted in the same plot and displayed.

5 Usage

This simulation has been implemented on MATLAB without the need for any specialized toolboxes. The submission folder would contain the code and a picture both of which need to be in the same directory on the system being used. On running the code, prompts will appear on the command window to take the user through the steps.

6 Outputs

The following outputs were generated for an SCS of 60KHz and a BW of 100MHz considering 100 frames of data being transmitted.

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Sampling time = 4.069e-09s Bandwidth used = 97.2MHz Nrb = 135
Sampling rate = 245.76MHz kappa = 8
For QPSK: Avg Tx power per TTI= 379.5452 PAPR at 0.0001 prob = 12.0238dB, Mean = 8.8162dB, Variance = 0.43748dB
For 16 - QAM: Avg Tx power per TTI = 268.3855 PAPR at 0.0001 prob = 11.7996dB, Mean = 8.4361dB, Variance = 0.51303dB
For 64 - QAM: Avg Tx power per TTI= 163.9175 PAPR at 0.0001 prob = 11.4813dB, Mean = 7.7836dB, Variance = 0.65636dB
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