Peak to Average Power Ratio Reduction in UFMC System Using Pre - Coding and Nonlinear Companding Techniques

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Abstract - Universal Filtered Multi-Carrier (UFMC) is a versatile fifth-generation communication technology that can be utilized in Internet of Things and Machine-to-Machine (M2M) communication to enhance connectivity and efficiency because of its spectral efficiency, low power consumption, reliability, and flexibility. The Internet of Things and Machine-to-Machine (M2M) communication enable devices to talk to each other, gather data, and make the world smarter and more efficient. However, the drawback of UFMC systems is they exhibit a very high peak -to-average-power-ratio which causes system Lower and latency on communication. Therefore, to lower the high peak -to-average-power-ratio of the UFMC system, this project proposes an efficient hybrid PAPR reduction approach that combines both non-linear companding techniques and precoding techniques.

***Key Words*:** Peak-to-average power ratio (PAPR), Hybrid PAPR reduction Techniques, Precoding Techniques, Non-Linear Companding Techniques (NCLTs),
Universal Filtered Multi-Carrier (UFMC).

1. INTRODUCTION

The introduction of 5G, the fifth generation of wireless communication, a new age of extraordinary connectedness and creativity has emerged. Fundamentally different from its predecessors, 5G technology introduces ground-breaking improvements in terms of data speed, capacity, latency, and network architecture. The integration of UFMC systems has drawn a lot of attention as the 5G landscape develops due to its potential to revolutionise spectral efficiency and data throughput.

The exploration of fifth-generation wireless networks has garnered substantial research interest, primarily driven by their potential to find applications across the wireless industry. The advent of novel use cases such as the Internet of Things (IoT), vehicular communications, and ultra-reliable and low-latency communications (URLLC) further adds to the relevance and appeal of this research endeavor."

Unlike existing 4G systems, the framework of 5G wireless technology necessitates adaptability to cater to a diverse array of applications and user requirements. Presently, 4G systems rely on cyclic prefix-orthogonal frequency division multiplexing (CP-OFDM) technology to mitigate inter-symbol interference (ISI) and withstand challenges like multipath propagation and fading. However, the application of CP-OFDM in 5G scenarios is less effective due to its cyclic prefix usage, which leads to substantial losses in spectrum efficiency and the generation of high out-of-band (OOB) side lobes.

New waveforms have been proposed that feature lower spectral side-lobe levels, such as filter-bank multicarrier, generalised frequency division multiplexing, filtered-OFDM, and universal filtered multicarrier. As a cutting-edge multi-carrier modulation technology, UFMC is drawing interest as a potential waveform for the next generation of wireless communication. Modern modulation and waveform techniques like the Universal Filtered Multi-Carrier (UFMC) architecture were created to improve spectral efficiency and address a number of problems with wireless communication systems. Because of its flexibility, UFMC is particularly significant because it can respond to the various requirements of contemporary communication situations.

By utilizing complex filtering algorithms, UFMC fundamentally redefines the way data is conveyed across wireless networks. UFMC uses a more sophisticated method than conventional Orthogonal Frequency Division Multiplexing (OFDM) systems, which use a cyclic prefix to reduce inter-symbol interference (ISI). In UFMC, sub-carriers are filtered with pulse-shaping functions prior to transmission, thus minimising ISI and lowering the side lobes of the signal.

2. UFMC SYSTEM

UFMC (Universal Filter Multi-Carrier) is a digital modulation and multiple access technique designed to enhance the performance of wireless communication systems. It is a relatively newer technology compared to traditional modulation schemes like OFDM (Orthogonal Frequency Division Multiplexing) and is designed to address some of the limitations of these older technologies. Its architecture is built upon several key principles:

- Subcarrier and Filter Design: UFMC employs a subcarrier-based approach, much like its predecessor OFDM. However, it distinguishes itself by using a filter bank that applies filtering to each subcarrier. These filters are carefully designed to exhibit improved spectral containment properties compared to the traditional rectangular subcarriers used in OFDM.
- Filter Characteristics: The filters used in UFMC are crucial components of its architecture. They are designed to minimize spectral leakage, which results in reduced out-of-band emissions. This spectral containment is a fundamental feature that sets UFMC apart from other modulation schemes.

- Orthogonality and Flexibility: UFMC maintains a degree of orthogonality between its subcarriers, ensuring efficient data transmission. Moreover, it offers flexibility in terms of subcarrier spacing and filter shapes, allowing for adaptation to various channel conditions and bandwidth requirements.
- Spectrum Efficiency: Compared to OFDM, UFMC is intended to have higher spectrum efficiency. It accomplishes this by reducing out-of-band emissions through the use of sophisticated filtering algorithms, allowing for a more effective utilisation of the available spectrum.
- Low Latency: UFMC is designed to provide low-latency communication, making it suitable for applications where real-time communication is crucial, such as autonomous vehicles and industrial automation.

Advantages of UFMC System

The UFMC system offers several advantages that make it an attractive choice for wireless communication:

- Reduced Out-of-Band Emissions: UFMC's spectral containment properties substantially reduce the interference with adjacent frequency bands. This is particularly advantageous in densely populated urban environments and situations where coexistence with other wireless systems is critical.
- Improved Spectral Efficiency: UFMC's innovative filter design optimizes spectrum utilization, leading to enhanced spectral efficiency. This means that more data can be transmitted within the available bandwidth, making it an ideal choice for future high-capacity communication systems.
- Flexibility: UFMC's adaptability to different channel conditions and bandwidth requirements makes it versatile for a wide range of communication scenarios. It can be tailored to meet the specific needs of different applications, from IoT devices with narrow bandwidth requirements to high-speed mobile data communication.
- Reduced Interference: The reduced out-of-band emissions of UFMC contribute to reduced interference with neighbouring systems, improving the quality of service for all users in shared spectrum bands.

Disadvantages of UFMC System

- Peak-to-Average Power Ratio (PAPR): The peak-to-average power ratio (PAPR) of UFMC systems is high, which seriously impairs the system's performance. The high value of the PAPR also has an impact on the efficiency of the power amplifiers used for up-link transmissions.

Applications of UFMC

- 5G Wireless Communication: For wireless communication systems in the 5G and beyond, UFMC is regarded as a potential modulation method. In comparison to other modulation systems, it has benefits including increased spectrum efficiency, fewer out-of-band emissions, and better interference mitigation.
- IoT and M2M Communication: Due to its capacity to accommodate a wide range of devices with various data rate needs, UFMC may be useful for Internet of Things (IoT) and Machine-to-Machine (M2M) communication. It can effectively support both high-data-rate applications and low-power, low-data-rate devices on the same spectrum.
- Wireless Broadband Services: UFMC can be used for providing wireless broadband services, offering high data rates to users while maintaining a reliable connection, even in challenging environments with interference and multipath propagation.
- Satellite Communication: UFMC can be used in satellite communication systems to improve spectral efficiency and minimize the impact of adjacent satellite signals, which is crucial in satellite networks where spectrum resources are limited.
- Industrial Automation: In industrial automation and control systems, UFMC can provide robust communication for devices and sensors in harsh environments, where interference and noise can be prevalent.
- Aeronautical Communication: UFMC networks can enhance communication systems for aircraft, including both passenger and military applications. They offer robust and interference-resistant communication, ensuring the safety and reliability of in-flight data and voice communication
- Maritime Communication: UFMC can be applied in maritime satellite communication for vessels, ships, and offshore platforms. It ensures reliable data exchange, including voice and data services, in challenging marine environments.
- Earth Observation and Remote Sensing: UFMC networks can be used for transmitting high-resolution imagery and data from Earth observation satellites. This is crucial for applications like environmental monitoring, disaster management, and scientific research.
- Military and Defense: UFMC can be employed in military and defense satellite communication systems to ensure secure and resilient communication for command and control, intelligence, surveillance, and reconnaissance (ISR), and other military applications.
- Scientific Missions: UFMC networks can support scientific missions involving space probes, rovers, and space telescopes. They facilitate the transmission of scientific data, images, and telemetry back to Earth.

3. Methodology

3.1 peak to Average Power Ratio of UFMC System

In a UFMC (Universal Filtered Multicarrier) system, the PAPR (Peak-to-Average Power Ratio) calculation formula is a complicated mathematical expression that is dependent on the particular UFMC signal and filtering being used. Although the precise formula can be quite complex, UFMC is intended to have a lower PAPR than some other

multicarrier modulation schemes, such as OFDM (Orthogonal Frequency Division Multiplexing).
The PAPR for a UFMC signal is typically expressed as:

$$PAPR=\frac{max_n |x(n)|^2}{E[|x(n)|^2]} \quad [1]$$

3.1.1 precoding Technique

In the context of UFMC communication system, precoding techniques refer to methods used to manipulate the transmitted signals before they are transmitted over the channel. These techniques are employed to improve the performance of the communication system in terms of signal quality, spectral efficiency, and interference mitigation.

3.1.1.1discrete Fourier Transform

To analyse and process discrete-time signals in the frequency domain, the Discrete Fourier Transform (DFT) is a mathematical transform used in a variety of signal processing applications. It is a crucial tool for comprehending the frequency components of a signal and is widely applied in many scientific and engineering fields, including telecommunications, audio processing, image processing, and many others.

The discrete Fourier Transform (DFT) converts a series of discrete time-domain samples into a corresponding series of complex frequency-domain coefficients. For a sequence of length N, x(n), the mathematical definition of the DFT is as follows:

$$X(k) = \sum_{n=0}^{N-1} x(n).e^{\left(-j\frac{2\pi}{N}\right)kn} \quad [2]$$

Where:

- X(k) is the DFT coefficient at frequency index k.
- x(n)is the input sequence.
- N is the length of the sequence.
- k is the frequency index, ranging from 0 to N-1.
- j represents the imaginary unit j = sqrt {-1}.

3.2. Nonlinear Companding Methods

There are different types of nonlinear companding like Advanced root companding technique and μ law and A law.

3.2.1. Advanced Root Companding Technique (ARCT)

To lower the PAPR, an NLCT called the ARCT is applied. The square root compounding approach has been modified in this case. is a representation of the modified rooting companding technique.

$$z(n) = C\,(y(n)) = |y(n)|^{R}\, sgn(y(n)) \quad [3]$$

where the sgn function is used to keep the UFMC signal's phase constant and R is a mean companding parameter whose value ranges from 0.1 to 0.9. The ARCT changes the signal's amplitude while leaving the phase value unaltered.

The amplitude of the signal changes at a rate determined by the value of R. The compressed signal is afterwards recovered at the receiver end using the rooted decompanding approach, which is represented as.

$$C^{-1}(r(n)) = |r(n)|^{1/R}\, sgn(r(n)) \quad [4]$$

3.3. proposed Hybrid Paper Reduction Approach

The proposed hybrid PAPR reduction strategy, which combines NLCTs with precoding to lower on UFMC system's PAPR, is examined. The PAPR of any multicarrier systems is decreased using both precoding techniques and NLCTs separately.

Size of FFT	1024
Total number of sub-carriers	384
Modulation method	QPSK & 16-PSK
Number of sub-bands	32
Number of sub-carriers in each sub-band	12
Sidelobe Attenuation	40dB
Window	Dolby-Chebyshev
Filter length	43
Channel	AWGN

TABLE 1: Simulation Parameters of UFMC System

The Peak-to-Average Power Ratio (PAPR) in a UFMC (Universal Filtered Multi-Carrier) system. Precoding, as an initial approach, was found to exert minimal influence on the receiver's data rate. Conversely, the companding transform introduced a certain level of signal distortion and amplified receiver noise. Therefore, the inherent advantages of both precoding and companding techniques were harnessed within the hybrid methodology, strategically combining their strengths to address the challenge of high PAPR in the system.

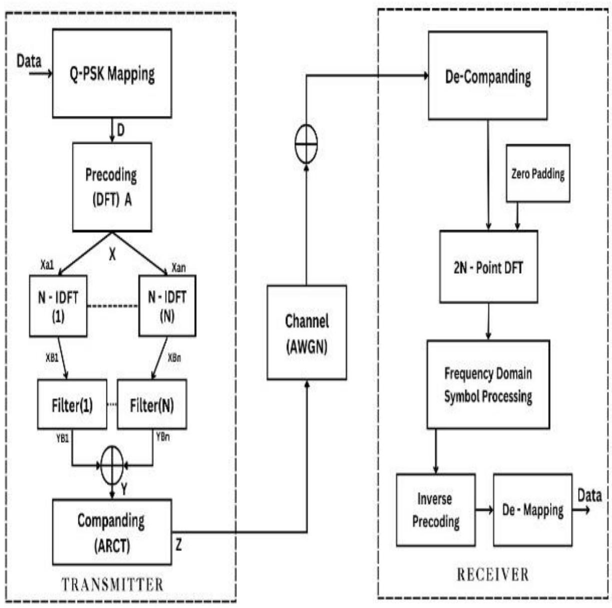


FIGURE 1: Block Diagram of Hybrid PAPR Reduction Approach of UFMC System.

4. Results and Discussions

A MATLAB-based simulation was executed to assess and compare the efficacy of a hybrid scheme incorporating QPSK and 16-PSK modulation techniques using randomly generated data bits. The primary objective of this simulation was to validate the proposed hybrid approach's effectiveness, with a specific focus on analyzing the Peak-to-Average Power Ratio (PAPR) outcomes

In this investigation, a total of 1024 sub-carriers were utilized, featuring a subcarrier spacing of 15 KHz. Among these sub-carriers, 600 were actively allocated, distributed across multiple sub-bands, each containing 12 sub-carriers. This configuration enabled a comprehensive evaluation of the performance of the Universal Filtered Multi-Carrier (UFMC) system under examination.

By employing both QPSK and 16-PSK modulation techniques with randomly generated data bits, this MATLAB simulation yielded valuable insights into the hybrid scheme's performance, specifically regarding its PAPR management capabilities and its efficiency in utilizing the allocated sub-carriers.

4.1. Analysis of peak to Average Power Ratio

concluded Analyzing the Peak-to-Average Power Ratio for precoding techniques like μ-law(mu-law) and ARCT (Amplitude-to-Residual clipping Transform) involves assessing how these techniques impact the signal peak power compared to its average power. Lower PAPR is desirable in communication system as it allows for more efficient power amplification.

The below figure shows the CCDF comparison of different orders of DFT-Precoding schemes for UFMC to reduce PAPR in a system.

Figure 2: CCDF Comparison of different orders of DFI-Precoding for UFMC

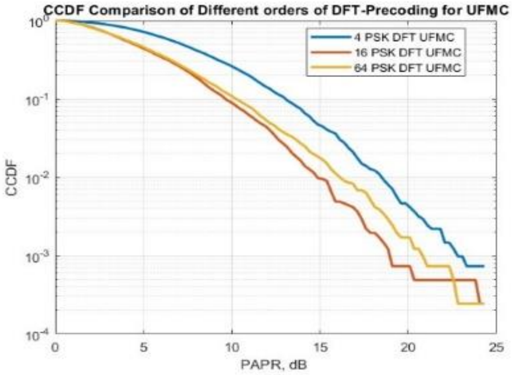


Table 2. Comparison of PAPR values of different orders of DFT-Precoding for UFMC

Order	PAPR
4 PSK DFT	23.72dB
16 PSK DFT	19.17dB
64 PSK DFT	21.08dB

A set of random data is initially created and modulated using 4,16,64-PSK techniques. Later, three separate precoding matrices are used to precode the modulated data. As shown in figure.2 and table.2, it is clear that the 16-PSK DFT-UFMC system surpasses previous precoding-based UFMC systems in terms of PAPR performance. As a result, enhancing the traditional UFMC modulation scheme with a DFT precoding block enhances the PAPR of the UFMC system without adding to the complexity of the system.

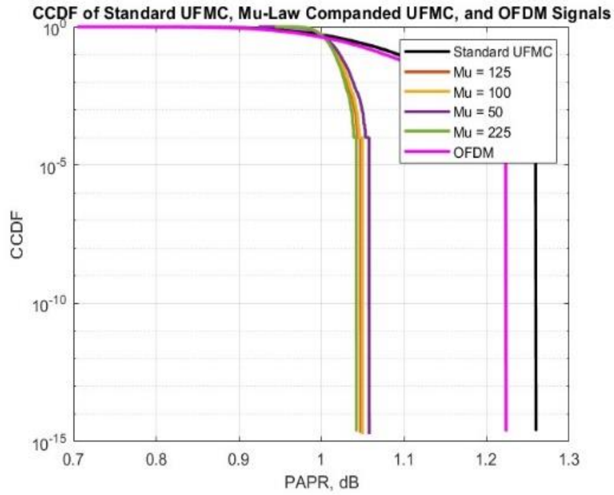


Figure 3. CCDF of Standard UFMC, Mu-Law companded UFMC and OFDM Signal

μlaw values	PAPR
50	1.0719dB
100	1.0579dB
125	1.0436dB
225	1.0214dB
OFDM	1.206dB
Standard UFMC	1.214dB

Table 3. Comparison of PAPR Values of different Values of Mu-Law Companded UFMC

"The Cumulative Complementary Distribution Function (CCDF) characteristics of Standard UFMC, Mu-companded UFMC, and OFDM signals using 16-PSK modulation are depicted in Figure 3 and summarized in Table 3. Notably, there is a clear trend of decreasing Peak-to-Average Power Ratio (PAPR) as the Mu-Law compression coefficients (μ) increase"

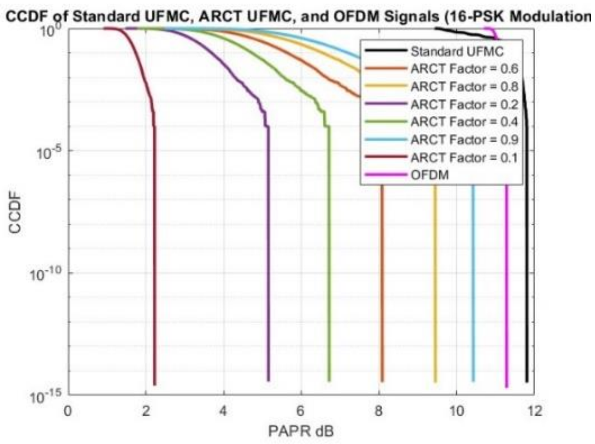


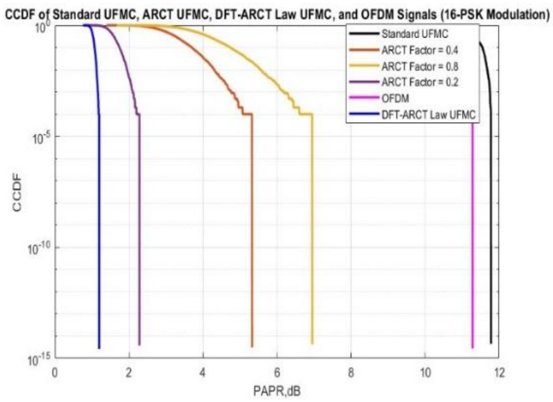
Figure 4. CCDF of Standard UFMC, ARCT Companded UFMC and OFDM Signals.

ARCT Factors	PAPR
0.1	2.12dB
0.2	4.86dB
0.4	6.24dB
0.6	7.62dB
0.8	8.86dB
0.9	9.85dB
OFDM	11.21dB
Standard UFMC	11.73dB

Table 4. Comparison of PAPR Values of different values of ARCT Factors

The study illustrates the Cumulative Complementary Distribution Function (CCDF) characteristics of OFDM, Standard UFMC, and ARCT UFMC Signals using 16-PSK Modulation, as seen in Figure 4 and summarized in Table 4. These findings consistently reveal a reduction in the Peak-to-Average Power Ratio (PAPR) as the parameter R increases, indicating a positive impact of the ARCT Factor on PAPR attributes.

In light of the insights derived from this analysis, it becomes apparent that both precoding and Non-Linear Companding Techniques (NLCTs) play significant roles in enhancing PAPR performance within our UFMC system when compared to the conventional UFMC approach. To further advance PAPR reduction, the paper introduces an innovative hybrid methodology.



Figures 5. CCDF Of Standard UFMC, ARCT UFMC, DFT-ARCT UFMC and OFDM Signals

Factors	PAPR
DFT-ARCT Law UFMC	1.166dB
0.2	4.82dB
0.4	6.24dB
0.8	8.86dB
OFDM	11.2dB
Standard UFMC	11.7dB

Table 5. Comparison of PAPR Values of DFT-ARCT UFMC, Standard UFMC, OFDM and ARCT Factors

The CCDF properties of OFDM, Standard UFMC, ARCT, and DFT - ARCT UFMC Signals for 16-PSK Modulation are shown in the Figure 5 and Table 5. The proposed hybrid technique which combines both Precoding and Non-Linear Companding Technique (DFT - ARCT) shows that better reduction in the PAPR in UFMC systems.

CONCLUSION:

This research introduces a novel hybrid strategy aimed at reducing the Peak-to-Average Power Ratio (PAPR) within UFMC systems. The study's outcomes reveal a significant enhancement in PAPR reduction when employing the hybrid approach, in comparison to the conventional UFMC system. Furthermore, the paper conducts an extensive comparative assessment involving three distinct techniques: precoding, Mu-Law, and the advanced rooting companding method. The results clearly indicate that the DFT-ARCT technique surpasses Mu-Law and precoding in its effectiveness in mitigating PAPR.

Additionally, the analysis underscores the consistent superiority of the precoded UFMC approach over conventional methods, particularly in scenarios involving Additive White Gaussian Noise (AWGN). The simulation results accentuate the remarkable effectiveness of the proposed hybrid ARCT approach in lowering PAPR compared to the hybrid Mu-Law technique.

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