Reducing PAPR with Low Complexity Filtered NOMA Using Novel Algorithm

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Abstract: Filtered Non-Orthogonal Multiple Access (F-NOMA) is a multi-carrier wave form and is considered a suitable contender for 5G radio. Peak to average power ratio (PAPR) is regarded as a major hurdle in the NOMA wave form because it hampers the efficiency of the power amplifier of the NOMA transmitter. In this study, a novel selective mapping (SLM) algorithm is used to minimize the PAPR of the NOMA. The conventional SLM increases the intricacy of the structure, and the projected SLM algorithm is applied to the transmitter part of the F-NOMA. Furthermore, we evaluate the performance of SLM on F-NOMA for 16, 64, and 256-Quadrature Amplitude Modulation (QAM) transmission methods. The parameters such as Bit Error Rate (BER), PAPR, power spectral density (PSD), and complexity are estimated and compared with different transmission patterns. The simulation outcomes of the work reveal that the optimal PAPR can be achieved by selecting the sub-block (S) and phase rotation elements (Ps). PAPR in F-NOMA achieves 1 dB gain in different QAM transmissions and its saving performance is 70.07%; however, complexity increases with an increase in modulation order.

Keywords: peak to average power ratio; selective mapping; quadrature amplitude modulation; fifth generation; filtered non orthogonal multiple access

1. Introduction

The enhancement of cellular communication is taking place all around the world, and there is an exponential demand for wireless applications. The integration of 5G with various machineries such as the Internet of Things (IOT), Cognitive Radio (Cr), massive MIMO, and wearable small devices is happening all the time [1]. Better quality of service (QoS), faster data, latency (1 ms), and more efficient bandwidth utilization are among the demands that the 5G rollout is expected to meet [2]. Multi-carrier waveforms will determine the success of 5G. Currently, the OFDM waveform is utilized in 4G. Several multi-carrier waveforms such as NOMA, FBMC, and UFMC are proposed for 5G radio; however, PAPR is a common concern in all advanced waveforms [3]. The increase in PAPR diminishes the performance of the system and it is considered one of the major constraints in 5G. The PAPR issue in OFDM is overcome by applying PAPR reduction algorithms [4]. However, due to the differences in the structure of the 4G and 5G waveforms, the algorithms used in 4G cannot be applied to the 5G waveform. In recent years, PAPR reduction algorithms have
been designed for 5G waveforms \[5\]. In this work, we evaluate the performance of the SLM algorithm for the 16-QAM and 64-QAM transmission methods. In \[6\], the SLM algorithm is designed for the UFMC waveform. The reduction in PAPR is obtained by generating an ideal phase vector of complex UFMC symbols. The proposed article reveals a substantial enhancement in PAPR performance. The authors in \[7\] introduced a novel hybrid PAPR technique for 5G wave forms. Their studied scheme is centered on the permutation of PTS and BFOA and concluded that the presented arrangement efficiently lowers the PAPR and reduces the complexity of the framework. In \[8\], the authors compared the PAPR performance for filtered OFDM and conventional OFDM. The PTS is used in the F-OFDM waveform to lower the PAPR and it is seen that the F-OFDM outperforms the conventional OFDM waveform framework. The authors introduced a novel Gray-PFPTS algorithm for OFDM and F-OFDM waveforms \[9\], which efficiently reduces the PAPR and intricacy. The model consequences confirm that the enactment of the projected process is superior to the prevailing systems. In \[10\], the PAPR of the FBMC wave is lowered by applying DCT and DST algorithms. The outcomes of the simulation show that the simulation shows that the proposed method effectively obtains a gain of 5 to 10 dB. In \[11\], the authors investigated the PAPR and latency of 5G wave forms. The QRM-MLD method is projected to increase the efficiency of the structure. The simulation results show an improved PAPR performance of the framework. It is seen that the PAPR algorithms used for OFDM cannot be utilized for the 5G waveforms. The author applied a hybrid algorithm (SLM-CT) on NOMA and OFDM \[12\]. The outcomes of the work show a significant PAPR performance improvement in 4G and 5G waveforms. In \[13\], the PAPR is lowered by using the companding method for a high number of QAM systems. It is seen that PAPR is significantly reduced for low-order modulation schemes. The key contributions made by this paper are:

- The suggested scheme has ominously lowered the PAPR with low complexity.
- We have analyzed the PAPR, BER, Power Spectral Density (PSD), Power Performance, and Intricacy of the proposed algorithm for a high number of QAM schemes.

The article is arranged as follows: in Section 1 we discuss the background, introduction, and related work; in Section 2, we present a system model; Section 3 deals with the simulation results; finally, Section 4 includes the discussion and conclusion. Table 1 indicates the proposed work published in a similar field.

<table>
<thead>
<tr>
<th>References</th>
<th>PAPR Reduction (dB) at $10^{-3}$</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>[14]</td>
<td>10</td>
<td>A Block Coding (BC) scheme is used to reduce the PAPR of the F-OFDM. However, the complexity and applicability of the BC for advanced waveforms is not discussed in the presented work.</td>
</tr>
<tr>
<td>[15]</td>
<td>7</td>
<td>The authors introduced a SLM for the OFDM structure. The increased number of subcarriers affects the amplifier efficacy. High BER is seen as one of the drawbacks of the suggested work.</td>
</tr>
<tr>
<td>[16]</td>
<td>7.2</td>
<td>The authors proposed a SLM for 5G waveforms and OFDM. When applied to OFDM, the proposed algorithms performed well, but the computation requirements for 5G were high.</td>
</tr>
<tr>
<td>[17]</td>
<td>6.8</td>
<td>The genetic algorithm-based PAPR schemes were introduced for advanced radio structure. The PAPR reduction is obtained at high BER.</td>
</tr>
<tr>
<td>[18]</td>
<td></td>
<td>The article discussed the role of SLM in reducing the bandwidth leakage issue for the Universal Filter Multi Carrier (UFMC) waveform. The PAPR and BER analysis are not performed in the presented article.</td>
</tr>
<tr>
<td>[19]</td>
<td>7.9</td>
<td>The authors studied the throughput and amplifier performance of the UFMC structure. A significant reduction in power is obtained with high throughput. However, the computational factor is not discussed.</td>
</tr>
<tr>
<td>Proposed Work</td>
<td>2.4, 4.9 and 5.2</td>
<td>A novel SLM-based F-NOMA is implemented, and significant power savings are obtained despite the low computation resource requirements.</td>
</tr>
</tbody>
</table>
2. System Model

The representation of the NOMA structure is specified in Figure 1a. NOMA is considered to be one of the primary contenders for 5G radio. The characteristics of NOMA, such as low outages, high data rates, high bandwidth, and the ability to connect multiple devices, make it suitable for 5G. However, high PAPR significantly reduces the performance of NOMA wave forms [20].

![Diagram of NOMA system](image-url)

Figure 1. (a): Proposed F-NOMA System. (b): Proposed method.

The NOMA signal can be expressed as:

\[ Y_n = \frac{1}{\sqrt{2}} \sum_{l=0}^{N-1} Y(l) \exp \left( i \frac{6.28}{N} (l) \right) \]  

(1)

where \( l = 0, 1, \ldots, N - 1 \). The characteristics of filter used in NOMA is given as:

\[ h(t) = \delta(t - mT) \exp(i2\pi f_c t) \]  

(2)
where $f_c$ is the frequency of the carrier signal. The time domain NOMA with filter can be written as:

$$Y(t) = \sum_{m=0}^{N-1} Y_m \delta(t - mT)$$

(3)

From Equation (3), we can estimate the PAPR of the NOMA signal by:

$$Y(t)_{PAPR} = \frac{\text{Maximum}_{t \in T}|Y(t)|^2}{\frac{1}{T} \int_0^T |Y(t)|^2 dt}$$

(4)

To lower the PAPR, the SLM algorithm is applied at the transmitter of the NOMA framework, shown in Figure 1b.

The transmit symbol $Y(t)$ can be expressed as:

$$Y = [Y_0, Y_1, \ldots, Y_{N-1}]^T$$

(5)

The Equation (5) is mapped into S (sub-blocks). The phase rotation element ($P^s$) is used to obtain an ideal PAPR value, expressed as:

$$P^s = [P^s_0, P^s_1, \ldots, P^s_{N-1}]^T$$

(6)

where $P^s = \exp\left(j\theta_p^s\right)$ and $\theta_p^s$ ranges among $[0, 360]$ for $p = 0, 1, \ldots, N - 1$, and $s = 1, 2, \ldots, S$.

The NOMA ($Y$) are scaled with $P^s$ to obtain an ideal PAPR value given by:

$$Z^s = [P^s \ast Y]$$

(7)

$$Z^s = [Y^s_0, Y^s_1, \ldots, Y^s_{N-1}]^T \ast [P^s_0, P^s_1, \ldots, P^s_{N-1}]^T$$

(8)

In order to further estimate the peak value of NOMA symbols, an IFFT is applied on Equation (8), given as:

$$z^s = [z^s_0, z^s_1, \ldots, z^s_{N-1}]^T$$

(9)

From Equation (9), the PAPR is estimated and the lowest PAPR signal is selected. The optimal PAPR is expressed as:

$$PAPR_{\text{optimum}} = \frac{\text{maximum}_{t \in T}|z^s(t)|^2}{\frac{1}{T} \int_0^T |z^s(t)|^2 dt}$$

(10)

The performance of the proposed algorithm is weighed by estimating the Complementary Cumulative Distribution Function (CCDF), given as [21]:

$$CCDF = \text{Prob}(PAPR \geq z^s_{\text{th}})$$

(11)

3. Simulation Results

In the proposed work, we analyzed the parameters such as PAPR, BER, (PSD), power performance, and complexity. The details of the constraints utilized in the model are shown in Table 2.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scheme: 16-QAM, 64-QAM and 256-QAM</td>
</tr>
<tr>
<td>2</td>
<td>Sub-block ($S$) = 2, 4</td>
</tr>
<tr>
<td>3</td>
<td>Sub-carrier ($N$) = 64</td>
</tr>
<tr>
<td>4</td>
<td>PHYDYAS filter $P^s = [2, 4]$</td>
</tr>
</tbody>
</table>
3.1. PAPR Performance of 16-QAM

Figure 2 investigated the efficiency of the suggested SLM for 16-QAM NOMA. At the CCDF of $10^{-3}$, the PAPR of conventional NOMA and F-NOMA is 9.4 dB and 8.2 dB, respectively. The SLM mode is applied to F-NOMA to lower the PAPR. It is shown that the PAPR is reduced to 2.4 dB, 4 dB, 4.8 dB, and 6.6 dB for SLM ($S = 4$, $p = 4$), ($S = 2$, $p = 2$), ($S = 2$, $p = 2$), and ($S = 2$, $p = 4$), respectively. Hence, it is concluded that SLM ($S = 4$) outperforms conventional SLM. The PAPR analysis of 64-QAM for the proposed SLM algorithm is given in Figure 3. At the CCDF of $10^{-3}$, PAPR is lowered to 5.2 dB, 5.9 dB, 7 dB, and 8.2 dB for SLM ($S = 4$, $p = 4$, $S = 4$, $p = 2$, $S = 2$, $p = 2$, and $S = 2$, $p = 4$). Therefore, it is shown that SLM attained a 5.8 dB better performance as equated with the conventional NOMA framework. In Figure 4, the PAPR of 256-QAM for the F-NOMA waveform is shown. At $10^{-3}$ CCDF, SLM ($S = 4$, $p = 4$) obtained a gain of 0.89, 1.8, and 4 dB, correspondingly.

![Figure 2. 16-QAM PAPR performance.](image)

![Figure 3. 64-QAM PAPR performance.](image)

![Figure 4. 256-QAM PAPR performance.](image)
3.2. BER Analysis

To examine the throughput of a Power Amplifier (PA) utilized in the NOMA framework, the BER analysis of the recommended SLM is given in Figure 5. It is seen that the BER of $10^{-3}$ is achieved at the SNR of 5.3 dB for SLM ($S = 4 p = 4$), 6.5 dB for SLM ($S = 4 p = 2$), 7.7 dB for SLM ($S = 2 p = 4$), 8.6 dB for SLM ($S = 2 p = 2$), 10.6 dB for F-NOMA, and 12.1 dB for NOMA, respectively; hence, it is concluded that the BER is effectively enhanced for the projected method.

![Figure 5. BER performance.](image)

3.3. Power Spectral Density

The PSD of the NOMA and F-NOMA with SLM is estimated and analyzed in this section. From Figure 6, it is seen that the spectrum emission of NOMA is $-50$ dB and F-NOMA is $-71$ dB. This indicates that the F-NOMA efficiently reduces the OOBE as equated with the NOMA. The OOBE of the NOMA and F-NOMA with SLM is estimated and given as $-63$ dB and $-80$ dB, respectively; therefore, it is determined that the spectral efficiency of the F-NOMA is efficiently enhanced and outperforms the conventional NOMA.

![Figure 6. PSD of F-NOMA and NOMA with and without SLM.](image)

3.4. Complexity

In this segment, we have estimated the complexity of the system by considering $n = 64$, $S = 4$, and $p = 4$ given in Table 3 and Figure 7. The number of additions and multiplications required by SLM ($S = 4 p = 4$) for 16-QAM is 12,288, 20,480, 64-QAM is 16,384, 24,576, and 256-QAM is 33,088, 32,768, respectively. Hence, it is concluded that the complexity of the framework will increase with high order transmission schemes such as 256-QAM.
Table 3. Complexity Comparison.

<table>
<thead>
<tr>
<th>S.NO.</th>
<th>Proposed Algorithm</th>
<th>Transmission Schemes</th>
<th>No of Additions</th>
<th>No of Multiplications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SLM (S = 4 p = 4)</td>
<td>16-QAM</td>
<td>12,288</td>
<td>20,480</td>
</tr>
<tr>
<td>2</td>
<td>SLM (S = 4 p = 4)</td>
<td>64-QAM</td>
<td>16,384</td>
<td>24,576</td>
</tr>
<tr>
<td>3</td>
<td>SLM (S = 4 p = 4)</td>
<td>256-QAM</td>
<td>33,088</td>
<td>32,768</td>
</tr>
</tbody>
</table>

Figure 6. PSD of F-NOMA and NOMA with and without SLM.

3.4. Complexity

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Table 4. Power saving of SLM in 16-QAM-F-NOMA.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Proposed PAPR Algorithms</th>
<th>Original PAPR for 16-QAM (dB)</th>
<th>PAPR Reduction (dB)</th>
<th>Power Saving *100 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SLM (S = 4 $p = 4$)</td>
<td>8.2</td>
<td>2.4</td>
<td>70.70%</td>
</tr>
<tr>
<td>2</td>
<td>SLM (S = 4 $p = 2$)</td>
<td>8.2</td>
<td>4</td>
<td>51.21%</td>
</tr>
<tr>
<td>3</td>
<td>SLM (S = 2 $p = 4$)</td>
<td>8.2</td>
<td>4.8</td>
<td>41.46%</td>
</tr>
<tr>
<td>4</td>
<td>SLM (S = 2 $p = 2$)</td>
<td>8.2</td>
<td>6.6</td>
<td>19.51%</td>
</tr>
</tbody>
</table>

Table 5. Power saving of SLM in 64-QAM-F-NOMA.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Proposed PAPR Algorithms</th>
<th>Original PAPR for 64-QAM (dB)</th>
<th>PAPR Reduction (dB)</th>
<th>Power Saving *100 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SLM (S = 4 $p = 4$)</td>
<td>9.5</td>
<td>5.2</td>
<td>45.26%</td>
</tr>
<tr>
<td>2</td>
<td>SLM (S = 4 $p = 2$)</td>
<td>9.5</td>
<td>5.9</td>
<td>37.89%</td>
</tr>
<tr>
<td>3</td>
<td>SLM (S = 2 $p = 4$)</td>
<td>9.5</td>
<td>7</td>
<td>26.32%</td>
</tr>
<tr>
<td>4</td>
<td>SLM (S = 2 $p = 2$)</td>
<td>9.5</td>
<td>8.2</td>
<td>13.68%</td>
</tr>
</tbody>
</table>

Table 6. Power saving of SLM in 256-QAM-F-NOMA.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Proposed PAPR Algorithms</th>
<th>Original PAPR for 256-QAM (dB)</th>
<th>PAPR Reduction (dB)</th>
<th>Power Saving *100 (%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>SLM (S = 4 $p = 4$)</td>
<td>10</td>
<td>4.9</td>
<td>51%</td>
</tr>
<tr>
<td>2</td>
<td>SLM (S = 4 $p = 2$)</td>
<td>10</td>
<td>5.8</td>
<td>42%</td>
</tr>
<tr>
<td>3</td>
<td>SLM (S = 2 $p = 4$)</td>
<td>10</td>
<td>6.7</td>
<td>33%</td>
</tr>
<tr>
<td>4</td>
<td>SLM (S = 2 $p = 2$)</td>
<td>10</td>
<td>9</td>
<td>10%</td>
</tr>
</tbody>
</table>

3.5. Power Saving Performance

The proposed SLM algorithm’s power-saving performance is evaluated for various transmission schemes, as shown in Table 4 and illustrated in Figure 8a. It is shown that the power performance of the Solid State Power Amplifier (SSPA) is effectively improved after PAPR is reduced by applying F-NOMA. The SLM (S = 4 $p = 4$) obtained 70% power saving. In conclusion, the SSPA efficiently enhanced the signal levels.
Table 4. Power saving of SLM in 16-QAM-F-NOMA.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Proposed PAPR Algorithms</th>
<th>Original PAPR for 16-QAM (dB)</th>
<th>PAPR Reduction (dB)</th>
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</tr>
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<tr>
<td>1</td>
<td>SLM (S = 4 p = 4)</td>
<td>8.2</td>
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<td>70.70%</td>
</tr>
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<td>2</td>
<td>SLM (S = 4 p = 2)</td>
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</tr>
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<td>4</td>
<td>SLM (S = 2 p = 2)</td>
<td>8.2</td>
<td>6.6</td>
<td>19.51%</td>
</tr>
</tbody>
</table>

Figure 8. (a) Graphical representation of Table 4. (b) Graphical representation of Table 5. (c) Graphical representation of Table 6.

The proposed SLM algorithm’s power-saving performance is evaluated for various transmission schemes, as shown in Table 5 and illustrated in Figure 8b. It is shown that the SLM (S = 4 p = 4) obtained 45.26% power saving.

The primary concern of the proposed work is to investigate the PAPR of the F-NOMA, which is regarded as the primary contender for 5G radio; the PAPR of SLM for different transmission schemes is also evaluated and analyzed. The PAPR can be reduced to an optimal level by selecting the maximum S and P. A significant outcome of the results is that PAPR in F-NOMA obtained a gain of 1 dB for different QAM transmissions without applying any PAPR minimization algorithms. The SLM with sub-blocks (S) and P is applied to F-NOMA. It is shown that the SLM (S = 4 p = 4) obtained optimal PAPR.
The power-saving performance is shown in Table 6 and exemplified in Figure 8c. The SLM (S = 4 p = 4) obtained 50% power saving for F-NOMA; therefore, it is established that the SSPA proficiently improved the signal levels.

4. Discussion and Conclusions

The primary concern of the proposed work is to investigate the PAPR of the F-NOMA, which is regarded as the primary contender for 5G radio; the PAPR of SLM for different transmission schemes is also evaluated and analyzed. The PAPR can be reduced to an optimal level by selecting the maximum S and P. A significant outcome of the results is that PAPR in F-NOMA obtained a gain of 1 dB for different QAM transmissions without applying any PAPR minimization algorithms. The SLM with sub-blocks (S) and P is applied to F-NOMA. It is shown that the SLM (S = 4 p = 4) obtained optimal PAPR and BER performance as compared with the conventional SLM. Further, it is seen that the complexity of SLM is increased with high-order modulation schemes. In future work, the performance of the SLM-based advanced waveforms can be studied for the Rician channel. The complexity and throughput of the Rician channel can be compared with the Rayleigh channel for its high number of sub-carriers and transmission scheme order (S = 256 and 256-QAM).

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