Simulation of 5G OFDM transmitter

Rahavi Selvarajan

1 Objective

This project is the simulation of a downlink OFDM signal assuming single port output i.e., no MIMO. The signal consists of samples spaced Tc apart and using the NR number of subcarriers and subcarrier spacing as specified in TS 38.101-1 (FR1 Range). The Figure 1 shows

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: Maximum Transmission Bandwidth Configuration N_{RB}

the maximum transmission bandwidth configuration N_{RB} for each UE channel bandwidth and subcarrier spacing. The N/A fields indicate that those configurations are not supported. For the chosen channel bandwidth and subcarrier spacing, the OFDM data 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 techniques.

2 Procedure

This section deals with the implementation steps followed for the simulation. The user is allowed to choose a combination of channel bandwidth and subcarrier spacing for which the number of resource blocks is valid. The user is also allowed to choose the modulation scheme.

A random OFDM data is generated based on the number of symbols per frame for a chosen configuration. To map these bit streams onto complex modulated signal, the mapping rules specified in the TS 38.211 is used. Equation 1, Equation 2, and Equation 3 corresponds to the mapping rule of QPSK, 16-QAM and 64-QAM modulation techniques respectively.

$$QPSK : d(i) = \frac{1}{\sqrt{2}}[(1-2b(2i)) + j(1-2b(2i+1))] \tag{1}$$

$$16{-}QAM : d(i) = \frac{1}{\sqrt{10}}\Big\{(1-2b(4i))[2-(1-2b(4i+2))]+j(1-2b(4i+1))[2-(1-2b(4i+3))]\Big\} \tag{2}$$

$$\begin{aligned} 64-QAM : d(i) = \frac{1}{\sqrt{42}}\Big\{&(1-2b(6i))[4-(1-2b(6i+2))[2-(1-2b(6i+4))]] \\ &+ j(1-2b(6i+1))[4-(1-2b(6i+3))[2-(1-2b(6i+5))]]\Big\} \end{aligned} \tag{3}$$

The modulated symbols are then propagated through an IFFT module. In 5G, the number of points used to calculate IFFT is 4096. A normal cyclic prefix is prepended to the IFFT samples. This constitutes a single OFDM symbol. The peak power, average power and the peak to average power ratio is calculated for each symbol based on the following equations,

$$Peak\ \ power = max(|x(n)|^2) \tag{4}$$

$$Average\ \ power = \frac{1}{N}\sum_{n=0}^{N-1}|x(n)|^2 \tag{5}$$

$$PAPR = \frac{Peak\ \ power}{Average\ \ power} \tag{6}$$

The complementary cumulative distribution function is calculated for the PAPR vector and plotted.

3 Calculations

This section deals with the numerical results and their corresponding formulae. The chosen subcarrier spacing be Δf. From the chosen subcarrier spacing, we can determine the number of symbols in a subframe as follows,

μ	$\Delta f = 2 * 15[kHz]$	Number of symbols per subframe
0	15	14
1	30	28
2	60	56

The basic units of 4G (T_s) and 5G (T_c) can be defined by the following formulae,

$$T_s = \frac{1}{15 * 10^3 * 2048}; \qquad T_c = \frac{1}{\Delta f * N_{fft}}; \qquad \kappa = \frac{T_s}{T_c}$$

The sampling rate is given by the reciprocal of T_c. The length of the cyclic prefix that need to be prepended to the IFFT samples are determined by equation 7.

$$N^l_{CP,l} = \begin{cases} 288 + 16 * 2^\mu & \text{l = 0 and l} = 7{*}2^\mu \\ 288 & \text{otherwise} \end{cases} \tag{7}$$

The occupied bandwidth is calculated as $(N_{RB} * 12 * \Delta f) + \Delta f$. The CCDF values are generated based on the obtained PAPR values and PAPR CCDF plot is plotted. The results are shown in the next section.

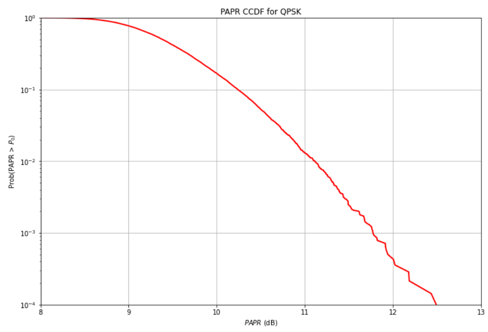
4 Numerical Results

The following results are observed for a subcarrier spacing, Δf of 30kHz; modulation scheme: 16-QAM and channel bandwidth of 10MHz.

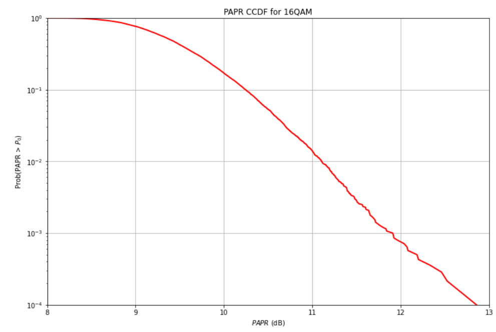
- Average Simulated power: 39.9994
- Maximal PAPR: 18.8157 (linear)
- OFDM data length: 32256000
- PAPR at 0.0001 probability: 12.745 dB
- Occupied Bandwidth: 8.67 MHz, Basic unit in 5G, Tc: 8.1380 ns, sampling rate: 122.88 Msps
- kappa: 4.0, CP Long: 352,CP short: 288
- Number of ofdm symbols in a 1ms subframe: 28

5 Plots

The PAPR CCDF plots for different configurations are shown below.

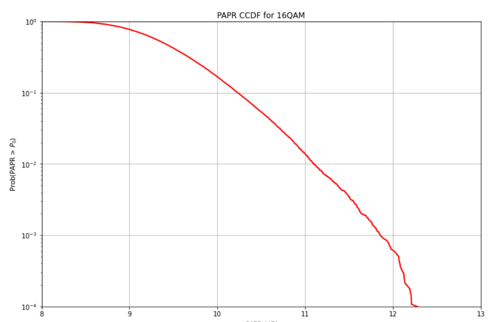


(a) QPSK; BW of 5 MHz

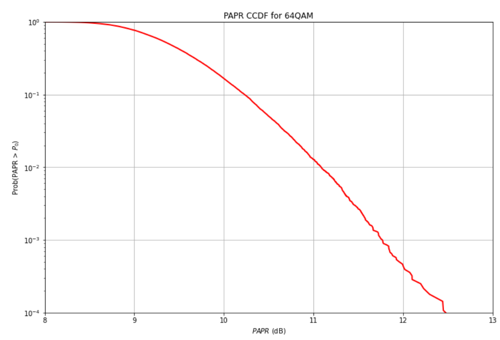


(b) 16-QAM; BW of 50 MHz

Figure 2: PAPR CCDF for a subcarrier spacing of 15kHz

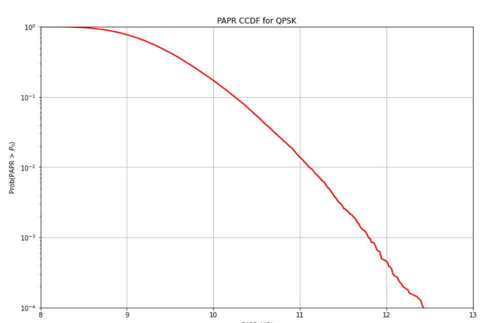


(a) 16-QAM; BW of 10 MHz

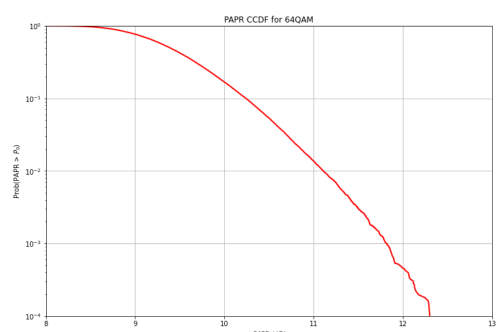


(b) 64-QAM; BW of 100 MHz

Figure 3: PAPR CCDF for a subcarrier spacing of 30kHz



(a) 16-QAM; BW of 25 MHz



(b) 64-QAM; BW of 100 MHz

Figure 4: PAPR CCDF for a subcarrier spacing of 60kHz