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Optimizing FBMC/OQAM: Hermite filter and DFT-based precoding for PAPR reduction

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ABSTRACT

In the ever-evolving landscape of wireless communication, there is a persistent quest for modulation schemes that optimize spectral efficiency, reduce interference, and enhance overall system performance. This paper introduces a novel modulation technique that synergistically improves on the strengths of filter bank multi-carrier (FBMC). A distinctive feature of our approach is the deployment of the Hermite prototype filter in the FBMC system, diverging from traditional FBMC architectures. An advanced precoding strategy leveraging a pruned discrete fourier transform (pDFT) paired with scaling is also introduced. This combination promises reduced inter-symbol interference and heightened spectral efficiency. As the management of the peak-to-average power ratio (PAPR) is a significant challenge in FBMC systems to addressing this iterative particle swarm optimization (IPSO) algorithm is proposed. Evaluations are carried out to demonstrate the efficiency of the proposes scheme in reducing PAPR substantially for FBMC/OQAM framework. Experiments are conducted and comparisons are performed among several prominent multicarrier modulation schemes. The results from the experiments indicate that the application of IPSO algorithm with Hermite functions and applied to an FBMC/OQAM system using pruned DFT has been successful in reducing the PAPR also a 6-13% decrease in error rate has been shown across varying QAM orders regardless of SNR level.

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1. INTRODUCTION

The evolution of wireless communications from 2G to 5G and beyond has been marked by significant technological advancements [1], [2], each generation bringing about improvements in speed, capacity, latency, and overall network performance. The ongoing developments toward 6G demonstrate a trajectory of continuous improvement, expanding the possibilities and applications in wireless communications [3]. Current wireless communication systems, notably 4G, face several significant issues and challenges that impact their efficiency and overall performance. One primary challenge is the increasing demand for data-intensive applications and services, which puts immense pressure on existing 4G networks [4]. The surge in mobile data usage for activities such as video streaming, online gaming, and large file downloads has led to congestion issues, resulting in reduced data speeds and potential service disruptions during peak hours.

Moreover, 4G networks are grappling with the challenge of providing consistent coverage in both urban and rural areas. Urban environments often experience network congestion due to the high concentration of users, while rural areas may have limited infrastructure, leading to coverage gaps and a lack of reliable connectivity. This digital divide poses challenges in delivering seamless communication experiences for all users. In addressing these challenges, the ongoing deployment and transition to 5G networks aims to provide solutions such as higher data rates, lower latency, and increased device capacity [5]. However, the coexistence of 4G and 5G networks during the transition period introduces interoperability challenges and requires careful management to ensure a smooth and seamless user experience. As wireless communication systems evolve, addressing these issues will be essential to meet the demands of an data-driven world.

New modulation schemes [6], including filtered- orthogonal frequency division multiplexing (F-OFDM), universal filtered multi-carrier (UFMC), and filter bank multi-carrier (FBMC) [7], have emerged to address specific challenges and limitations associated with traditional OFDM in wireless communication systems. These schemes bring increased flexibility, adaptability to dynamic channel conditions, and improved spectral containment, making them valuable contenders for the evolving landscape of wireless communication systems [8].

Advance modulation schemes such as F-OFDM, UFMC, and FBMC is the need for coexistence with existing modulation schemes during transition periods [9]. Ensuring backward compatibility and interoperability with legacy systems is crucial for a smooth deployment of these advanced modulation techniques. Implementing advanced modulation schemes may require more sophisticated transceiver architectures, potentially leading to higher power consumption and hardware costs [10]. Adaptive resource allocation in dynamic environments, while a strength of these schemes, can also present challenges in terms of efficient algorithms for real-time adaptation, especially when dealing with rapidly changing channel conditions. Robustness against various impairments, such as phase noise, frequency offset, and non-linearities, is a shared challenge. Ensuring that these advanced modulation schemes perform well under diverse and sometimes adverse conditions is essential for their practical viability peak-to-average power ratio (PAPR) remains a significant concern for advanced modulation schemes [11]. Managing PAPR is crucial for ensuring the practical viability and efficient deployment of these schemes in real-world wireless communication systems [12]. Researchers and engineers continue to explore innovative solutions to strike the right balance between PAPR reduction, spectral efficiency, and hardware complexity.

This work is motivated by the quest for a modulation scheme that transcends the limitations of existing approaches. Overall contributions of our work can be summarized as follows:

– Development of a novel modulation scheme that amalgamates FBMC-OQAM with various improvements such as better prototype filter, advanced precoding method and optimization of scaling factors using efficient optimization algorithm.
– Integration of Hermite prototype filters in the FBMC system, offering a departure from traditional FBMC architectures.
– Development of an advanced precoding method using a pruned DFT and scaling factors to enhance spectral efficiency.
– Proposal of an IPSO algorithm for PAPR reduction by optimizing scaling factors in the FBMC/OQAM system.

2. RELATED WORK

Multicarrier modulation techniques play a vital role in modern wireless communication systems, providing efficient ways to transmit data over communication channels [7], [13]. These techniques are characterized by the use of multiple subcarriers, each carrying a portion of the total data, and are particularly relevant in the context of high-speed data transmission. The most notable multicarrier modulation technique is OFDM [14], which is widely employed in various communication standards, including Wi-Fi, LTE, and, more recently 5G, in the initial stages of 5G [15]. For OFDM signal time-domain representation can be expressed as the sum of modulated subcarriers. Let N be the total number of subcarriers, T be the symbol duration, $x(t)$ be the OFDM signal in the time domain represented as:

$$x(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t} \tag{1}$$

X_k represents the complex amplitude of the modulated subcarrier at index k. f_k is the frequency of the kth subcarrier. In the frequency domain, the modulated subcarriers X_k can be obtained using the discrete fourier transform (DFT). The discrete frequency components of the OFDM signal can be expressed as

$$X_k = \frac{1}{N} \sum_{n=0}^{N-1} x_n e^{-j2\pi \frac{kn}{N}} \tag{2}$$

x_n Represents the samples of the time-domain signal at discrete time indices n.

OFDM however faces several challenges like high PAPR, which can result in power inefficiencies. These challenges highlight the need for innovative modulation schemes that can address the limitations of existing techniques and pave the way for more robust and efficient wireless communication systems. F-OFDM introduces the concept of filtering individual subcarriers, allowing for more flexible signal shaping. F-OFDM's adaptability to varying channel conditions contributes to its effectiveness in scenarios where spectral efficiency and interference management are critical. F-OFDM utilizes a filter bank structure to improve spectral efficiency and address issues such as out-of-band radiation [16]. The time-domain representation of F-OFDM [17] can be expressed similarly to that of OFDM but with additional considerations for the filter bank for $g(t)$ which is the pulse shaping function associated with each subcarrier is:

$$x(t) = \sum_{k=0}^{N-1} X_k \, . \, g(t - kT) \tag{3}$$

UFMC is designed to overcome the limitations of traditional OFDM in scenarios with high mobility and rapidly changing channel conditions [18]. It employs a filter bank similar to F-OFDM but incorporates additional waveform shaping techniques. UFMC provides greater flexibility in terms of time and frequency localization of the transmitted signals, allowing for efficient adaptation to dynamic channel environments. This adaptability results in improved performance for mobile communication scenarios, making UFMC a promising candidate for future wireless communication systems [19]. The use of individual shaping filters $g_{k\,(t)}$ for each subcarrier allows for more flexibility in shaping the spectral characteristics of each subcarrier. The expression for UFMC in the time-domain signal can be written as:

$$x(t) = \sum_{k=0}^{N-1} X_k \, . \, g(t) \, . \, e^{j2\pi f_k t} \tag{4}$$

FBMC is a modulation scheme that deviates from the traditional OFDM structure by employing a filter bank at the transmitter and receiver. FBMC is particularly well-suited for scenarios with highly dispersive channels, as its inherent ability to shape the transmitted signal helps mitigate inter-symbol interference [20]. The expression for FBMC in the time-domain signal can be written as:

$$x(t) = \sum_{k=0}^{N-1} X_k \, . \, g(t - kT) \tag{5}$$

While FBMC has advantages in terms of reduced spectral leakage and improved spectral efficiency, it introduces challenges related to synchronization [21]. Synchronization errors can lead to inter-carrier interference and impact system performance. Robustness against various impairments, such as phase noise, frequency offset, and non-linearities, is a shared challenge. Ensuring that these advanced modulation schemes perform well under diverse and sometimes adverse conditions is essential for their practical viability.

The research articles [22] explored the use of FBMC with higher order QAM and Hermite filter to improve bit error rate (BER) and power spectral density (PSD) in 5G wireless communication systems. An improved version called enhanced partial transmit sequences (EPTS) is proposed in [23]. Subsequently, a low-complexity search is utilized to identify the optimal combination of phase factors. FS-FBMC/OQAM and OFDM systems in an additive white gaussian noise (AWGN) channel are investigated in [24]. PTS-TS [25] An additional multi-hybrid scheme takes into account the overlapping of multiple data blocks within each segment signal. In contrast, the hybrid PTS-TR scheme focuses solely on the overlapping effect of the two adjacent data blocks. PTS-DPSO-TH [26] method employs discrete particle swarm optimization (DPSO) to explore the optimal solution, effectively mitigating the excessively high PAPR in the FBMC/OQAM system. These research gaps urge for an improved FBMC system that not only addressed the challenges of spectral efficiency and interference but also introduced innovative elements to elevate overall system performance.

3. PROPOSED SCHEME

A novel modulation scheme that combines FBMC-OQAM and Hermite prototype filters in the FBMC system, deviating from conventional FBMC architectures. An advanced precoding method based on a pruned discrete fourier transform (pDFT) [27] is used with scaling factors. Finally, an Iterative PSO algorithm is proposed to address the challenge of PAPR in FBMC systems. Working of each component of the scheme is described as follow:

3.1. FBMC/OQAM

FBMC-OQAM is an advanced modulation scheme that has gained attention for its potential advantages in wireless communication systems [28]. Here we show an illustration of FBMC/OQAM in

Figure 1. FBMC employs a filter bank structure at both the transmitter and receiver. Instead of using a single wideband filter, it divides the overall system bandwidth into multiple narrower sub-bands, allowing for better frequency localization and reduced spectral leakage.

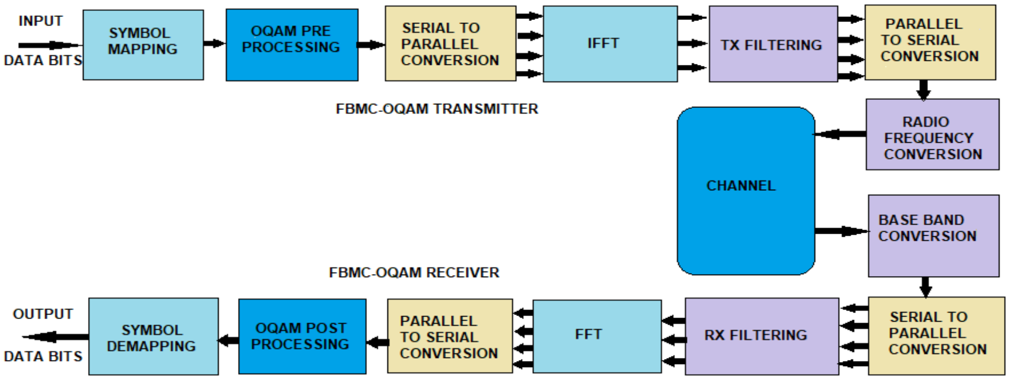

Figure 1. Illustration of FBMC/OQAM

The subcarriers generated by the filter bank are designed to be orthogonal, minimizing interference between them. This orthogonality contributes to improved spectral efficiency and mitigates inter-carrier interference (ICI) compared to conventional OFDM [29]. FBMC-OQAM's ability to handle frequency-selective fading channels and mitigate ISI makes it suitable for communication scenarios with challenging channel conditions, such as urban environments with multipath propagation [21]. The time-domain expression of FBMC/OQAM can be represented as a sum of modulated subcarriers. Generalized expression for the time-domain signal $x(t)$ in FBMC/OQAM is:

$$x(t) = \sum_{k=0}^{N-1} Re \{\alpha_k(t)\, e^{j2\pi f_k t}\} \quad (6)$$

the Re extracts the real components of a complex signal. The improved spectral containment in FBMC-OQAM contributes to lower out-of-band emissions, reducing the potential for interference with adjacent frequency bands.

3.2. Hermite filter

The Hermite prototype filter is used as a crucial component of the system's filter bank [30]. The Hermite prototype filter is employed to shape the subcarriers in the frequency domain, allowing for more precise localization and reduced spectral leakage compared to traditional filter designs. Hermite functions are well-suited for achieving sharp frequency localization [31]. The Hermite prototype filter is integrated into the filter bank structure of FBMC as shown in Figure 2.

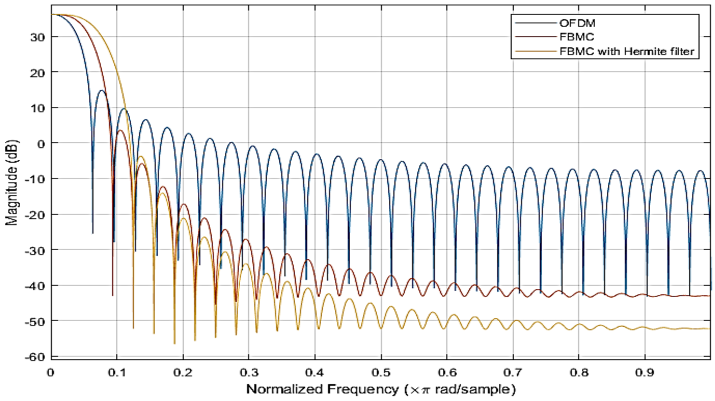

Figure 2. Comparison of magnitude response in (dB) of multicarrier modulation techniques plotted against normalized frequency

The graph shows that the magnitude response of each subcarrier is more confined, with significantly reduced side lobes. The orthogonal nature of Hermite functions helps in minimizing ICI in FBMC. The Hermite prototype filter's ability to provide precise frequency localization contributes to improved spectral efficiency [32]. This is essential for accommodating a higher number of subcarriers within the available bandwidth, thereby increasing the overall data throughput. The Hermite filter impulse response can be expressed using the Hermite functions. The Hermite functions are a set of orthogonal polynomials denoted as $H_n(X)$, The impulse response of the Hermite filter associated with the k^{th} subcarrier in the proposed Filter Bank Multicarrier (FBMC) system can be represented as follows:

$$h_k(t) = \frac{1}{\sqrt{T}} H_k\left(\frac{t}{T}\right) e^{-j2\pi f_k t} \quad (7)$$

where$H_k(.)$, is the k^{th} Hermite function, T is the symbol duration f_k is the frequency of the k^{th} subcarrier. The Hermite functions $H_k(x)$ are orthogonal polynomials that can be expressed in terms of the physicist's Hermite polynomials $He_n(x)$ as:

$$H_k(x) = \frac{1}{\sqrt{2^k k! \sqrt{\pi}}} He_k(x) \quad (8)$$

the complete expression for the Hermite filter impulse response combines these elements and provides a mathematical representation of how the Hermite prototype filter shapes the subcarriers in the FBMC system.

3.3. Pruned DFT precoding strategy

Precoding is a technique used in wireless communication systems to manipulate the transmitted signals before they are transmitted over the channel. The pDFT [27], [33] is a technique that involves selecting a subset of DFT coefficients while discarding others. This "pruning" process helps in reducing the computational complexity associated with the full DFT. The pruned DFT is used for precoding. The implementation involves identifying the most relevant DFT coefficients based on the channel characteristics and system requirements. By selecting only, a subset of coefficients, the computational burden is significantly reduced without sacrificing essential information. Pruned DFT in FBMC precoding brings several advantages [34].

Scaling involves application of scaling factors to each subcarrier independently. The scaling factor is determined based on the channel characteristics and the goal of optimizing the signal transmission. It essentially adjusts the amplitude of each subcarrier to improve the overall transmission quality. Scaling is used in conjunction with pDFT precoding to fine-tune the transmitted signals, addressing issues such as amplitude imbalances and optimizing power distribution.

3.4. Iterative particle swarm optimization (IPSO)

A novel IPSO algorithm is proposed for facilitating the iterative refinement of precoding parameters, optimization of the precoding approach, reduction of PAPR, adaptation to dynamic channel conditions, and efficient allocation of resources. IPSO is inspired from the particle swarm optimization (PSO) which is a metaheuristic optimization algorithm inspired by the collective behavior of social organisms [35], [36], such as birds and fish. The algorithm seeks to find optimal or near-optimal solutions to optimization problems in complex search spaces.

IPSO is applied to optimize the parameters associated with the proposed precoding strategy. This includes the tuning of parameters related to pruned DFT and Scaling in the precoding process. IPSO involves finding a balance between maintaining signal quality and reducing the PAPR, which is crucial for efficient power amplification. Adaptability of IPSO helps the system maintain optimal performance in scenarios with varying channel characteristics, by iteratively adjusting the weights and scaling factors associated with these pDFT, IPSO enhances the overall performance of the communication system. This optimization process considers the trade-offs and dependencies between the different precoding components.

3.5. Iterative IPSO with Hermite basis functions in an FBMC system using DFT

Step 1. Initialization**:** Generate a random population of N p particles. Set the initial inertia weight ω_i and the final inertia weight ω_d, learning factors $c_1$and c_2 Initialize particles with random positions x and velocities v. Set the maximum velocity limit v_{max}. Set the maximum number of iterations G. Step 2. Hermite Basis Functions Application**:** For each symbol in the FBMC system, apply Hermite basis functions to modulate the data.

Step 3. DFT Application: Use DFT to convert each modulated symbol into the frequency domain. Step 4. Fitness Function Calculation: Calculate the current PAPR of the modulated symbols. Min PAPR as the fitness function, aiming to minimize it. Min PAPR is defined as: Step 5. Personal and Global Best Update**:** For each particle, determine p_{id} (personal best) and p_{gd} (global best) based on the fitness value. Step 6. Velocity and Position Update: Update the velocity and position of each particle using the IPSO equations. If a particle's velocity exceeds v_{max}, set it to v_{max}. Step 7. Convergence Check:

- Check if the maximum number of iterations G has been reached or if the algorithm has converted to a threshold.
- If the stopping criteria are met, output the current population's global best p_{gd} as the optimal solution.
- Otherwise, increment the iteration counter g and return to Step 4.

Step 8. Post-processing:

- Once the optimal solution is identified, use DFT to convert the symbol back into the time domain, obtaining the optimized FBMC signal modulated with Hermite basis functions.

Step 9. Iteration through Symbols:

- Increment the symbol count n and check if all symbols N have been processed. If not all symbols are processed, return to Step 2.

The fitness function in the context of the proposed FBMC system, especially for PAPR reduction using the IPSO algorithm, needs to quantify the quality of a particular set of parameters. The goal is to find a set of parameters (scaling factors, in this case) that minimizes the PAPR. The fitness function is typically designed to evaluate how well the current set of parameters achieves this objective.

3.6. Working of proposed FBMC/OQAM

The proposed FBMC system involves the use of a filter bank structure to transmit information over multiple subcarriers. Let's $x(t)$ represent the transmitted signal in the time domain, and X_t be the complex baseband representation of the k^{th} subcarrier. The FBMC signal in the time domain can be expressed as:

$$x(t) = \sum_{k=0}^{N-1} X_k \cdot p_k(t) \tag{9}$$

Where N is the number of subcarriers, and $p_k(t)$ is the impulse response of the filter associated with the k^{th} subcarrier. The Hermite prototype filter $p_k(t)$ can be represented using the Hermite functions. The filter's impulse response is denoted as $h_k(t)$and it is used to shape each subcarrier.

$$\frac{1}{\sqrt{T}} h_k\left(\frac{t-kT}{T}\right) \tag{10}$$

the complex baseband representation X_k of each subcarrier is modulated using OQAM. The b_k represents the binary data for the subcarrier, and OQAM_M be the OQAM modulation with M constellation points. The OQAM-modulated signal b_k is given by:

$$X_k = \mathrm{OQAM}_M(b_k) \tag{11}$$

the precoding strategy involves using pruned pDFT and x_k represents the signal samples in the time domain. The pruned DFT coefficients $\tilde{X}_k$ can be expressed as:

$$\tilde{X}_k = \frac{1}{N} \sum_{n=0}^{N-1} x_n e^{-j2\pi\frac{kn}{N}} \tag{12}$$

α_kScaling is applied to each subcarrier such that

$$Y_k = \alpha_k \cdot \tilde{X}_k \tag{13}$$

The Iterative PSO (IPSO) algorithm is applied to optimize the precoding parameters, including the scaling factors α_k to minimize the PAPR. The optimization process involves updating the positions of particles in the search space based on the fitness function related to PAPR reduction. IPSO tries to quantify the quality of a particular set of parameters. The goal is IPSO is to find a set of parameters (scaling factors) that minimizes the PAPR. The fitness function is typically designed to evaluate how well the current set of parameters achieves this objective. $PAPR(x_n)$ Represent the function that calculates the PAPR of the time-domain signal (x_n). The fitness function $f(\alpha_0\alpha_0, \ldots \alpha_{N-1})$ is defined as the inverse of the PAPR, aiming to minimize it such that:

$$f(\alpha_0, \alpha_1, \ldots \alpha_{N-1}) = \frac{1}{PAPR(x_n)} \tag{14}$$

Here $\alpha_0, \alpha_1, \dots \alpha_{N-1}$ are the scaling factors applied to the corresponding subcarriers. The optimization process involves updating the positions of particles in the search space based on the fitness function related to PAPR reduction The optimization task, as framed by the IPSO algorithm, is to find the set of scaling factors $\{\alpha_0^*, \alpha_i^* \ \dots \ \alpha_{N-1}^*\}$ in other words:

$$\{\alpha_0^*, \alpha_i^* \ \dots \ \alpha_{N-1}^*\} = argmin_{\alpha_0, \alpha_1, \dots \alpha_{N-1}} f(\alpha_0, \alpha_1, \dots \ \alpha_{N-1}) \tag{15}$$

the IPSO algorithm iteratively explores the parameter space (scaling factors) to find the optimal set that minimizes PAPR, guided by the fitness function. The optimization process involves updating the positions of particles in the search space based on the fitness values, aiming to converge toward a solution that results in the lowest PAPR.

4. EXPERIMENTAL ANALYSIS

In the experimental analysis, a rigorous comparison is performed among several prominent multicarrier modulation schemes, namely OFDM, FBMC/OQAM, and Filter Bank Multicarrier with Quadrature Amplitude Modulation and Hermite filter (FBMC/QAM with Hermite filter). Additionally, a proposed FBMC/QAM scheme, augmented with IPSO for PAPR reduction, is introduced. The simulations are meticulously conducted using MATLAB to assess the performance of these modulation schemes across key metrics. The evaluation criteria include Bit Error Rate (BER), which quantifies the accuracy of data transmission, and PAPR, a crucial parameter reflecting the efficiency of power amplification. Simulated power spectral density (PSD) is employed to characterize the spectral efficiency and compliance with regulatory spectral masks. OFDM serves as a benchmark, while FBMC/OQAM and FBMC/QAM with Hermite filter represent alternative multicarrier approaches.

4.1. Simulation parameters

The simulation is configured with various parameters to comprehensively investigate the performance of a FBMC/OQAM communication system. The simulation spans a duration of 30 symbols, each with a subcarrier spacing of 15 KHz. Signal to noise ratio (SNR) is explored across a range from 20 to 40 dB to assess system robustness under varying noise conditions. The FBMC/OQAM system is characterized by an overlapping factor of 4, indicating that the shaping filters for adjacent subcarriers overlap over four symbols. QAM modulation orders of 64, 256, and 1024 are employed to evaluate the impact of constellation size on system performance. A side-lobe attenuation of 40 dB underscores the emphasis on suppressing side lobes in the spectrum. The system operates at a sampling frequency of 15.36 MHz and employs 64 subcarriers. The Hermite filter is chosen as the prototype filter. All these simulation parameters are shown in Table 1. These parameters collectively define the experimental conditions, enabling a comprehensive exploration of the FBMC/OQAM system's behaviour under diverse scenarios.

Table 1. Simulation parameters considered for the evaluation of the schemes

Simulation parameter	Value
Number of symbols	30
Subcarrier spacing	15 KHz
Signal to noise ratio	20-40 dB
FBMC/OQAM Overlaping factor	4
QAM modulation order	64/256/1024
Side-lobe attenuation	40 dB
Sampling frequency	25 MHz
Number of subcarriers	64
Prototype filter	Hermite filter

4.2. Simulated power spectral density (PSD)

The Figure 3 displays the PSD of signals for different modulation and signal processing techniques across a specific frequency range. Figure represents the frequency range under consideration. It ranges from approximately 3.8 MHz to 4.1 MHz; the PSD is used to show how the power of a signal is distributed over the frequency spectrum.

FBMC has a more pronounced presence of sidelobes compared to OFDM. This could be due to the overlapping nature of FBMC subcarriers, which can lead to a spread in the frequency spectrum. IPSO-Hermite-FBMC-pDFT demonstrated a very sharp peak but has a noticeable drop in sidelobe levels compared to the standard FBMC. This indicates that the IPSO-Hermite technique has optimized the signal to reduce the sidelobes and inter-channel interference.

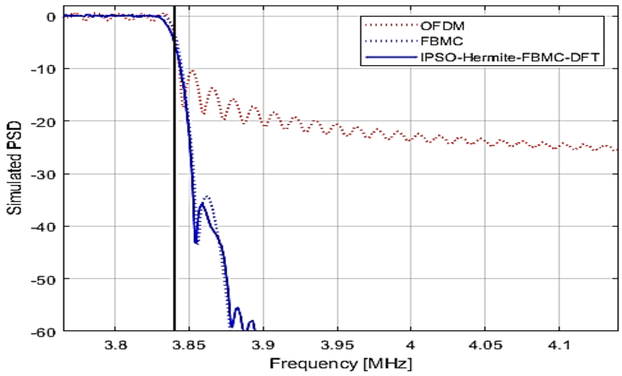

Figure 3. Simulated power spectral density (PSD) of signals for the modulations

4.3. PAPR evaluations

The Figure 4 depicts the CDF of the PAPR for different modulation and signal processing techniques. A higher PAPR typically requires more sophisticated and costly power amplifiers to handle the peaks without distortion. Reducing PAPR is desirable as it can lead to simpler and more energy-efficient transmitter designs. The CDF shows the probability that a random variable (in this case, PAPR) will take a value less than or equal to a particular value. As shown in Figure the OFDM has the highest PAPR for a significant portion of its curve, which implies that for most instances, OFDM will have a relatively high PAPR compared to the other techniques. FBMC and FFT-FBMC have lower PAPRs than standard OFDM. FBMC and FFT-FBMC curves are close to each other, indicating that the PAPR characteristics of these two are similar for the considered scenarios. Proposed work using IPSO Hermite filter and pDFT has the best performance in terms of PAPR reduction, especially for higher probabilities (closer to 1 on the CDF).

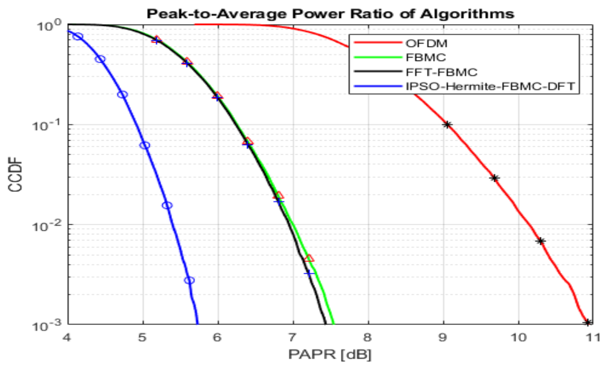

Figure 4. CDF of the PAPR for different modulation

4.4. BER evaluations

Table 2 provides the BER performance of selected schemes at varying QAM orders and SNRs, From the table it clear that OFDM generally has the worst BER performance out of the schemes tested, especially at higher QAM orders and SNRs. FBMC/OQAM has better BER performance than OFDM, but is still outperformed by FBMC/QAM with Hermite filter. For instance, at 40dB SNR and 1024 QAM, FBMC/OQAM has an ER of 1.70E-02 while FBMC/QAM with Hermite filter has an ER of 3.96E-03. FBMC/QAM with Hermite filter consistently provides the best ER performance out of the techniques evaluated. Adding IPSO processing further improves the ER slightly. At 40dB SNR and 1024 QAM, FBMC/QAM with Hermite filter has an ER of 3.96E-03 versus 3.64E-03 with IPSO. Increasing the QAM order generally worsens the ER across all schemes for a fixed SNR level. Similarly, improving the SNR reduces the ER for a given QAM configuration. FBMC/QAM with Hermite filter, especially with IPSO processing, delivers the strongest error rate performance out of the evaluated waveform.

Table 2. BER performance of selected schemes at varying QAM orders and SNRs

Waveforms	QAM order	20 dB	30 dB	40 dB
OFDM	64	2.50E-02	4.75E-03	1.03E-03
OFDM	256	6.15E-02	1.41E-02	2.97E-03
OFDM	1024	1.18E-01	3.82E-02	1.00E-02
FBMC/OQAM	64	2.54E-02	5.10E-03	1.53E-03
FBMC/OQAM	256	6.33E-02	1.68E-02	5.68E-03
FBMC/OQAM	1024	1.18E-01	4.41E-02	1.70E-02
FBMC/OQAM with Hermite filter	64	1.35E-02	2.27E-03	3.69E-04
FBMC/OQAM with Hermite filter	256	3.66E-02	6.79E-03	1.11E-03
FBMC/OQAM with Hermite filter	1024	8.14E-02	2.11E-02	3.96E-03
FBMC/OQAM with Hermite filter & IPSO	64	1.19E-02	1.97E-03	3.24E-04
FBMC/OQAM with Hermite filter & IPSO	256	3.41E-02	6.04E-03	1.04E-03
FBMC/OQAM with Hermite filter & IPSO	1024	7.57E-02	1.98E-02	3.64E-03

At 64 QAM, adding IPSO provides a 12-13% improvement across the different SNR levels. For example, at 20dB SNR, IPSO reduces the error rate by 12%. For 256 QAM, IPSO generates a 6-11% reduction in error rate depending on SNR. At 40dB SNR, adding IPSO decreases the error rate by 6%. With 1024 QAM, IPSO produces a 6-8% error rate improvement over FBMC/QAM with Hermite filter alone. At 40dB SNR, the reduction is 8% with IPSO. Generally, IPSO generates a 6-13% decrease in error rate across varying QAM orders when combined with FBMC/QAM and Hermite filter equalization. The gains are relatively consistent regardless of SNR level. This demonstrates the value of IPSO for further enhancing the error performance compared to just FBMC/QAM and Hermite filtering alone. The improvement is especially noticeable at higher QAM orders like 1024 QAM.

4.5. Bitrate evaluations

The Figure 5 shows the comparison of bit rates for selected modulation and signal processing techniques. The results indicates that by incorporating the IPSO algorithm with Hermite functions and DFT into the FBMC system, one can achieve significant improvements in bit rate compared to traditional methods like OFDM and standard FBMC.

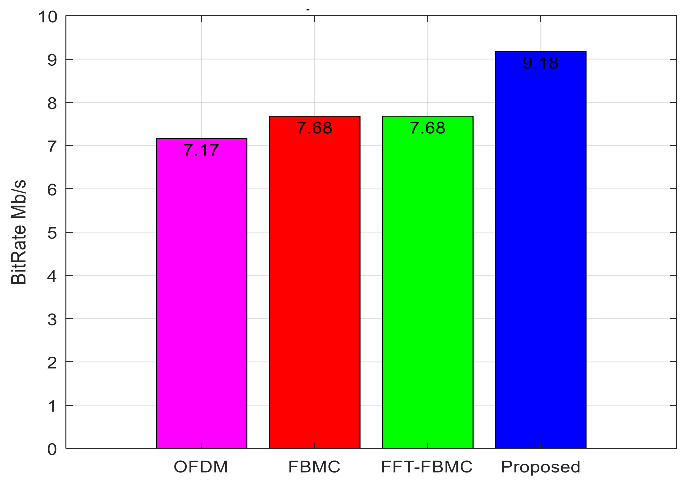

Figure 5. Comparison of bit rates (Mb/s) of the selected schemes

5. PAPR COMPARISONS WITH STATE-OF-THE-ART ALGORITHMS

FBMC/OQAM is the baseline waveform with a PAPR of 7.15 dB. It's typically higher because FBMC/OQAM systems have not applied any PAPR reduction techniques. Partial transmit sequences with discrete particle swarm optimization (PTS-DPSO) [26] have a PAPR of 6.22 dB, which is significantly lower than the baseline, indicating that this method is effective at PAPR reduction. PTS-DPSO-TH [26] a variant of the PTS-DPSO method, a thresholding technique (TH) applied. The PAPR is similar to PTS-DPSO at 6.23 dB, suggesting that the thresholding does not significantly change the PAPR from the original PTS-DPSO method. Iterative clipping and filtering method [37] has a PAPR of 6.10 dB, which is slightly lower than the

PTS methods. It shows that iterative clipping and filtering can effectively reduce PAPR, likely at the cost of some signal distortion that must be carefully managed.

The clipping and filtering with channel null constraint (CFCNC) [38] technique has a PAPR of 5.98 dB, which indicates a more significant reduction compared to the previous methods. By using a Hermite filter in the FBMC system, the PAPR is further reduced to 5.95 dB. This result supports the notion that Hermite filters can improve system performance in terms of PAPR. Also, when combining the Hermite filter with the IPSO algorithm, the PAPR decreases to the lowest value in the table at 5.83 dB. This demonstrates that the combination of the advanced filter design with the optimization algorithm synergistically reduces PAPR more than any other method listed. The results show a clear trend: as more sophisticated techniques are applied, specifically those tailored to address PAPR in FBMC/OQAM systems, the PAPR value decreases. The proposed method, which combines the Hermite filter with the IPSO algorithm, provides the best PAPR reduction according to Table 3. This indicates that the proposed scheme significantly enhances the performance of FBMC/OQAM systems in terms of PAPR, which is a critical metric for power efficiency and signal quality in communication systems.

Table 3. Peak-to-average power ratio (PAPR) results for various multicarrier waveform techniques

Waveforms	PAPR (dB)
FBMC/OQAM	7.15
PTS-DPSO	6.22
PTS-DPSO-TH	6.23
Iterative clipping and filtering	6.10
CPCNC	5.98
FBMC/QAM with Hermite Filter	5.95
FBMC/QAM with Hermite Filter & IPSO	5.83

6. RESULTS DISCUSSION

Numerical evaluation completed in the previous sections reveals that the proposed Hermite filter and DFT-based precoding scheme offers significant PAPR reduction in FBMC/OQAM systems. From these results, some observations can be made concerning the system performance in such parameters as PAPR, BER, PSD, and bit rates. Figure 4 depicted that proposed method give less PAPR values as compared to FBMC/OQAM and other advanced techniques. Consequently, the integration of Hermite filter with IPSO provides PAPR reduction of 5.83 dB, which shows better results than PTS-DPSO with efficiency of 6.22 dB, and Iterative Clipping and Filtering, which has Reduced PAPR to 6.10 dB. Table 2 shows this BER performance while comparing the various modulation schemes based on the different QAM orders and the signal to noise ratios. The performance of the BER of the proposed FBMC/QAM with Hermite filter and particle swarm optimization is better than the other schemes at all SNR levels and higher QAM orders. For instance, the simulation of 40 dB signal-to-noise radio and 1024 QAM enhances the proposed method to have an overall BER of 3. It is worth to mention that the proposed OFDM system achieved a BER of 64E-03, while standard OFDM system has BER 1.00E-02.

Figure 3 provides the Simulated PSD of the investigated approaches. From the PSD results, it can be clearly seen that the suggested method, that is the combination of Hermite filtering and pDFT, has a better spectral confinement than OFDM and conventional FBMC. This is because unlike other filters used in data transmission, the Hermite filter’s steep roll off offers better sidelobe levels and minimal out of band radiations that are of significance in preventing interferences to neighboring channels. In this case, the proposed scheme beats other techniques because it attains a bit rate of 9. 18 Mbps, this judicious rate is higher from OFDM and standard FBMC.

From the above results, it can be concluded that the proposed Hermite filter incorporated with pDFT precoding and accompanied by IPSO proves itself to be a viable solution to combat the issues related to PAPR in FBMC/OQAM systems. The enhancement of PAPR, BER, PSD, and bit rate in turn provide the evidence that the proposed method can yield significant advancements for next generation wireless communication systems specifically in high spectral efficient and low error rate scenarios. The proposed scheme improves the spectral efficiency, lowers the interference, and optimizes power efficiency all at high err rates, high throughput data.

7. CONCLUSION AND FUTURE SCOPE

This research delves into the challenges and opportunities within the domain of wireless communication, specifically focusing on modulation techniques that can potentially revolutionize how we approach spectral efficiency and interference reduction. Our proposed modulation scheme uniquely integrates the merits of FBMC-OQAM with Hermite filters, pruned DFT and IPSO for optimization of scaling factors manifesting a system that capitalizes on the best aspects of both. The proposed has successfully addressed the perennial challenge of high PAPR in FBMC/OQAM systems, highlighting the algorithm's capability to significantly diminish PAPR levels. The proposed scheme generates a 6-13% decrease in error rate across varying QAM orders regardless of SNR level. This demonstrates the value of IPSO for further enhancing the error performance compared to just FBMC/QAM and Hermite filtering alone. The improvement is especially noticeable at higher QAM orders like 1024 QAM. The study provides valuable insights for selecting efficient multicarrier modulation schemes, showcasing the potential for enhanced communication systems in evolving wireless networks. As the realm of wireless communication continues to evolve, there's ample scope for extending the research presented in this paper. While the IPSO algorithm has proven effective for PAPR reduction, future studies could delve into hybrid optimization algorithms that combine the strengths of multiple optimization techniques. The Hermite prototype filter's performance could be juxtaposed with other potential filters, allowing for a broader comparison and possible enhancements.

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