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An Improved PAPR Reduction Scheme using Green OFDM

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ABSTRACT

Due to its high data rate, orthogonal frequency division multiplexing (OFDM) has gained popularity as a method for data communication. To address OFDM's drawback of a high peak-to-average power ratio, selective mapping OFDM (SLM OFDM) has been introduced (PAPR). By choosing the OFDM waveform with the lowest PAPR out of several waveform options, SLM OFDM reduces PAPR. Green OFDM emerges with more candidates, $U^2/4$, as the world be-comes increasingly digitalized and demanding without making computing more difficult. In comparison to the SLM OFDM, more candidates will propose options with lower PAPR values. Recent years have seen the development of an upgraded Green OFDM version 2, with more U^2 waveform possibilities available for selection. Comparing the PAPR values of the improved green OFDM version 2 scheme to those of the SLM OFDM and the original Green OFDM, they will be lower. As a result, it is possible to develop technologies for better da-ta transfer.

1. Introduction

A well-known modulation technique called orthogonal frequency division multiplexing (OFDM) is used in many modern wireless and wired communications, including satellite, 4G, 5G, Wi-Fi, and cellular devices. It is a multiplexing technique that divides a channel into numerous sub-channels to allow different users to share a path. The sub-channels in OFDM overlap because they are situated near one another and lack a guard band. The sub-channels are arranged in an orthogonal fashion to prevent interference, ensuring that each signal operates independently of the others. High-speed data transfer is the outcome. Because not all carriers are affected at once, OFDM is also known to guard against the frequency-selective fading channel [1].

Despite this, one of the main drawbacks of using OFDM for signal transmission is that it results in high PAPR values, which might harm the system's performance. Additionally, it results in non-linear power amplification, which reduces the high-power amplifier's (HPA) efficiency and generates in-band and out-of-band radiation. Several PAPR reduction techniques, including clipping, filtering, tone

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reservation, partial transmit sequence (PTS), and selective mapping OFDM (SLM OFDM), have been developed to address these issues [2,3].

SLM OFDM is a well-known approach that has been updated and integrated into the Green OFDM method, one of the reduction schemes that have been stated, to overcome the old, inefficient OFDM techniques. SLM OFDM is used to generate a variety of possibilities for the OFDM signal waveform. Then, among the candidates, the one with the lowest PAPR waveform will be chosen as the best. The Green OFDM method is an improved variant of SLM OFDM that generates a variety of candidate symbols, allowing for a larger number of waveform possibilities without adding more Inverse Fast Fourier Transform (IFFT) operations and complicating processing. More applicants will result in a wider range of PAPR values, and the candidates who are chosen will have a lower PAPR value [4]. Therefore, the Green OFDM approach is a more logical strategy to lower the PAPR value than the original SLM OFDM.

The suggested method outperforms other SLM OFDM methods according to [1], which produce $\frac{U^2}{4}$ signal candidates from U IFFT that already exist. A Green OFDM extension was suggested in [4], which multiplies the number of candidates by four and decreases the number of IFFT by two. The suggested approach was successful in preserving PAPR performance while bringing down the system's computing complexity. The approach and the simulation of the suggested method will be covered in the following parts.

2. Methodology

2.1 Simulation Procedure

The MATLAB platform will be used for all simulation-based project procedures. The simulation processes that will be run to achieve PAPR reduction are shown in Figure 1. First, the values for subcarriers (N = 64), oversampling factor (L = 4), IFFTs (U = 16), and symbols (1000) will be inserted into the input simulation. These figures are adequate, as higher figures will just increase calculation complexity. The important variables that will affect the results and analysis are these regulated parameters. To create the desired OFDM waveform, both input parameters—the controllable and constant parameters—will be created. Using a random binary generator included in the coding, the binary data will also be generated in accordance with the settings.

The data will next be transformed from series to parallel and modulated using the QPSK technique, which was selected since it supports 2 bits per carrier for long-distance transmission and can be simulated quickly. The QPSK signal can be written as follows:

$$s(t) = A\cos 2\pi f_c t + \theta_n;\ 0 \le t \le T_{sym};\ n = 1, 2, 3, 4 \tag{1}$$

where the phase of the signal is equal to:

$$\theta_n = (2n - 1)\frac{\pi}{4} \tag{2}$$

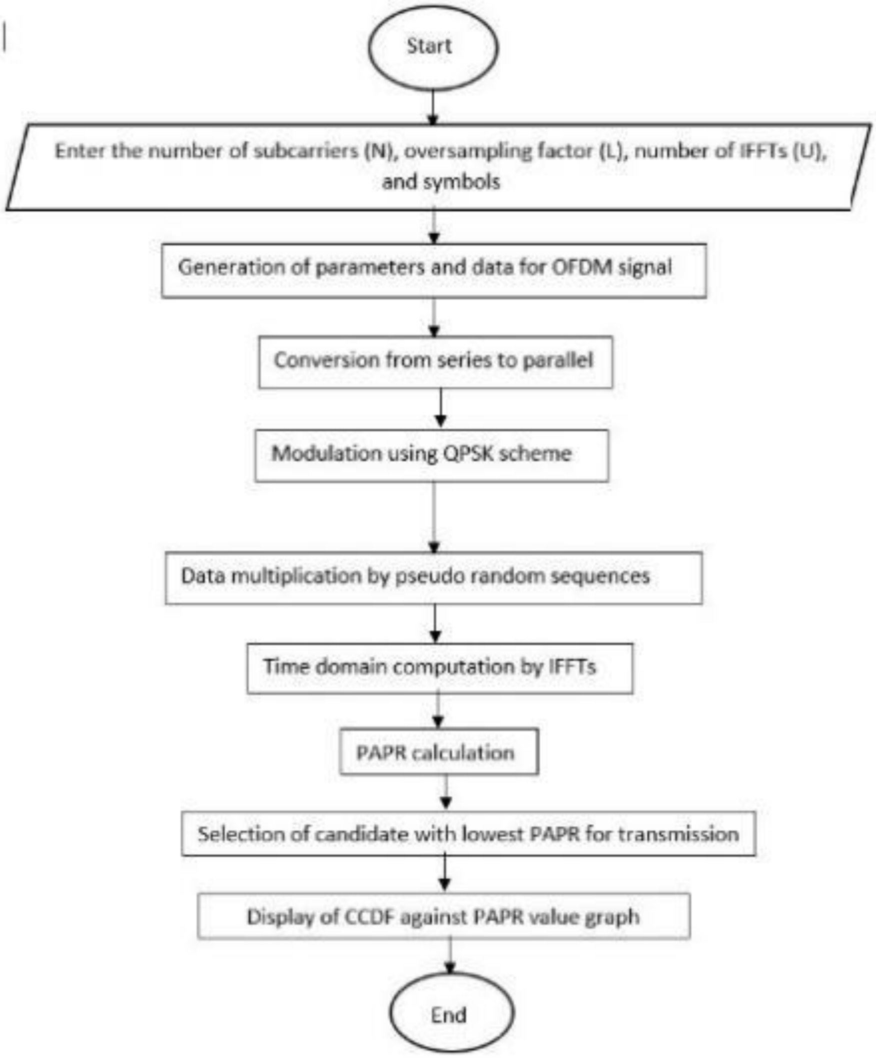

Fig. 1. Flowchart of Simulation Project Design

The input data is then multiplied by U times and increased using a pseudo-random sequence because more candidates are required for better PAPR selection. The computation will be used by the IFFTs to produce the OFDM base-band time-domain symbol:

$$x(t_n) = \frac{1}{\sqrt{N}} X[k] e^{j2\pi \frac{kn}{N}} \tag{3}$$

Where

$$t_n = \left(\frac{n}{B}\right); f\,or\ 0 \le n \le N-1\ and\ B = \frac{n-1}{T} \tag{4}$$

Where T is the symbol period and B is the bandwidth. To calculate a conversion:

$$x(n) = \sum_{0}^{N-1} x(k) \sin\left(\frac{2\pi \mathrm{kn}}{N}\right) - i \sum_{0}^{N-1} x(k) \cos\left(\frac{2\pi kn}{N}\right) \tag{5}$$

Then, the program will calculate the PAPR value for each candidate using the formula:

$$CCDF_{OFDM}(\gamma) \approx \left(1-\left(1-e^{-\gamma}\right)^{2.8N}\right)^{C} \tag{6}$$

where C is a potential waveform and N is a subcarrier. SLM's C is U, Green OFDM's C is U^2/4 and Green OFDM v2's C is U^2. Next, among the many choices, the waveform candidate with the lowest PAPR value will be selected. The primary objective of this project will be to broadcast the chosen waveform as an OFDM signal. Finally, the MATLAB software will produce a graph of the analysis's CCDF and PAPR values.

2.2 Data Analysis Method

This section will outline the methods used in this project to collect and analyze the data produced from MATLAB simulation. To construct the OFDM signal using default settings, parameters such as N = 64, symbols = 1000, and U = 16 are first added as simulation inputs while other parameters are maintained constant (see Figure 2).

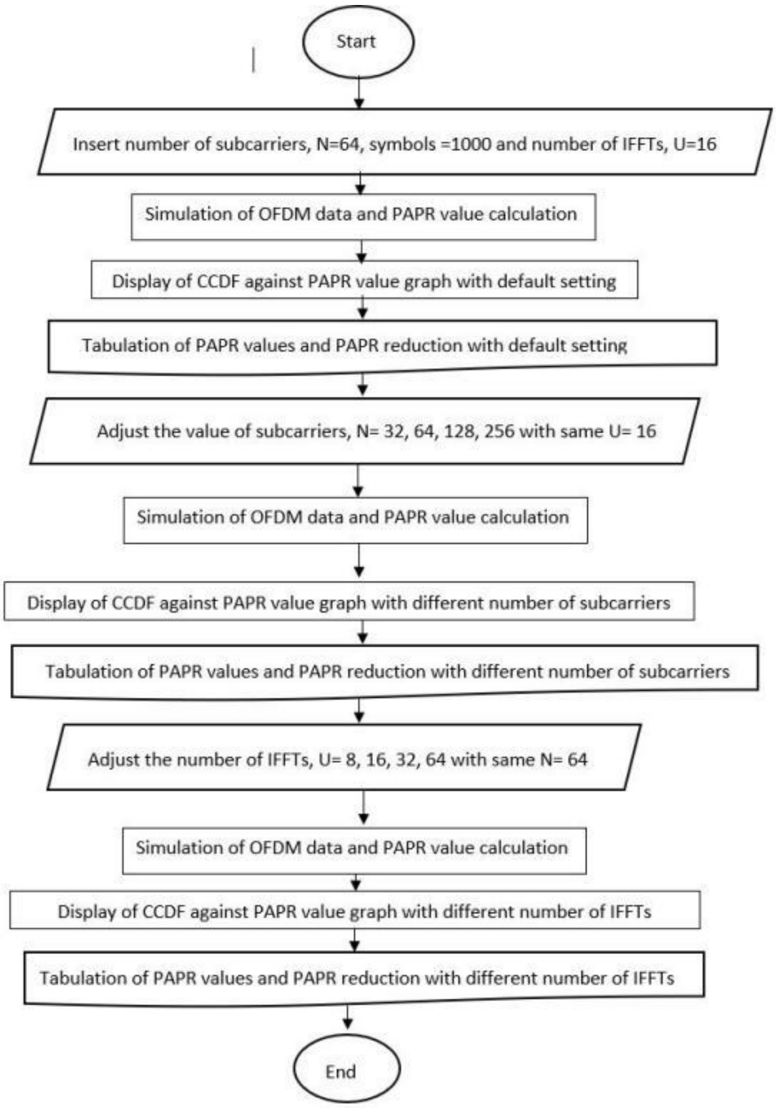

Fig. 2. Flowchart of Data Acquirement and Analysis Method

Second, utilizing the MATLAB platform, simulation of OFDM data and PAPR value calculation will be initiated based on the parameters. Thirdly, MATLAB will provide the graph of CCDF versus PAPR value, which will show four curves from the transmission of the OFDMs. The table of PAPR value and PAPR reduction will be created for analysis in the fourth step. The following are the PAPR-lowering formulas:

$$PAPR\ reduction = PAPR_{original\ OFDM} - PAPR_{proposed\ method} \quad (7)$$

SLM OFDM, Green OFDM, or Green OFDM version 2 are the available OFDM techniques. The subcarriers, N, must be changed to 32 to analyze OFDMs with varied subcarrier counts while keeping the same number of IFFTs, U, and symbols. The simulation will then be completed, and a graph of the CCDF against the PAPR for N = 32 and U = 16 will be shown. Then, repeat the steps for N = 64, 128, and 256 more subcarriers. Finally, all N's PAPR values and PAPR reductions are calculated and recorded. This demonstrates that each value of the number of subcarriers, N, will be simulated separately rather than all at once.

U must be changed to 3 for analyses with varied numbers of IFFTs, but the numbers of subcarriers and symbols must remain at 64 and 1000, respectively. The simulation will then be completed, and graphs of CCDF versus PAPR for U = 8 and U = 16 will be shown. Repeat these steps for U = 16, 32, and 64 IFFTs, if needed. Finally, PAPR readings and PAPR reductions are tallied and recorded for all U. Additionally, the data will be examined using CCDF simulation, which serves as an indicator of how well each strategy reduces PAPR. There is another technique to analyze the PAPR reduction of these methods, according to [4]. With the help of the provided N subcarriers, U waveform, and CCDF (γ) probability, you may use this method to estimate the PAPR. It can be translated into the following formula:

$$\gamma \approx -\log\left(1-\left(1-p^{\frac{1}{c}}\right)^{2.8N}\right) \quad (8)$$

where C is the waveform candidate, N is the subcarrier, and p is the fixed CCDF probability.

3. Result and Discussion

3.1 Comparison Between OFDM Performance

This section will compare the PAPR values of all OFDMs using the default settings, N=64, U=16, L=4, symbol= 10^3 with the QPSK technique. The value comparison will be set at CCDF=10^(-3). According to Table 1, the PAPR reduction for SLM OFDM is 5.9047, the PAPR re-duction for Green OFDM is 6.5015, and the PAPR reduction for Green OFDM version 2 is 6.8882. SLM OFDM, Green OFDM, and Green OFDM v2 each have a PAPR reduction percentage of 42.20, 46.46, and 49.23 percent, respectively. These demonstrate that Green OFDM v2 has the biggest PAPR value reduction, with Green OFDM coming in second and SLM OFDM coming in last. This comparison statement is since each formula-based technique has the same number of IFFTs, U = 16, and C candidates:

$$\begin{aligned} &For\ SLM\ OFDM: C = U = 16 \\ &For\ Green\ OFDM: C = \frac{U^2}{4} = \frac{16^2}{4} = 64 \\ &For\ Green\ OFDM: C = U^2 = 16^2 = 256 \end{aligned} \quad (9)$$

The most candidates are found in Green OFDM v2, followed by Green OFDM with 64 candidates and SLM OFDM with 16 candidates. The results demonstrate the fact that the more waveform candidates C generated, the greater the variety of PAPR produced by candidates and the less likely the PAPR would be chosen.

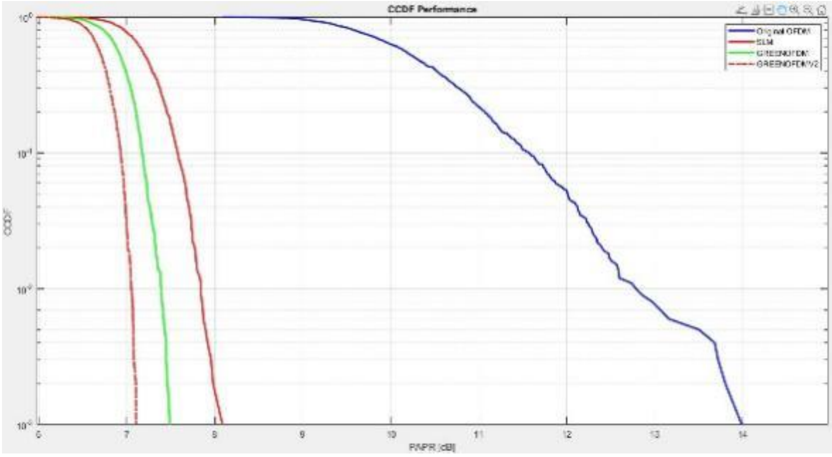

Fig. 3. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when N=64 and U=16

Table 1
Table of PAPR values comparison for OFDM, SLM OFDM, Green and Green OFDM v2 with N= 64 and U=16

PAPR values (dB)			
Original OFDM	SLM OFDM	Green OFDM	Green OFDM v2
13.9931	8.0884	7.4916	7.1049
PAPR Reduction(dB)			
SLM OFDM	Green OFDM	Green OFDM v2	
5.9047	6.5015	6.8882	

3.2 Results with Different Number of Subcarriers

This section will compare the PAPR values of all OFDMs using the same U=16, L=4, symbol= 10^3, QPSK technique but with different N such as 32, 64, 128, 256. The value comparison will be set at CCDF=10^(-3) to make the analysis reliable. Based on Table 2, it can be shown that, except for the original OFDM when N = 256, the PAPR value increases as the number of subcarriers grows. Since the simulation is excessively sophisticated and it takes the software many hours to finish just one simulation, the distinct pattern for N = 256 is the result of a simulation tool error. Next, the average PAPR reduction percentage for the three methods for N = 32 is 47%. As opposed to this, the average PAPR decrease percentages for N = 64, 128, and 256 are 45.96%, 44.55%, and 41.22%, respectively. These reduction data show that as the number of subcarriers increases, the PAPR reduction diminishes.

Table 2
Table of PAPR values comparison for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 with different N=32, 64, 128, 256

Number of Subcarriers, N	PAPR Value (dB)			
	Original OFDM	SLM OFDM	Green OFDM	Green OFDM v2
32	13.0893	7.5330	6.8377	6.4404
64	13.9931	8.0884	7.4916	7.1049
128	14.5055	8.5639	7.9383	7.6294
256	14.2356	8.7711	8.3334	7.9988
Number of Subcarriers, N	PAPR Reduction (dB)			
	SLM OFDM	Green OFDM	Green OFDM v2	
32	5.5563	6.2516	6.6489	
64	5.9047	6.5015	6.8882	
128	5.9416	6.5672	6.8761	
256	5.4645	5.9022	6.2368	
Number of Subcarriers, N	PAPR Reduction Percentage (%)			
	SLM OFDM	Green OFDM	Green OFDM v2	
32	42.45	47.76	50.80	
64	42.20	46.46	49.23	
128	40.96	45.27	47.40	
256	38.39	41.46	43.81	

This indicates that as the number of subcarriers rises, so do PAPR values. This relationship exists because each subcarrier requires sufficient power to transmit data signals with an intact signal-to-noise ratio while carrying bits in symbols (SNR). As a result, adding additional subcarriers requires more power, which raises the PAPR value and lowers the OFDM signal's overall performance. The least PAPR reduction is achieved by SLM OFDM with the greatest N = 256, while the most PAPR reduction is achieved by Green OFDM v2 with the lowest N = 32.

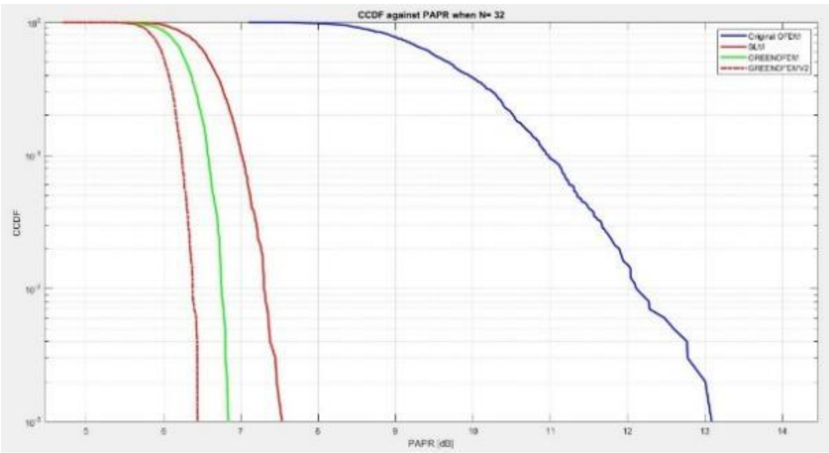

Fig. 4. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when N=32

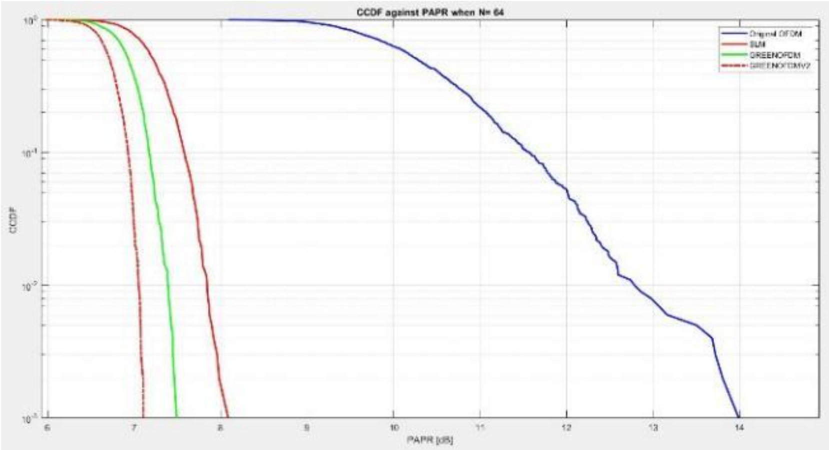

Fig. 5. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when N=64

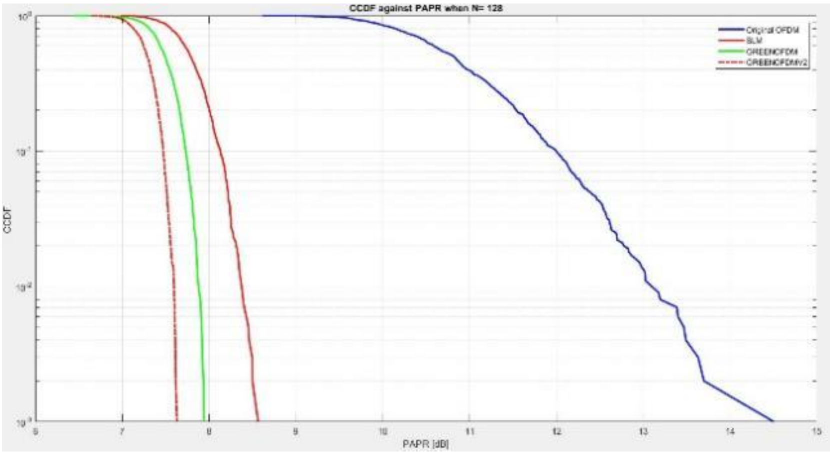

Fig. 6. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when N=128

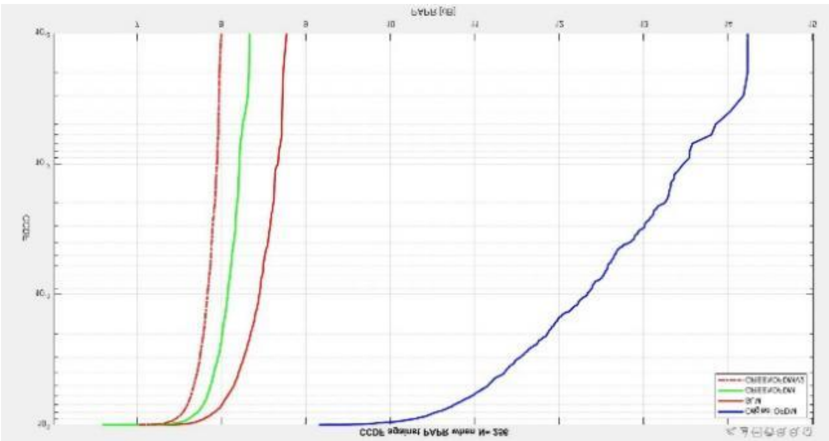

Fig. 7. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when N=256

3.3 Results with Different Number of IFFTs

This section will compare the PAPR values of all OFDMs using the same N=64, L=4, symbol= 10^3, QPSK technique but with different U such as 16, 32, 64, 128, 256. The value comparison will be set at

CCDF=10^(-3) to make the analysis reliable. According to Table 3, the PAPR value decreases as the number of IFFTs rises, except for the original OFDM when U = 8. Since the simulation is performed one at a time and involves numerous data and procedures, the unusual pattern for U=8 is caused by an accuracy error. As the project uses a random data generator, each simulation for a given value of U will produce unique data, leading to unique OFDM signal forms in each simulation.

Table 3
Table of PAPR values comparison for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 with different U= 8, 16, 32, 64

Number of IFFTs, U	PAPR Value (dB)			
	Original OFDM	SLM OFDM	Green OFDM	Green OFDM v2
32	13.6860	8.5807	8.1623	7.5682
8	13.9931	8.0884	7.4916	7.1049
16	13.8812	7.6530	7.1413	6.8728
32	13.6860	7.4387	6.8334	6.6430
Number of IFFTs, U	PAPR Reduction (dB)			
	SLM OFDM	Green OFDM	Green OFDM v2	
32	5.1053	5.5237	6.1178	
8	5.9047	6.5015	6.8882	
16	6.2282	6.7399	7.0084	
32	6.2473	6.8526	7.0430	
Number of IFFTs, U	PAPR Reduction Percentage (%)			
	SLM OFDM	Green OFDM	Green OFDM v2	
32	37.30	40.36	44.70	
8	42.20	46.46	49.23	
16	44.87	48.55	50.49	
32	45.65	50.07	51.46	

The average PAPR reduction percentage for the three methods is hence 40.79 per-cent for U=8. While the typical PAPR reduction rates for U=16, 32, and 64 are 45.96%, 47.97%, and 49.06%, respectively. These results demonstrate that when the number of IFFTs decreases, the PAPR reduction increases. This indicates that as there are more subcarriers, the PAPR values decline more, as would be predicted. This occurs because more waveform candidates are generated when more IFFTs are used. According to the following calculations, the number of IFFTs, U, is directly proportional to the waveform candidates, C:

$$\begin{aligned} &SLM\ OFDM\colon C_{SLM} = U \\ &Green\ OFDM\colon C_{Green} = \frac{U^2}{4} \\ &Green\ OFDM\ v2\colon C_{Green2} = U^2 \end{aligned} \tag{10}$$

Finally, Green OFDM v2 achieves the greatest PAPR reduction with a U = 64, but SLM OFDM achieves the lowest PAPR reduction with a U = 8. Additionally, it is evident that when U rises, the PAPR reduction between U values falls.

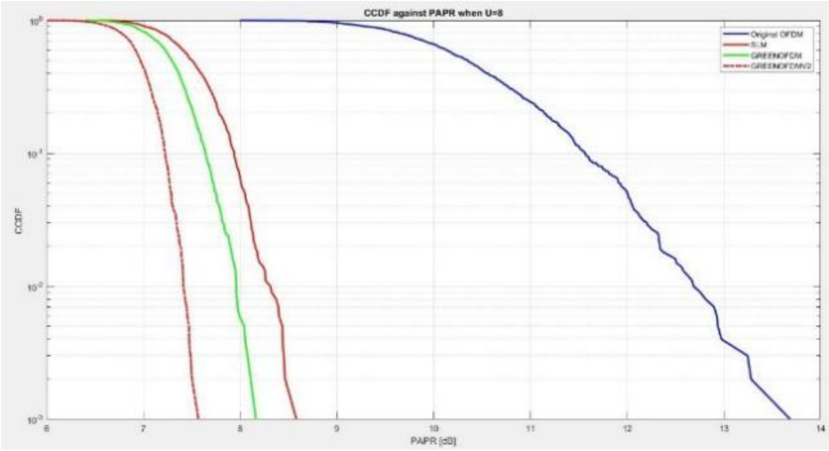

Fig. 8. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when U=8

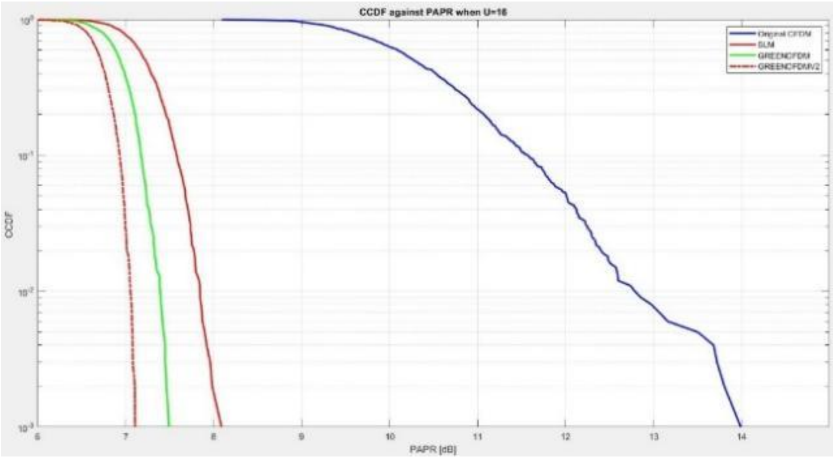

Fig. 9. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when U=16

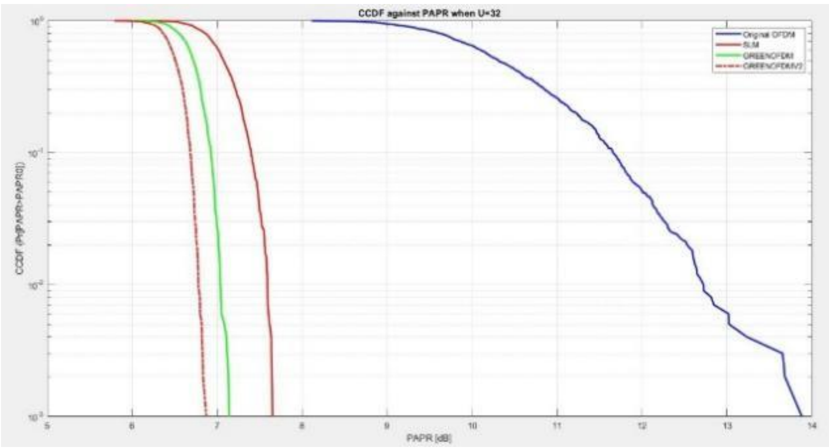

Fig. 10. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when U=32

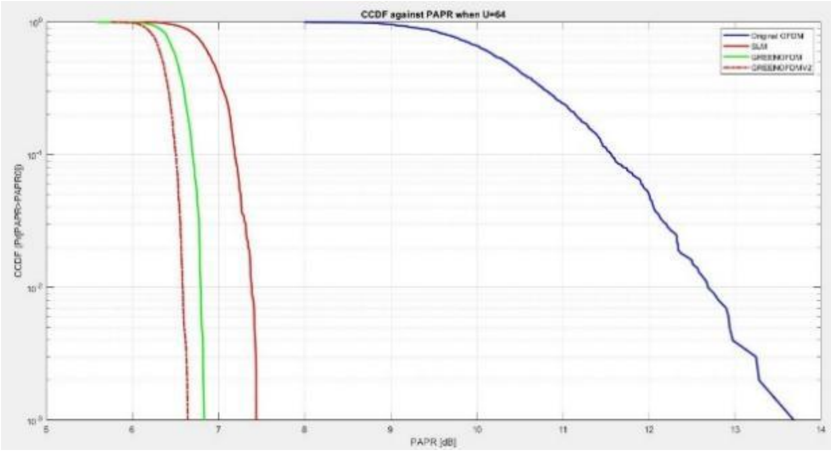

Fig. 11. Graph of CCDF against PAPR (dB) for OFDM, SLM OFDM, Green OFDM and Green OFDM v2 when U=64

4. Conclusion

SLM OFDM, Green OFDM, and Green OFDM version 2 are some of the techniques that have been proven to be effective in this research for reducing the major draw-back of OFDM signals, which is their high PAPR value. All these approaches have the same philosophy, which is to produce many waveform candidates—copies of the data set—and then select the candidate with the lowest PAPR to be broadcast. First off, this research has been successful in developing an upgraded PAPR reduction scheme employing the Green OFDM method, which is the Green OFDM version 2 approach. By utilizing the IFFT's linearity property and keeping its orthogonality, this variant has maximized the utilization of IFFTs. Due to this benefit, waveform choices for Green OFDM version 2 are four times as many as those for the original Green OFDM. Second, it can be inferred from the results that SLM OFDM has the lowest PAPR reduction among the three approaches, followed by Green OFDM version 2 and Green OFDM. The performance of the new Green OFDM version meets the project's goals and expectations. Thirdly, it can be seen from the CCDF graph that the PAPR values rise along with the number of subcarriers. On the other side, it is discovered that the PAPR values fall as the number of waveforms candidates rises.

Finally, because OFDM signals are frequently used in our lives for Wi-Fi, 4G, 5G, and cellular devices due to their high data transmission and excellent resistance to intersymbol interference (ISI), efforts to upgrade OFDM are crucial. These benefits enable us to speak with someone far away without lagging and with maximum quality thanks to the good data reception after multipath transmission.

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References
[1] Mestdagh, D. J. G., J. L. Gulfo Monsalve, and J-M. Brossier. "GreenOFDM: a new selected mapping method for OFDM PAPR reduction." *Electronics Letters* 54, no. 7 (2018): 449-450. https://doi.org/10.1049/el.2017.4743

[2] Aghdam, Mehdi Hosseinzadeh, and Abbas Ali Sharifi. "PAPR reduction in OFDM systems: An efficient PTS approach based on particle swarm optimization." *ICT Express* 5, no. 3 (2019): 178-181. https://doi.org/10.1016/j.icte.2018.10.003

[3] Jawhar, Yasir Amer, Lukman Audah, Montadar Abas Taher, Khairun Nidzam Ramli, Nor Shahida Mohd Shah, Mustafa Musa, and Mustafa Sami Ahmed. "A review of partial transmit sequence for PAPR reduction in the OFDM systems." *IEEE Access* 7 (2019): 18021-18041. https://doi.org/10.1109/ACCESS.2019.2894527

[4] Gulfo Monsalve, Jorge Luis, Laurent Ros, Jean-Marc Brossier, and Denis Mestdagh. "An improved GreenOFDM scheme for PAPR reduction." In *Telecom*, vol. 1, no. 3, pp. 196-210. MDPI, 2020. https://doi.org/10.3390/telecom1030014

[5] Gupta, Saruti, and Ashish Goel. "Improved selected mapping technique for reduction of papr in ofdm systems." *International Journal of Advanced Computer Science and Applications* 11, no. 10 (2020). https://doi.org/10.14569/IJACSA.2020.0111016

[6] Jiang, Tao, Da Chen, Chunxing Ni, and Daiming Qu. *OQAM/FBMC for future wireless communications: Principles, technologies and applications*. Academic Press, 2017. https://doi.org/10.1016/B978-0-12-813557-0.00010-3

[7] Xing, Zhitong, Kaiming Liu, and Yuanan Liu. "Low-complexity companding function design for PAPR reduction in OFDM systems." *IET Communications* 14, no. 10 (2020): 1581-1587. https://doi.org/10.1049/iet-com.2019.0812

[8] Abed, D., and A. Medjouri. "Discrete sliding norm transform-based 50% PAPR reduction in asymmetrically clipped optical OFDM systems for optical wireless communications." *Electronics Letters* 51, no. 25 (2015): 2128-2130. https://doi.org/10.1049/el.2015.2813

[9] Jiang, Tao, Da Chen, Chunxing Ni, and Daiming Qu. *OQAM/FBMC for future wireless communications: Principles, technologies and applications*. Academic Press, 2017. https://doi.org/10.1016/B978-0-12-813557-0.00010-3

[10] Sandoval, Francisco, Gwenael Poitau, and François Gagnon. "Hybrid peak-to-average power ratio reduction techniques: Review and performance comparison." *IEEE access* 5 (2017): 27145-27161. https://doi.org/10.1109/ACCESS.2017.2775859

[11] Kumar, A., and M. Gupta. "Reduction of PAPR by using clipping and filtering for different modulation schemes." *Am. J. Appl. Sci* 12 (2015): 601-605.

[12] N. I. Bakri, “Particle Swarm Optimization For PAPR Reduction Of OFDM Systems.” thesis, 2021.