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RESEARCH ARTICLE

Scrambled UFMC and OFDM Techniques With APSK Modulation in 5G Networks Using Particle Swarm Optimization

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ABSTRACT This research addresses the challenges of high Peak-to-Average Power Ratio (PAPR), sideband leakage, and spectrum efficiency in 5G wireless networks. We compare Universal Filtered Multi-Carrier (UFMC), Scrambled UFMC (S-UFMC), and Orthogonal Frequency Division Multiplexing (OFDM) techniques using Amplitude Phase Shift Keying (APSK) modulation. Our findings show that APSK modulation significantly reduces PAPR compared to traditional methods. Integrating Particle Swarm Optimization (PSO) with Partial Transmit Sequences (PTS)-OFDM and S-UFMC minimizes PAPR and computational complexity. Results demonstrate that S-UFMC with PSO optimization achieves superior performance, offering lower PAPR, reduced complexity, and enhanced spectral efficiency, positioning it as a promising 5G waveform. This research highlights the potential of advanced waveform designs to improve 5G communication systems. UFMC demonstrated improved spectral efficiency with sidelobe levels reaching as low as 0.2, indicating efficient spectrum utilization. The research achieved a PAPR of 7.393 dB for 16-APSK with 512 subcarriers and 7.414 dB for 1024 subcarriers after optimization. The PSO algorithm significantly reduced PAPR values, with the Scrambled UFMC system outperforming PTS-OFDM and standard UFMC in terms of PAPR.

INDEX TERMS APSK, PAPR, Dolph Chebyshev filter, OFDM, PTS-OFDM, universal filter multi-carrier (UFMC), scrambled universal filter multi carrier (S-UFMC), CCDF, PSO, computational complexity.

I. INTRODUCTION

The demand for multimedia data services has propelled wireless communication systems into the era of fourth generation (4G) networks [1]. The exponential growth in mobile users, coupled with the constraints imposed by limited available spectrum, has accentuated the need for advanced digital wireless communication techniques [2]. These techniques are anticipated to adeptly exploit the available bandwidth and navigate the intricacies of multipath channel environments [3]. The effectiveness and reliability of wireless communications heavily depend on the quality and efficiency of waveform design, serving as a cornerstone of the system's performance [4]. An ideal waveform must fulfill a spectrum of requirements:

Low Power Consumption: Characterized by a low PAPR, minimizing power variation to avert distortion and interference in the transmitter and channel while conserving system power.

High Data Rates: Ensuring spectral efficiency, the waveform must transmit maximum information units within the least possible bandwidth, thereby increasing system throughput, capacity, and diminishing spectrum usage costs.

Spectrum Efficiency: Marked by low Out-of-Band Emissions (OOBE), preventing signal bleed onto neighboring

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frequency bands to avoid disturbances to other users and adhere to spectrum regulations and standards.

Low Latency: Achieved through a waveform with a brief symbol duration, facilitating rapid data transmission and reception, reducing system delay, jitter, and enabling swift feedback and control [5], [6].

Ease of Implementation: Defined by a simple and flexible structure, easing the transmission and reception process, and reducing system complexity and cost while allowing adaptability to diverse scenarios and requirements [7], [8].

In 4G communication systems, Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a powerful and sophisticated waveform, acclaimed for its ability to deliver high data rates [9]. However, OFDM faces significant challenges such as high PAPR, sideband leakage, and spectrum inefficiency [10]. To address these issues, UFMC has been proposed as an advanced waveform design technique [11], [12]. UFMC aims to mitigate the limitations of OFDM by reducing sideband leakage and enhancing spectral efficiency [13]. Despite these improvements, the high PAPR remains a concern. Recent research has explored various approaches to reduce PAPR, including the use of Amplitude Phase Shift Keying (APSK) modulation, which has shown promising results in lowering PAPR compared to traditional modulation schemes like Quadrature Amplitude Modulation (QAM) and Phase Shift Keying (PSK) [14]. Furthermore, the integration of optimization algorithms, such as PSO, with Partial Transmit Sequences (PTS)-OFDM and Scrambled UFMC (S-UFMC) has been investigated to further minimize PAPR and computational complexity [15]. This paper aims to evaluate and compare the performance of UFMC, S-UFMC, and OFDM techniques with APSK modulation in the context of 5G networks. The proposed Scrambled UFMC with PSO optimization demonstrates superior performance in terms of PAPR reduction, computational complexity, and spectral efficiency, positioning it as a promising 5G waveform.

Objectives:

1. To assess the challenges and limitations of OFDM and other existing waveform designs for communication systems.
2. To explore the concept and advantages of SC-UFMC as a novel waveform design for 5G applications.
3. To compare the performance of SC-UFMC and OFDM in terms of spectral efficiency, PAPR, and computational complexity using simulation and analysis.
4. To design and implement Swarm Optimization algorithms to optimize the system parameters and enhance the performance of SC-UFMC.

The remainder of this paper is organized as follows: Section II reviews the related works, discussing various PAPR reduction techniques and optimization approaches. Section III describes the system model and the proposed methodology. Section IV presents the experimental results and discussions, comparing the performance of the different techniques. Finally, Section V concludes the paper and outlines potential directions for future research.

II. RELATED WORKS

Index modulation (IM) is an emerging technique for 5G wireless communications that aims to achieve high spectral efficiency, low complexity, and enhanced energy efficiency. IM conveys information bits by using the indices of certain communication building blocks, such as antennas, subcarriers, or time slots, in addition to the conventional amplitude and phase modulation. IM has been applied to various domains, such as MIMO and multi-carrier systems, and has shown promising performance gains over the conventional techniques. In this literature review, we summarize some of the recent works on IM and its applications for 5G and beyond. E. Basar and his research team have been leading the development and analysis of IM techniques for 5G wireless networks [16]. They have proposed and studied three types of IM schemes: spatial modulation (SM), channel modulation (CM), and OFDM with IM (OFDM-IM). SM is an IM scheme for MIMO systems that uses the indices of the active transmit antennas to carry information bits. SM can reduce inter-channel interference, hardware cost, and energy consumption in MIMO systems. CM can create artificial sub-channels with different parameters and improve the robustness, diversity, or reliability of the system. OFDM-IM is an IM scheme that uses the indices of the active subcarriers in an OFDM system to carry information bits. OFDM-IM can reduce PAPR, OOBE, and improve spectral efficiency and resilience of the system. These IM schemes represent innovative approaches to modulating and transmitting information in wireless communication systems, each with its own characteristics and advantages.

Vittala and Naidu have proposed a novel method to reduce the PAPR of OFDM systems using IM [17]. Their method aims to optimize the PAPR phase sequence matrix, which determines the phase shifts applied to the subcarriers, to minimize the PAPR of the OFDM signal. Their method can reduce the computational complexity and the number of IFFT operations required for PAPR reduction. Zhang et al. have proposed a new technique called filtered-OFDM (F-OFDM) to address the diverse and dynamic requirements of 5G cellular networks [18]. F-OFDM is a flexible waveform design that allows different numerologies for different sub bands, depending on the channel characteristics and service requirements. F-OFDM can mitigate the tradeoff between spectral efficiency and robustness that often limits the performance of conventional OFDM. Huang and Su have presented an extended model and techniques for fast-convolutional (FC) waveforms [19]. FC waveforms are a class of waveforms that use fast convolution to implement sub band filtering for OFDM processing. FC waveforms can achieve spectrally well-localized transmitter processing, which is important for the implementation of 3GPP 5G standards. Naga Rani et al. have published a paper on UFMC, a 5G modulation technique that outperforms OFDM [20]. UFMC is a variant of FBMC that filters subcarriers in groups rather than individually, which reduces the filter length and complexity compared to FBMC. UFMC can offer better spectral efficiency, lower PAPR, and lower OOBE than OFDM. UFMC can also achieve better BER performance than many other modulation schemes under various mapping configurations. In Hassan's study (2024), the focus is on Performance enhancement and PAPR reduction for Multiple-Input Multiple-Output (MIMO) based QAM-FBMC systems. This work likely explores novel techniques to optimize system performance and mitigate PAPR issues, crucial for achieving reliable and efficient wireless communication **[21]**. Hassan et al. [22] conducted a study focusing on reducing Peak-to-Average Power Ratio (PAPR) in Visible Light Communication (VLC) systems based on Filter Bank Multicarrier (FBMC) technology, as detailed in their research published in the IET Communications journal. Their investigation delves into tailored techniques aimed at mitigating PAPR challenges within VLC systems. This research endeavor holds significance in enhancing the robustness and consistency of VLC technology, particularly in the context of indoor wireless communication environments [22]. Freag et al. proposed new hybrid PAPR reduction techniques for OFDM-based VLC systems in their work published in the Journal of Optical Communications [23]. This research likely explores innovative approaches to minimize PAPR in VLC systems, aiming to enhance the efficiency and performance of optical wireless communication. Abdalla et al. presented a three-layer PAPR reduction technique for FBMC-based VLC systems in their study published in IEEE Access [24]. By introducing a multi-layered approach to PAPR reduction, this research contributes to addressing the unique challenges of VLC systems, potentially improving their reliability and scalability for various applications.

III. METHODOLOGY

A. PTS OFDM WITH PSO

PSO is indeed a popular optimization algorithm inspired by the social behavior of birds and fish. It's an iterative process that adjusts the paths of individual particles towards their own best location and the best location of their neighbors. Over time, the swarm converges towards the best solution. It's particularly useful for problems where the search space is large and complex, and it's known for its simplicity and efficiency in finding a satisfactory solution relatively quickly [25]. Operating by adjusting a population of potential solutions, known as particles, in accordance with predefined rules inspired by swarm cooperation in nature, PSO proves valuable in diverse fields, including signal processing. In the domain of wireless communication, particularly in OFDM systems, the management of the high PAPR of transmitted signals poses a significant challenge. This issue, commonly referred to as the PAPR problem, can lead to distortion and inefficiencies in power amplifiers, posing critical concerns in wireless communication systems [26].

OFDM divides the frequency spectrum into subcarriers for data transmission, but the combination of these subcarriers can result in high peak amplitudes, causing distortion and inefficiencies in power amplifiers. To address this challenge, the Partial Transmit Sequence (PTS) technique has been developed for OFDM systems, optimizing the transmission sequence to minimize PAPR while preserving signal quality. Researchers have further enhanced PTS efficiency by introducing a PSO approach. This PSO-PTS approach optimizes a suboptimal partial transmission sequence, aiming to reduce both computational complexity and PAPR in an OFDM signal. By merging the swarm intelligence of PSO with the PAPR reduction capabilities of PTS, this approach strikes a balance between computational efficiency and signal quality improvement in OFDM-based communication systems. Compared to OFDM, PSO-based PTS OFDM demonstrates lower PAPR. This PSO-based approach often improves the PAPR of OFDM and PTS OFDM systems. However, the increasing number of sub-blocks necessitates a thorough search of all possible weighting factor combinations [27].

In PSO, each particle keeps track of its coordinates and the best solution achieved so far (p_{best}). Additionally, it tracks the highest value assigned from its neighboring particles, referred to as the global best (g_{best}). PSO aims to locate the position with the highest particle density by altering the speed of each particle at each phase. The primary objective is to partition data within OFDM and UFMC systems into sub-blocks, multiplied by weights generated from phase rotation factors to achieve optimal outcomes in terms of PAPR. The input data, mapped to 16-APSK and 64-APSK, undergoes modulation index increases for higher data rates [28]. For PTS, the input data of N symbols is segmented into M sub-blocks, and modulation generates baseband OFDM signals through an Inverse Fast Fourier Transform (IFFT) block. Each sub-block undergoes separate IFFT, followed by the application of a complex phase factor (b_w), contributing to the customization and optimization of signal processing. These phase adjustments aim to minimize the PAPR of the overall signal formed by combining contributions from all sub-blocks. The discrete OFDM signal transmitted by N subcarriers can be given as x_n as shown in the equation 1.

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e \frac{i2\pi}{N} kn \quad 0 \le x \le N-1 \tag{1}$$

This optimization reduces signal distortion and enhances transmission efficiency, albeit with considerable computing complexity. The data stream X is divided into M orthogonal sub-blocks $X_{m,}$ with phase factors b_w chosen to minimize the combined temporal signal's PAPR. The selection of correct phase factors involves an exhaustive search for potential combinations, resulting in significant computing complexity. Figure 1 illustrates PTS-OFDM with PSO [29].

B. SCRAMBLED UFMC WITH PSO

The scrambling strategy is applicable to UFMC by conducting a separate subblock division operation on UFMC sub bands. The information bits are initially assigned to APSK symbols. The entire band is then broken into multiple sub-bands of varying sizes. Each group of APSK symbols is subjected to an N-point inverse fast Fourier transform after

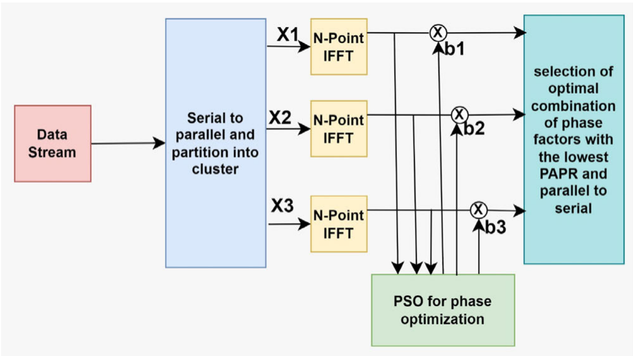

FIGURE 1. PTS OFDM with PSO for phase factor optimization.

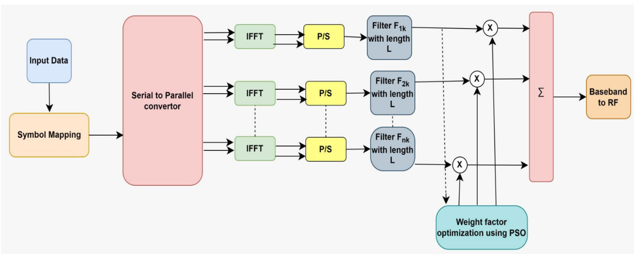

FIGURE 2. Scrambled UFMC using PSO.

being mapped to their appropriate sub bands (IFFT). The k_{th} sub band's discrete signal time domain can be described as follows.

$$x_n = \frac{1}{\sqrt{N}} \sum\nolimits_{k=0}^{N-1} X_b(k)\, e\frac{i2\pi}{N} kn0 \leq n \leq N-1; 1 \leq b \leq B \tag{2}$$

where $X_b(k) = [X_b(0), X_b(1) \ldots\ldots\ldots\ldots\ldots\ldots]$ corresponding to frequency domain signal on the kth sub-band. The scrambled version of UFMC is defined in Equation.

$$x_k = \sum\nolimits_{i=1}^{B} F_{i,k} Y_{i,k} \cdot b'_B \tag{3}$$

$$F_{I,k} = \frac{\cos\left\{M\cos^{-1}\left[\beta cos\left(\frac{\pi k}{M}\right)\right]\right\}}{\cos\left[M\cosh^{-1}(\beta)\right]} \tag{4}$$

where

$$\beta = \cosh\left[\frac{1}{M} h^{-1}\left(10^{\alpha}\right)\right], \quad \alpha = 2, 3, 4.$$

where x_k is the power amplifier's input signal. $F_{(i,k)}$ denotes the i_{th} filter, while $Y_{(i,k)}$ denotes the i_{th} symbol block among the B blocks. $b_{B'}$ is the phase vector of length B that creates a UFMC signal with a low PAPR value.

The modulation in equation (5), X'(t) represents the modified time-domain signal in the scrambled UFMC system. Each sub band signal, denoted as X_i, is multiplied by its associated phase factor, b_i, to produce the signal. After this multiplication, the results from all B sub bands are summed together. This process of multiplying the sub band signals by their respective phase factors and then summing them collectively is crucial for achieving the desired characteristics of the scrambled UFMC signal. These characteristics typically include a reduction in the PAPR and improved spectral efficiency, which are important aspects of signal quality and efficiency in communication systems. These attributes include a lowered PAPR and enhanced spectral efficiency.

$$X'(t) = ((X_1 * b_1) + (X_2 * b_2) + (X_3 * b_3) \ldots + (X_B * b_B)) \tag{5}$$

The UFMC signal is the sum of all independent random subcarriers. PAPR usually used for measuring the changes of a time-domain signal and can be described as

$$PAPR = \frac{\underset{B€\{0,\ldots.N+F_{i,k}\}}{max}\left(|x|^2\right)}{E\left(\left|x^2\right|\right)} \tag{6}$$

C. PRACTICAL SWAM OPTIMIZATION

This research uses PSO to lower the PAPR of UFMC and OFDM systems and the computational complexity caused by PTS and scrambling methods. The suggested PSO algorithm is started with a primary category of solutions known as "particles." At any time, each particle is in the temporal domain of M dimensions. Each particle's phase vector is M long, with each member chosen from the phase factors. The i_{th} particle's vector is $L_i = (l_{i1}, l_{i2}, \ldots l_{iM})$, $P_i = (p_{i1}, p_{i2}, \ldots, p_{iM})$ is the i_{th} particle's best position (P_{best}), and all particles with the best g_{best} index are considered. The i_{th} particle's velocity (V) is shown as

$$v_i(t+1) = W \times v_i(t) + a.r_1(t) \tag{7}$$

Equation (7) defines the velocity update for a particle in the PSO algorithm. The operation involving 'x' denotes multiplication. W is the inertia weight, and it changes with time because it is positive in terms of a linear function. The balance between local and global variables leads to an optimal solution for the algorithm in fewer iterations if the inertia weight is chosen correctly.

$$W = (\text{Iteration Number})/(\text{Max Iteration}) \tag{8}$$

The fitness value of the particles is given by.

$$\text{fitness}(x) = 1/\text{PAPR}(x) \tag{9}$$

The flow chat depicts the suggested PSO algorithm for PAPR reduction in PTS-OFDM and Scrambled UFMC methods.

1. Generate randomly, the first swarm of size S.
2. Initialize velocity $V_i(i = 1,2,..S)$, and position $P_i(i = 1,2,..S)$ are connected with the S particles.
3. For each position of the particle Pi from the swarm S, calculate the fitness function.
4. Set the location of each particle with its initial position, $P_{best} = P_i$ $(i = 1,2,..S)$.
5. If the present fitness is greater than P_{best}, then update P $_{bes}$ t as current fitness.
6. If the present fitness is lesser than P_{best}, then keep previous P_{best} as best

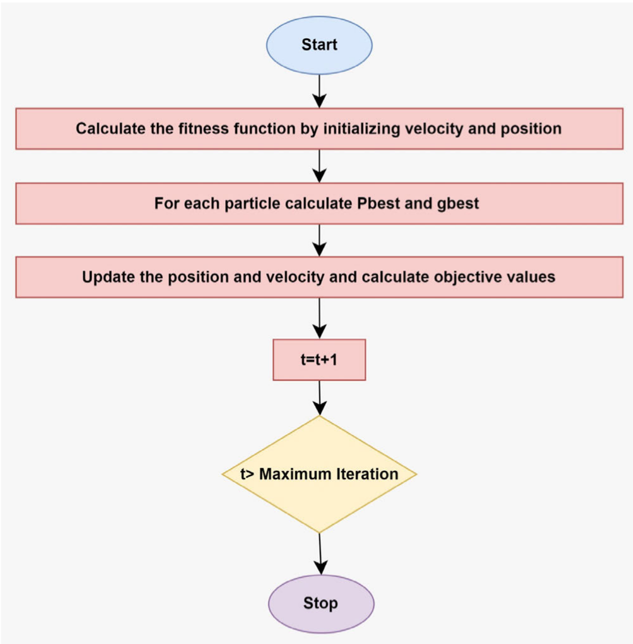

FIGURE 3. Procedure for PAPR reduction using PSO.

7. Find the greatest global position P_{g_best} in the swarm using all P_{best} particles.
8. Velocity of each particle is to be updated by using:

$$V_i(t) = w \times V_i(t-1) + a * r_1(t-1) \times (P_{best}(t-1) - P_i(t-1)) + b * r_2(t-1) \times \left(P_{g_{best}} - P_i(t-1)\right) \quad (10)$$

9. Position of each particle is to be updated:

$$P(t) = P_i(t-1) + V_i(t-1) \quad (11)$$

10. Repeat the steps from 3 to 9 until the stopping criteria is reached.

D. PEAK TO AVERAGE POWER RATIO

PAPR is a ratio of highest power level of the signal by its average power level. Another parameter related to PAPR is the crest factor, which is the square root of the PAPR. In essence:

$$\text{PAPR} = (\text{Highest Power in the Signal}) / (\text{Average Power of the Signal}) \quad (12)$$

$$Crest\ factor = \sqrt{PAPR} \quad (13)$$

The crest factor in equation 13 is a measure of how much the signal's power can momentarily exceed its average power, and it provides valuable insights into the signal's behavior, particularly in terms of its peak amplitudes. A lower crest factor indicates that the signal is less likely to have large peak amplitudes, which is often desirable in communication systems to avoid distortion and optimize the use of power amplifiers.

$$PAPR = \frac{\max_{t\in[0,T]} \left\{|x(t)|^2\right\}}{E\left\{|x(t)|^2\right\}} \quad (14)$$

where $\max\left\{||\,x\,(t)\,|^2\right\}$ represents the maximum Symbol power.

The value of PAPR in dB is given by

$$PAPR_{in\ dB} = 10\log_{10}\frac{\max_{t\in[0,T]} \left\{|x(t)|^2\right\}}{E\left\{|x(t)|^2\right\}} \quad (15)$$

In multi-carrier systems, particularly those with many subcarriers, a notable phenomenon occurs during modulation and summation in the transmitter section. As multiple subcarriers are modulated and combined coherently, the overall peak power tends to increase, while the average power remains constant. Specifically, For N subcarriers, the peak power will be increased by N times than the average power [26]. To analyse and understand the impact of PAPR, the Complementary Cumulative Distribution Function (CCDF) is commonly employed. CCDF provides insights into the likelihood that the PAPR will exceed a particular level. It helps assess the probability of encountering high PAPR values, which is crucial in designing and optimizing multi-carrier systems to manage power characteristics effectively.

$$\text{CCDF} = \text{P}(\text{PAPR} \geq \text{R}) = 1 - (1 - \exp(-\text{R}))^{\text{N}} \quad (16)$$

E. POWER SPECTRAL DENSITY

In multicarrier modulation schemes like OFDM and UFMC, when the peak deviation of the signal is larger, it can cause the signal level to exceed the dynamic range of the system. This leads to an increase PAPR, forcing the amplifier to operate in the saturation region and resulting in out-of-band (OOB) emissions. To visualize the energy fluctuations of a signal, the power spectral density (PSD) function can be utilized. The PSD provides information about the energy distribution over different frequencies. In UFMC, the PSD is calculated using the Fast Fourier Transform (FFT) method [27]. The integration of the PSD over a specific frequency band indicates the energy present in that band. Compared to OFDM, UFMC exhibits a lower spectrum loss due to the absence of a cyclic prefix. The power spectral density in UFMC is typically around −40dB out-of-band and can approach −80dB, indicating reduced energy leakage beyond the desired frequency band [28].

Furthermore, UFMC demonstrates lower sidelobe levels compared to OFDM. Sidelobes refer to the energy leakage to neighboring subcarriers or frequency bins. As shown in Figure 4, the sidelobe levels in UFMC gradually decrease and then remain almost constant, reaching a value of 0.2. This indicates that UFMC utilizes the allocated spectrum more efficiently, resulting in higher spectral efficiency [33], [34]. By effectively managing sidelobe levels, UFMC minimizes

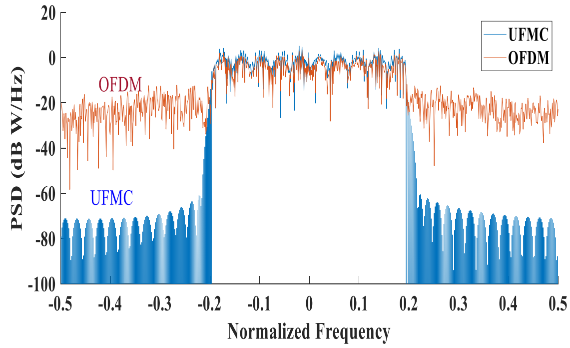

FIGURE 4. PSD of UFMC and OFDM.

interference with neighboring subcarriers, enhancing the system's capacity to transmit data [35].

$$\text{PSD} = \text{Energy}/\text{Frequency} \tag{17}$$

F. COMPUTATIONAL COMPLEXITY

The computational complexity of various modulation and optimization techniques can have a significant impact on the practical feasibility of their implementation. The complexity of OFDM is typically [36].

$$O(N\log N) \tag{18}$$

where N is the number of subcarriers.

For an 512 subcarriers, the computational complexity is approximately O(512 × log2(512)) ≈ O(512 × 9) ≈ O(4608) operations and for 1024 subcarriers is approximately O (1024 × log2(1024)) ≈ O(1024 × 10) ≈ O(10240) operations.

If the filters used in UFMC have a length of L taps, and for N subcarriers, then the complexity for each subcarrier would be proportional to

$$L \times N \tag{19}$$

For a system with 512 subcarriers and a filter length of 43, the computational complexity is approximately 512 × 43 = 22,016.

For the same system, but with 1024 subcarriers, the computational complexity increases to approximately.

$$1024 \times 43 = 44,032.$$

These calculations reflect the computational demands associated with processing different numbers of subcarriers and their corresponding filter lengths. Additionally, PSO (Particle Swarm Optimization) plays a crucial role in optimizing the configuration of phase sequences [37]. It helps in minimizing the PAPR while concurrently reducing the complexity associated with generating and processing multiple candidate signals. PSO efficiently explores the solution space and identifies the optimal phase sequence configuration that strikes a balance between PAPR reduction and computational complexity, resulting in improved signal quality and efficiency [38], [39]. UFMC uses filtering on each subcarrier to mitigate sideband leakage. PSO can optimize the filter design parameters to reduce the number of taps in the filter, thus lowering the computational complexity of the filtering operation while maintaining acceptable performance [40].

TABLE 1. System parameters.

Sl No	Parameter	Number
1	Number of sub bands	10
2	Offset value	156
3	Filter Length	43
4	Attenuation of Side lobe	40
5	IFFT	512,1024
6	Signal to Noise Ratio	15
7	Type of Modulation	APSK
8	Population	50
9	Inertia	1
10	Damping Ratio	0.99

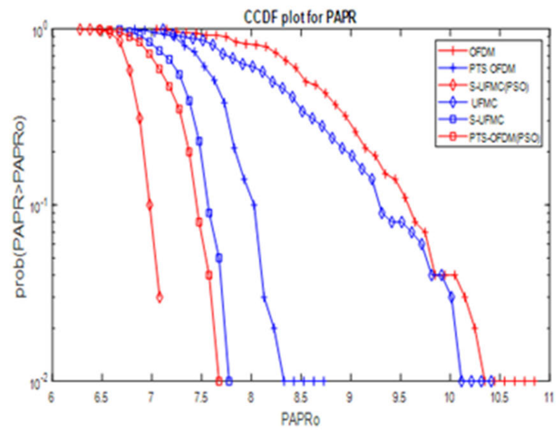

FIGURE 5. PSO-based CCDF plot for 20 Iterations, 512 subcarriers with 16-APSK.

The computational complexity of PSO is given as number of iterations multiplied with number of particles. For every I iterations P evaluations are carried out and the fitness value is evaluated [41].

$$C_c = I \times P \tag{20}$$

where

I = Number of iterations
P = population size

A population size of 50 particles is considered. The maximum number of iterations allowed is set to 100. With

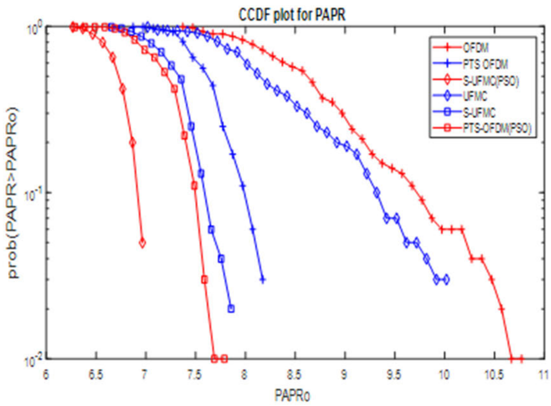

FIGURE 6. PSO-based CCDF plot with 16-APSK for 50 iterations and 512 subcarriers.

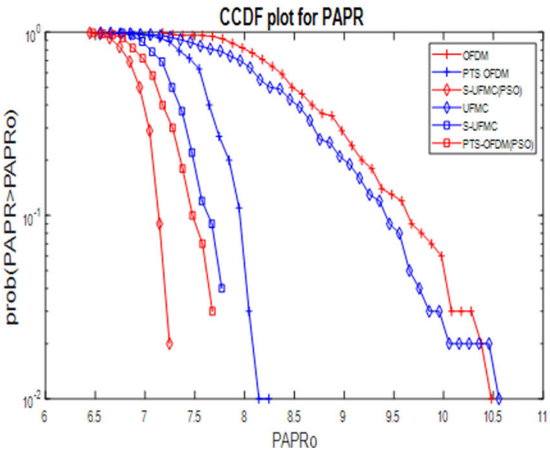

FIGURE 7. PSO-based CCDF plot for 512 subcarriers with 16-APSK across 100 iterations.

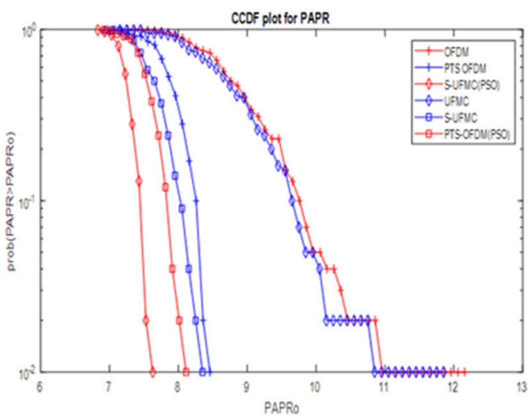

FIGURE 8. PSO-based CCDF plot for 20 Iterations, 1024 subcarriers with 16-APSK.

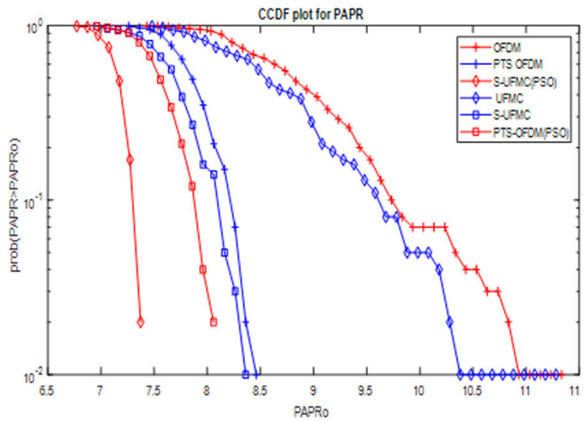

FIGURE 9. PSO-based CCDF plot with 16-APSK for 50 iterations and 1024 subcarriers.

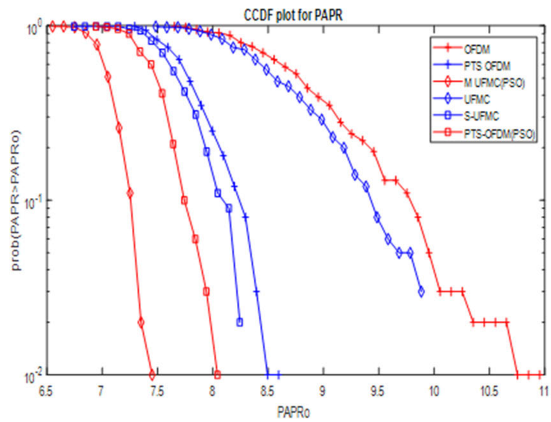

FIGURE 10. PSO-based CCDF plot for 1024 subcarriers, 100 iterations, and 16-APSK.

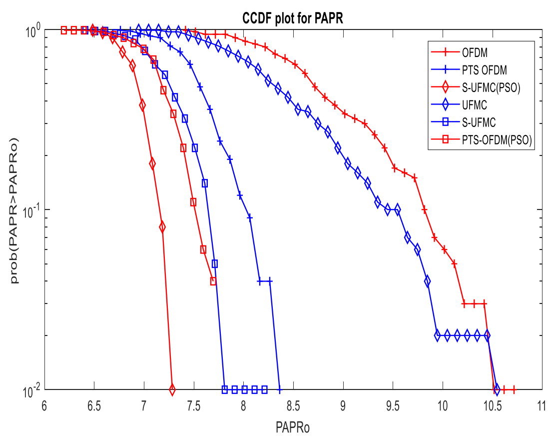

FIGURE 11. PSO-based CCDF plot for 512 subcarriers with 64-APSK and 20 iterations.

these parameters, the maximum computational complexity, in terms of the number of function evaluations or iterations performed by the PSO algorithm, is calculated as the product of the population size and the maximum number of iterations: Maximum Computational Complexity = Population Size × Maximum Number of Iterations = 50 × 100 = 5000.This value represents the total number of function evaluations or iterations that will be carried out by the PSO algorithm during its execution. It provides an estimate of the computational effort required for the optimization process, which is a key consideration when using PSO for solving optimization problems.

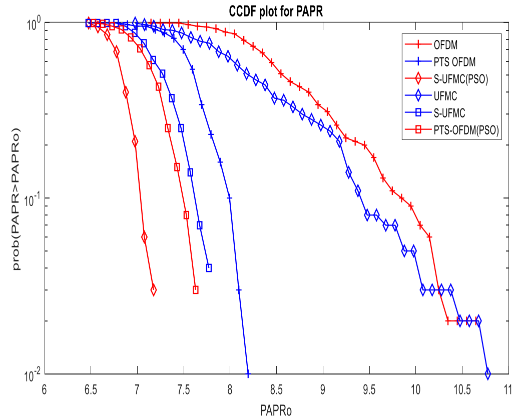

FIGURE 12. CCDF plot based on PSO for 50 iterations, 512 subcarriers, and 64-APSK.

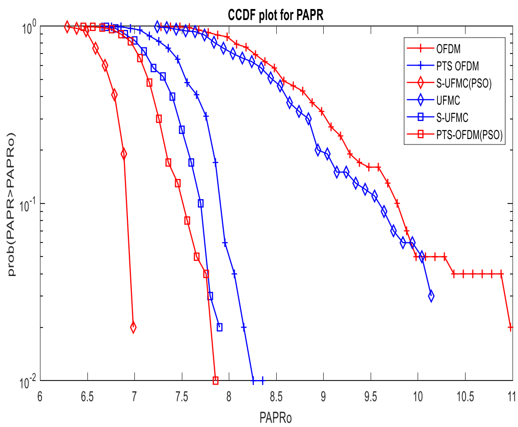

FIGURE 13. CCDF plot using PSO for 100 iterations, 512 subcarriers, and 64-APSK.

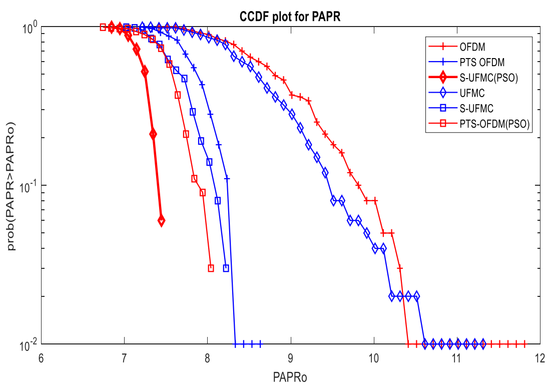

FIGURE 14. PSO-based CCDF plot with 64-APSK for 20 iterations and 1024 subcarriers.

IV. RESULTS AND DISCUSSION

In the comparative analysis of PTS-OFDM, UFMC, and in the context of Scrambled UFMC systems employing APSK modulation, the PSO algorithm is employed to assess their performance. Cumulative Distribution Function (CCDF) diagrams are generated to analyze the behavior of the PAPR in these systems. The analysis considers various parameters, as outlined in Table 1. Here's a summary of the key findings: It's observed that in both OFDM and UFMC systems, the PAPR tends to decrease as the number of optimization iterations increases. This suggests that iterative optimization methods can help improve the power efficiency of these systems. Notably, the Scrambled UFMC system with PSO optimization achieves even lower

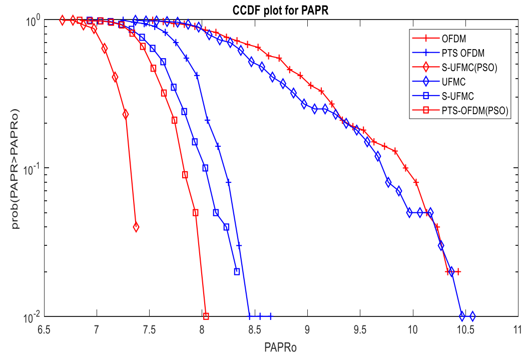

FIGURE 15. PSO-based CCDF plot with 64-APSK for 50 iterations and 1024 subcarriers.

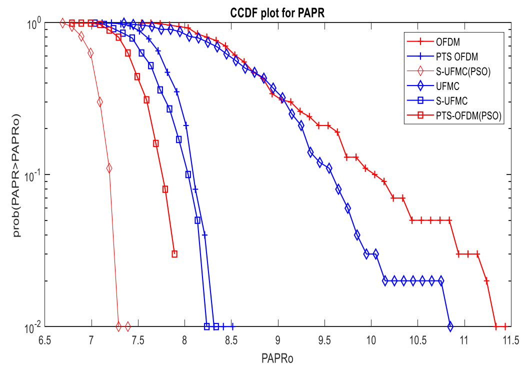

FIGURE 16. PSO-based CCDF plot with 64-APSK for 100 iterations and 1024 subcarriers.

TABLE 2. PAPR values for different sub carriers for 16 APSK with PSO.

Parameters	PAPR(dB) For 20 iterations	PAPR(dB) For 50 iterations	PAPR(dB) For 100 iterations	number Subcarriers
UFMC	08.112	08.062	08.061	512
PTS-OFDM	08.077	07.982	07.856	
S-UFMC	07.9269	07.767	07.652	
PSO-PTS-OFDM	07.8178	07.645	07.542	
PSO-S-UFMC	07.505	07.491	07.393	
UMFC	08.234	08.112	08.091	1024
PTS-OFDM	08.141	08.014	07.983	
S-UFMC	08.041	07.852	07.773	
PSO-PTS-OFDM	07.915	07.612	07.543	
PSO-S-UFMC	07.665	07.524	07.414	

TABLE 3. PAPR values for different sub carriers for 64 APSK with PSO.

Parameters	PAPR (dB) For 20 iterations	PAPR (dB) For 50 iterations	PAPR (dB) For 100 iterations	Number of Subcarriers
UFMC	08.687	08.435	08.324	512
PTS-OFDM	08.543	08.456	08.124	
S-UFMC	08.213	08.0165	07.943	
PSO-PTS-OFDM	08.126	07.876	07.763	
PSO-S-UFMC	07.914	07.654	07.576	
UMFC	08.765	08.667	08.427	1024
PTS-OFDM	08.631	08.367	08.235	
S- UFMC	08.365	08.125	08.023	
PSO-PTS-OFDM	08.026	07.954	07.863	
PSO-M-UFMC	08.112	07.986	07.867	

PAPR values compared to both OFDM and UFMC systems alone. This improvement is illustrated in Figures 5 to 7. Figures 8 to 10 depict CCDF plots for OFDM and UFMC systems with 1024 subcarriers. It's evident that the PAPR increases with the number of subcarriers in both systems. This emphasizes the relationship between subcarrier count and PAPR.A similar trend is observed in Figures 11 to 13 when comparing OFDM and UFMC systems for 64-APSK with 512 subcarriers. The PAPR increases with the modulation index, indicating that higher-order modulation can lead to higher PAPR values. Tables 2 and 3 provide a quantitative comparison of PAPR values between PTS-OFDM and S-UFMC, both with and without PSO optimization. Notably, PSO-based S-UFMC consistently produces lower PAPR. For example, with 16-APSK and 512 subcarriers, PSO-based S-UFMC achieves a PAPR of 7.393, which increases slightly to 7.414 with 1024 subcarriers. Increasing the number of subcarriers also influences the PAPR in PSO-based S-UFMC, as seen in the comparison of PAPR values between 512 and 1024 subcarriers. The analysis demonstrates that the PAPR tends to increase with the modulation index, as seen in the results for 64-APSK.These findings collectively suggest that the Scrambled UFMC system with PSO optimization offers enhanced PAPR performance compared to PTS-OFDM and UFMC systems alone. Additionally, the study highlights the importance of considering the number of subcarriers and modulation index when optimizing multi-carrier communication systems.

V. CONCLUSION

In conclusion, this research investigated the performance of PTS-OFDM, UFMC, and scrambled UFMC employing APSK modulation, with a focus on parameters such as PAPR and spectral efficiency. To address the complexity associated with phase factor search and PAPR reduction, a PSO algorithm was introduced, leveraging each particle's position vector for defining the specific factor. The analysis revealed that PAPR increases with the number of subscribers and bits per subscriber but can be mitigated by increasing the number of iterations. Comparative assessments with PTS-OFDM and S-UFMC demonstrated that the proposed PSO-based S-UFMC outperforms in terms of PAPR and BER reduction. The findings highlight the efficiency of the proposed approach in striking a reasonable balance between PAPR reduction and computational complexity. The research findings demonstrate the effectiveness of the PSO-based optimization approach in enhancing UFMC and OFDM performance in 5G wireless systems. By applying PSO with 100 iterations for 512 subcarriers, a significant decrease in PAPR to 7.393 for 16 APSK and 7.565 for 64 APSK was achieved. This optimization technique strikingly balances PAPR reduction and computational complexity, showcasing UFMC as a promising alternative with superior PAPR compared to OFDM. The PSO-based Scrambled UFMC particularly excelled, affirming the potential of this approach to elevate the performance of UFMC and OFDM with APSK modulation in the context of 5G communication systems. Consequently, UFMC emerges as a promising alternative for widespread adoption in 5G communications. The application of the PSO algorithm to APSK-based OFDM and UFMC demonstrated notable PAPR reduction, with PSO-based Scrambled UFMC exhibiting superior performance over other techniques. In summary, the results affirm the efficacy of the proposed PSO-based optimization approach, emphasizing its potential to enhance the performance of UFMC and OFDM with APSK modulation in the context of 5G wireless systems. The findings contribute valuable insights into the feasibility of employing UFMC as a viable replacement for OFDM in various 5G communication scenarios.

A. LIMITATIONS AND FUTURE WORK

The limitations of this research include the focus on specific modulation schemes and optimization techniques, potentially limiting the generalizability of the findings to broader communication systems. Future work could explore the integration of machine learning algorithms or adaptive techniques to further enhance PAPR reduction and spectral efficiency in 5G networks. Additionally, investigating the impact of varying channel conditions and mobility scenarios on the proposed UFMC and OFDM systems could provide valuable insights for real-world deployment and performance optimization.

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