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PAPR Reduction in OFDM using Selective Mapping Technique

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A B S T R A C T

In this paper, we investigate the performance of Peak-to-Average Power Ratio (PAPR) reduction in both Orthogonal Frequency Division Multiplexing (OFDM) and Non-Orthogonal Multiple Access (NOMA) systems using the Selective Mapping (SLM) technique. The simulation is conducted with 256 subcarriers, QPSK modulation, and 100,000 OFDM symbols, comparing the PAPR characteristics of original and SLM-optimized OFDM and NOMA systems. The SLM technique utilizes 10 phase sequences, and NOMA is evaluated with two users, where power allocation is set to 0.8 for the stronger user and 0.2 for the weaker user. Results show that the SLM technique effectively reduces the PAPR in both systems, with a 2dB reduction in OFDM (corresponding to a 22.22% decrease) and a 3dB reduction in NOMA (resulting in a 33.33% decrease). The findings suggest that SLM-NOMA offers superior PAPR reduction compared to SLM-OFDM, making it a more efficient solution for power domain multiple access, particularly in advanced wireless networks like 5G. This research highlights the potential of SLM optimization for enhancing power efficiency in modern communication systems.

Keywords: OFDM, NOMA, PAPR, SLM

1. Introduction

The current surge in the demand for multimedia data services is driving us toward the fifth generation of wireless communication. Multipath channel environments, also known as multicarrier communication systems, offer strong and bandwidth-efficient technologies that wireless communication leverages to address multimedia requirements in situations with big clientele and restrictive spectrum.

Modern digital multicarrier wireless communication technology offers inexpensive, rapid data rates, and excellent dependability. A multicarrier system divides the communication bandwidth into multiple sub-carriers in a way that minimizes the amount of bandwidth used by each subcarrier in comparison to a single carrier system. In a single carrier system, the entire transmission allowed for communication is used. These noteworthy benefits of the multicarrier technique encourage us to think about orthogonal frequency division multiplexing, or OFDM.

All wireless communication, including 4G and 5G, is based on OFDM structures due to their extreme subcarrier limitation and high information rate.

The need for high information rates is the main component of multi-carrier systems. It ought to be able to function without difficulty in a setting with high carrier frequency, high mobility, and high information transmission rate.

OFDM is a multi-carrier modulation (MCM) method that modulates data symbols such as BPSK, QPSK, QAM, MPSK, and others over an orthogonal sub-carrier and then sends them in parallel. A single carrier (SC) system broadcasts one complex data point, while a parallel transmission of N complex data points is carried out via N sub-carriers. The system's effective data rate in this instance is the same as the SC system's. The symbol's duration is extended and the multipath delay-induced relative time separation is decreased by the parallel transmission.

The OFDM framework uses the Reverse Fast Fourier Transform (IFFT) to implement the orthogonality idea. A guard band is inserted in between the progressive OFDM symbols. The three methods that ought to enable the addition of a guard band to an OFDM symbol are cyclic prefix, cyclic postfix, and zero padding. By appending a guard band to OFDM symbols, one channel is transformed from a wideband channel into a set of parallel narrowband channels, one channel for each subcarrier. Inter-Symbol Interference (ISI) is thereby eliminated. Due to OFDM's benefits-including resilience to multipath fading, fast data transmission rates, and fewer technical requirements-many broadband wireless communications now use it. [1], [2].

Nomenclature

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CDMA	Code Division Multiple Access
OFDMA	Orthogonal Frequency Division Multiplexing Access
IBO	Input Power Back-Off
NOMA	Non-Orthogonal Multiple access
PAPR	Peak-to-Average-Power Ratio
SLM	Selective Mapping
SNR	Signal to Noise Ratio

1.1 Principle of Orthogonality

The amount of bandwidth used in a multi-carrier system can be decreased if the frequency gap between the carriers can be adjusted to avoid overlapping. Therefore, by using the orthogonal principle, the distance between carriers can be shortened. The idea of an orthogonal signal states that two signals are orthogonal if their time average integral product is zero.

Mathematically, the orthogonality of two signals can be expressed as-

$$\frac{1}{T}\int_{t_1}^{t_1+T} f_k(t) \times f_l(t)\,dt = 0 \;\; if\; k \neq l \qquad \text{Eqn. 1}$$

here, $f_k(t)$ and f_l (t) are two signals between time span [t, t_1+T], T is signal time period. On the other hand, when dealing with orthonormal signals, the time averaged integral product of two signals ought to equal one.

Mathematically, ortho-normal signals can be given as-

$$\frac{1}{T}\int_{t_1}^{t_1+T} f_k(t) \times f_l(t)\,dt = 1 \;\; if\; k = l \qquad \text{Eqn. 2}$$

Using equation (1) and (2) orthogonality of system shown as-

$$\frac{1}{T}\int_0^T e^{j2\pi f_k t} \times e^{-j2\pi f_l t} dt = \frac{1}{T}\int_0^T e^{\frac{j2\pi kt}{T}} \times e^{\frac{-j2\pi lt}{T}} dt = \frac{1}{T}\int_0^T e^{\frac{j2\pi(k-1)t}{T}} dt \qquad \text{Eqn. 3}$$

Solving equation (3), we get-

$$\frac{1}{T}\int_0^T e^{j2\pi f_k t} \times e^{-j2\pi f_l t} dt = \begin{cases} 0 & \forall \;\; k \neq l \\ 1 & \forall \;\; k = l \end{cases} \qquad \text{Eqn. 4}$$

Taking the samples at sampling time at t = nT_s = nT/N, n= 0,1, 2,… N-1

Equation (4) can be written in the discrete time domain as-

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{\frac{-j2\pi k}{T} nT_s} \times e^{\frac{-j2\pi k}{T} nT_s} = \frac{1}{N}\sum_{n=0}^{N-1} e^{\frac{-j2\pi(k-l)}{N} n} = \begin{cases} 0 & \forall \;\; k \neq l \\ 1 & \forall \;\; k = l \end{cases} \qquad \text{Eqn. 5}$$

Subcarrier overlap makes the usage of frequency spectrum by OFDM systems efficient.

1.2 Advantages of OFDM System

The advantages of OFDM system are given as-

- Saving of Bandwidth
- Simpler modulation and demodulation
- Easy Equalization
- Susceptible to frequency selective fading
- Eliminates Inter symbol interference

1.3 Disadvantages of OFDM System

There are many advantages, the OFDM systems have major problems like-

- High Peak to Average Power Ratio (PAPR) of transmitted signal
- Synchronization (timing and frequency) at the receiver

1.4 Objective of the work

One of the primary reasons for concern with OFDM systems is their high peak to average power ratio (PAPR). Because of the high PAPR, the high-power amplifier (HPA) has to run in the non-linear zone. This non-straight area activity distorts the non-linear region operation, resulting in a larger back-off power requirement and a reduction in the amplifier's power efficiency. Furthermore, it incorporates ISI into the OFDM system, which ultimately impacts the performance of the bit error rate (BER). Over the last ten years, numerous tactics have been used to lower the PAPR. The primary issues with these methods are HPA efficiency, BER performance, and computational complexity. The primary objective of this postulation is to examine and investigate the PAPR reduction mechanisms of the OFDM system in order to create a new tactic that will require less computing.

2. Literature Review

Orthogonal Frequency Division Multiplexing (OFDM): OFDM is a widely used technique in wireless communications due to its robustness against multipath fading and efficient bandwidth utilization. The foundational works by Bahai and Saltzberg (2000) [1] and Van Nee and Prasad (2000) [2] provide a comprehensive exploration of OFDM principles and applications, particularly in wireless multimedia communications. This technique is also detailed in early patent filings, such as the U.S. Patent No. 3,488,455 (1970) [3].

Standards and Applications: The IEEE 802.11 standards, including 802.11a [5], 802.11g [6], and 802.11n [7], play a critical role in defining wireless local area networks (WLAN) using OFDM. These standards have enabled high-speed data communication over wireless networks. Additionally, OFDM is used in digital broadcasting, as discussed by Sari et al. (1995) [11], and in emerging technologies like WiMAX for multicast and broadcast services (Jiang et al., 2007) [9].

Peak-to-Average Power Ratio (PAPR) Reduction: A significant challenge in OFDM is the high PAPR, which degrades power efficiency. Several recent studies propose techniques for reducing PAPR, particularly in non-orthogonal multiple access (NOMA) systems. These include selective mapping (Mounir et al., 2023) [15], neural networks (Zou et al., 2021) [23], and hybrid algorithms (Kumar, 2023) [19]. Furthermore, the integration of low-complexity and selective mapping techniques in OFDM-NOMA has been examined by Sayyari et al. (2021) [21] and Alsabah et al. (2021) [24].

NOMA and 5G Networks: Non-orthogonal multiple access (NOMA) is a promising candidate for 5G and beyond. NOMA enables multiple users to share the same time and frequency resources, improving spectral efficiency. Recent works (Sharma & Kumar, 2022) [16] and Budhiraja et al. (2021) [25] analyze NOMA's potential in 5G security and efficiency. Moreover, time-frequency domain NOMA for power-efficient communications has been explored by Hama and Ochiai (2023) [17].

Advanced Techniques in OFDM: The use of machine learning (ML) and other advanced signal processing techniques is emerging in modern OFDM systems. Jaiman et al. (2023) [18] and Hu et al. (2020) [28] propose ML-based approaches for detecting signals in massive multiple-input multiple-output (MIMO) systems, enhancing the performance of OFDM in complex communication scenarios.

The evolution of OFDM and its variants like NOMA plays a crucial role in modern wireless communication systems, especially as networks advance towards 5G and 6G technologies. PAPR reduction remains a key challenge, and novel methods, including machine learning, continue to push the boundaries of OFDM's efficiency and scalability.

3. Research Methodology

Selective Mapping (SLM) is a technique used in Orthogonal Frequency Division Multiplexing (OFDM) systems to improve system performance by limiting the impacts of peak-to-average power ratio (PAPR). Non-orthogonal multiple access (NOMA) solutions, in contrast to conventional OMA, allow an indefinite number of users to share the same resource unit (i.e., time and frequency) concurrently, improving spectrum efficiency and facilitating mass connection. Power domain NOMA and code domain NOMA are the two basic types of NOMA systems. The power domain NOMA (PD NOMA) is simpler to implement than the code domain NOMA. Instead of applying IFFT multiple times for each phase sequence, we can perform a vectorized approach to reduce the computation time. The phase sequence application and PAPR calculations for both OFDM and NOMA are vectorized, which avoids unnecessary loops and speeds up execution. This optimization improves the speed and scalability of the code for large numbers of OFDM symbols. The CCDF plots still provide the PAPR reduction comparison between the original and SLM-based methods for both OFDM and NOMA systems.

Figure 1: Flow diagram of the modified SLM technique

Figure 1 shows the flow diagram of the proposed work. The figure presents a **flowchart** that outlines the **simulation process** for **PAPR reduction** in both **OFDM** and **NOMA** systems using the **Selective Mapping (SLM)** technique. The simulation starts by setting the system parameters such as the number of subcarriers, modulation scheme (QPSK), number of users in NOMA, power allocation, and number of phase sequences for SLM. Then Random data symbols are generated for both OFDM and NOMA systems. These symbols will be modulated and used to evaluate the system performance. After then generated random data is modulated using **Quadrature Phase Shift Keying (QPSK)**, a commonly used modulation scheme in wireless communication systems. Now for the NOMA system, superposition coding is performed. This step involves combining the signals from multiple users (with different power levels) in accordance with NOMA's power-domain multiplexing. An **Inverse Fast Fourier Transform (IFFT)** is applied to convert the frequency-domain symbols into time-domain signals for both OFDM and NOMA. This step is crucial for transforming modulated data into an OFDM or NOMA waveform. After that, **SLM phase sequences** are generated. These sequences are applied later to create different signal representations, which will help reduce PAPR. The generated phase sequences are applied to the time-domain OFDM and NOMA signals to modify their PAPR. This process is known as the **Selective Mapping (SLM) technique**, which selects the signal with the lowest PAPR from different mapped signals. The PAPR for both the original signals and the SLM-optimized signals is calculated. This allows for comparison to determine how effectively SLM reduces PAPR in both systems. Finally, the **Complementary Cumulative Distribution Function (CCDF)** of PAPR is plotted. The CCDF plot shows the probability of the PAPR exceeding a certain threshold, which helps visualize the impact of SLM on PAPR reduction for OFDM and NOMA systems. This flowchart outlines the entire simulation process from parameter initialization, data generation, modulation, and superposition coding (for NOMA), to applying the SLM technique and evaluating the PAPR performance. It clearly shows how the SLM approach is used to optimize the PAPR in both OFDM and NOMA communication systems. Now explain some parameters and terms used in this system are defined as the following.

3.1 System Model

QPSK Modulation

QPSK (Quadrature Phase Shift Keying) modulates data symbols into phase values. Given a data symbol $d_n = \{0,1,2,3\}$, the QPSK Modulation can be expressed as:

$$x_n = e^{\frac{-j2\pi d_n}{M}} \qquad \text{Eqn. 6}$$

Where x_n is the modulated symbol, d_n is input data symbol and M=4 for QPSK.

Superposition coding for NOMA

In NOMA different user's signal are superposed with different power allocations. For 2 users superposed signal is

$$x_{NOMA}(n) = \sqrt{P_1} \cdot x_1(n) + \sqrt{P_2} \cdot x_2(n) \qquad \text{Eqn. 7}$$

Where $x_1(n)$ and $x_2(n)$ are QPSK symbols of user1 and user2 respectively. P_1 and P_2 are the power allocation factors (P_1=0.8 and P_2 = 0.2)

OFDM Modulation (IFFT)

OFDM Modulation is achieved by performing the Inverse Fast Fourier Transform on the modulated data symbols.

$$X_k = IFFT(x_n) \qquad \text{Eqn. 8}$$

Where X_k are the time-domain OFDM symbols after applying the IFFT. For both OFDM and NOMA, this operation converts frequency-domain symbols into time-domain symbols.

Peak-to Average Power Ratio (PAPR)

The PAPR of an OFDM symbol is defined as the ratio of the peak power to the average power of the signal;

$$PAPR(X_k) = \frac{max|X_k|^2}{\mathbb{E}|X_k|^2} \qquad \text{Eqn. 9}$$

Where $max|X_k|^2$ is the maximum power of the signal and $\mathbb{E}|X_k|^2$ is the average power of the signal.

Selective Mapping (SLM)

SLM involves multiplying the OFDM symbols by different phase sequences to reduce PAPR. The phase sequence is expressed as;

$$X_k^{(p)} = X_k \cdot P^{(p)} \qquad \text{Eqn. 10}$$

Where $P^{(p)}$ is the phase sequence for the p-th trial and $X_k^{(p)}$ is the new OFDM symbol after applying the phase sequence.

The goal is to minimise PAPR across different phase sequences;

$$PAPR_{SLM} = \min_p \left(\frac{max\left|X_k^{(p)}\right|^2}{\mathbb{E}\left|X_k^{(p)}\right|^2} \right) \qquad \text{Eqn. 11}$$

$$PAPR_{dB} = 10 \log_{10}(PAPR) \qquad \text{Eqn. 12}$$

Complementary Cumulative Distribution Function (CCDF)

The CCDF of PAPR is used to evaluate the probability that PAPR exceeds a certain threshold

$CCDF_{PAPR} = P_r(PAPR) > PAPR_{threshold}$ Eqn. 13

4. Results and Discussion

For the simulation used of the modified SLM OFDM and SLM NOMA system used the MATLAB R2024a. Taking some simulation parameter for the both systems as shown in Table 2.

4.1 Modified SLM technique

For the modified SLM technique follow the following procedure for reduction PAPR and get the optimized compared plot as shown in Figure 3.

- Initialize Parameters.
- Generate Random Data for OFDM and NOMA.
- Perform QPSK Modulation.
- Superposition Coding for NOMA.
- Perform IFFT for OFDM and NOMA.
- Generate Phase Sequences for SLM.
- Apply Phase Sequences to OFDM and NOMA.
- Calculate PAPR for Original and SLM symbols.
- Plot the CCDF of PAPR.

Table 2: Simulation parameters for OFDM and modified SLM

Simulation parameter	**Value**
Number of subcarriers (K)	256
QPSK Modulation (M)	4
Number of OFDM symbols	100000
Number of phase sequences for SLM	10
Number of users in NOMA	2
Power allocation for 2 users	0.8 and 0.2

The Figure 3 shows the Complementary Cumulative Distribution Function (CCDF) for Peak-to-Average Power Ratio (PAPR) in both OFDM and NOMA systems. The curves show the performance of the Selective Mapping (SLM) technique for PAPR reduction, comparing the original (unoptimized) and SLM-optimized versions for both OFDM and NOMA.

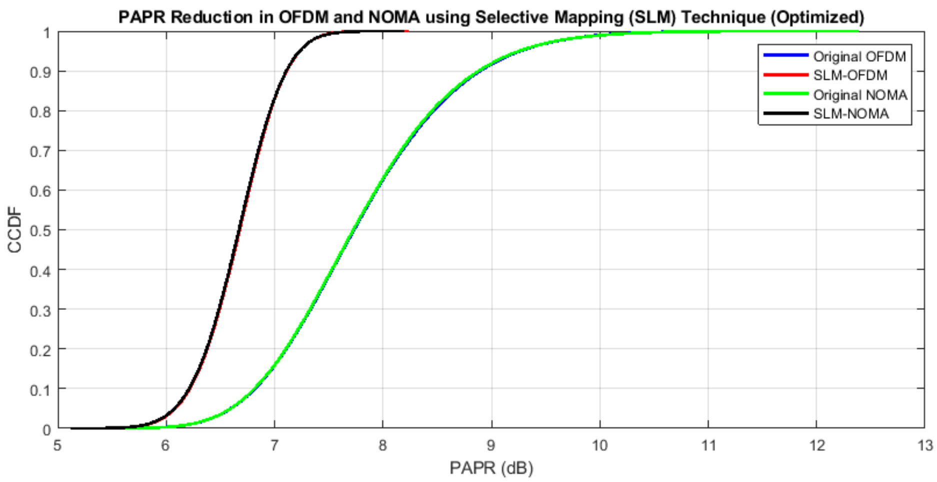

Figure 3: CCDF Comparison of Modified SLM OFDM and OFDM

The original OFDM system has a higher PAPR curve, reaching about 9 dB at the 0.1 CCDF level. This means that, without optimization, the PAPR in OFDM is higher. The SLM technique applied to OFDM significantly reduces the PAPR. The curve shifts left, showing a reduction in PAPR compared to the original OFDM. The PAPR is reduced to around 7 dB at the 0.1 CCDF level. The original NOMA system starts with a slightly lower PAPR compared to the original OFDM. Its curve intersects the OFDM at around 9 dB, indicating that unoptimized NOMA generally has a comparable PAPR to OFDM but with slight variations at different CCDF levels. The SLM-optimized NOMA shows the best PAPR reduction. The curve is significantly shifted leftward, with the PAPR being reduced to about 6 dB at the 0.1 CCDF level. This indicates a notable improvement over the original NOMA system.

Table 3: PAPR reduction in terms of dB and percentage

System	PAPR (in dB)	Reduction	Percentage
OFDM	9 dB	2 dB	22.22%
SLM-OFDM	7 dB		
NOMA	9 dB	3 dB	33.33%
SLM-NOMA	6 dB		

The **SLM-OFDM** scheme achieves a **2dB** reduction in PAPR, which corresponds to a **22.22%** decrease in PAPR. The **SLM-NOMA** scheme achieves a **3dB** reduction in PAPR, corresponding to a **33.33%** decrease in PAPR. **SLM-NOMA** provides better PAPR reduction compared to **SLM-OFDM**, both in terms of dB reduction and percentage reduction, making it a more efficient approach for reducing power inefficiencies in NOMA systems.

5. Conclusion

The simulation results demonstrate that the Selective Mapping (SLM) technique is effective in reducing the Peak-to-Average Power Ratio (PAPR) for both OFDM and NOMA systems. SLM-OFDM achieves a 2dB reduction in PAPR, translating to a 22.22% improvement over the original OFDM system. This indicates that SLM optimization enhances the power efficiency of OFDM, though the improvement is moderate. SLM-NOMA performs better, achieving a 3dB reduction in PAPR, which represents a 33.33% improvement over the original NOMA system. This highlights that SLM is more effective in NOMA, further reducing PAPR and thus enhancing the efficiency of power domain multiple access techniques. NOMA systems inherently show slightly lower PAPR than OFDM systems, and applying SLM optimization further enhances this advantage, making SLM-NOMA a more suitable choice for systems where power efficiency is critical, such as in 5G and beyond. The SLM technique is a valuable tool for PAPR reduction, with NOMA systems benefiting more from its application compared to OFDM systems. This suggests that SLM-NOMA can be a promising candidate for future wireless communication technologies requiring high efficiency and reduced power consumption.

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