

Performance Evaluation of OFDM and its Variants Including FBMC and UPMC for 5G Wireless Networks

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Abstract— This paper presents a comprehensive performance evaluation of five multicarrier modulation schemes: Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM), Discrete Fourier Transform (DFT's-OFDM), Windowed OFDM (W-OFDM), Filter Bank Multicarrier (FBMC) and Universal Filtered Multicarrier (UFMC). These schemes are assessed with respect to key performance metrics including Bit Error Rate versus Signal-to-Noise Ratio, Power Spectral Density, and Peak-to-Average Power Ratio. The study aims to highlight the strengths and limitations of each modulation technique in the context of modern wireless communication systems, particularly in 5G and beyond. Through extensive simulations, OFDM's spectral inefficiency and high PAPR are contrasted against the improved spectral containment of FBMC, the sub-band filtering advantages of UFMC, and the enhanced spectral shaping offered by W-OFDM. CP-OFDM's robustness and simplicity, along with DFT-s-OFDM's lower PAPR characteristics, are also analyzed. Results demonstrate that while CP-OFDM remains widely adopted due to implementation simplicity and resilience to multipath fading, FBMC and UFMC achieve superior spectral efficiency and reduced out-of-band emissions, and W-OFDM and DFT-s-OFDM provide intermediate trade-offs between complexity, spectral containment, and PAPR reduction. This analysis provides critical insights into the trade-offs involved in selecting an appropriate modulation technique for diverse application scenarios.

Index Terms— Orthogonal Frequency Division Multiplexing, Discrete Fourier Transform OFDM, Windowed OFDM, Signal to Noise Ratio, Filter Bank Multicarrier, Universal Filtered Multicarrier, Power Spectral Density, Peak to Average Power Ratio.

I. INTRODUCTION

A. Overview of Multicarrier Modulation

Multicarrier modulation is a key technique in modern wireless communication systems, designed to transmit data efficiently over frequency-selective channels. It achieves this by dividing a high-rate data stream into several lower-rate sub streams, which are transmitted simultaneously over multiple subcarriers. This approach minimizes the effects of multipath fading and inter-symbol interference (ISI), improving signal reliability. OFDM is the most widely adopted method, forming the foundation for standards like LTE, Wi-Fi, and 5G. However, advanced schemes such as FBMC and UFMC have been introduced to address OFDM's limitations, offering improvements in spectral efficiency, power consumption, and latency [1].

B. Motivation for Comparing OFDM Variant's, FBMC, and UFMC

While OFDM is popular due to its simplicity and robustness, it suffers from key drawbacks such as high out-of-band (OOB) emissions, large Peak-to-Average Power Ratio (PAPR), and sensitivity to synchronization errors. These issues become more pronounced in scenarios like dynamic spectrum access, Internet of Things (IoT), and heterogeneous 5G networks, where flexibility and spectral efficiency are crucial. FBMC and UFMC have emerged as promising alternatives. FBMC improves spectral containment by applying filtering at the subcarrier level, removing the need for a cyclic prefix. UFMC filters groups of subcarriers rather than individual ones, offering a trade-off between complexity and performance. Comparing these schemes is essential to understand their suitability for future communication systems [2].

C. Objectives and Contributions of the Paper

- To analyse and compare the performance of OFDM, FBMC, and UFMC in terms of:
- SNR vs. BER: Measuring the error performance under varying noise conditions.
- Power Spectral Density: Assessing spectral leakage and bandwidth efficiency.
- PAPR: Evaluating the power efficiency and impact on RF hardware.
- To conduct a comparative study of different OFDM variants (e.g., CP-OFDM, DFT-s-OFDM, and W-OFDM) with respect to the same metrics.
- To provide insights into which modulation technique is best suited for different 5G wireless communication scenarios based on the trade-offs observed [3].

II. SURVEY OF RELATED WORK

A. Brief Literature Review on OFDM variant's, FBMC, and UFMC

CP-OFDM is the most widely used multicarrier modulation scheme, employed in standards such as LTE and Wi-Fi. It appends a cyclic prefix to each OFDM symbol to combat inter-symbol interference (ISI) caused by multipath fading. While it offers high spectral efficiency and robustness against channel delay spread, it suffers from high Peak-to-Average Power Ratio (PAPR) and poor out-of-band (OOB) emission control [4]. DFT's OFDM Also known as SC-FDMA, this variant introduces a DFT precoding step before IFFT, making the signal more like a single-carrier waveform. It significantly reduces PAPR, making it ideal for uplink transmission in LTE. However, it loses subcarrier-level flexibility and is less effective in frequency-selective fading [5]. W-OFDM improves the spectral containment of standard OFDM by applying time-domain windowing at symbol boundaries. This reduces out-of-band emissions and improves coexistence with adjacent channels. However, it introduces a small loss in spectral efficiency and increases system complexity due to the overlapping windows [6].

FBMC replaces the CP and IFFT-based structure of OFDM with a filter bank approach, providing excellent time-frequency localization. It avoids the use of CP and hence achieves higher spectral efficiency. Its intrinsic interference and implementation complexity (e.g., real-valued OQAM signaling) make it more suitable for low-latency or cognitive radio applications rather than mainstream wireless standards [5]. UFMC applies filtering at the sub band level rather than per subcarrier (FBMC) or whole band (OFDM), striking a balance between spectral efficiency and complexity. It provides better spectral containment and robustness to synchronization errors. UFMC is seen as a strong candidate for 5G and beyond, especially in scenarios with fragmented spectrum [5].

B. Justification for Chosen Performance Metrics

To evaluate and compare the real-world suitability of CP-OFDM, DFT'S-OFDM, W-OFDM, FBMC, and UFMC, it is crucial to examine them against performance metrics that directly impact system efficiency and reliability:

- Bit Error Rate (BER) vs Signal-to-Noise Ratio (SNR): BER is a fundamental metric reflecting the accuracy of data transmission. Plotting BER against SNR gives insight into the robustness of each modulation scheme under noisy conditions.
- Power Spectral Density (PSD): PSD analysis helps determine the spectral containment of the waveform. This is critical for minimizing interference with adjacent channels and maximizing spectrum usage—especially important in 5G networks with dynamic spectrum allocation.
- Peak-to-Average Power Ratio (PAPR): High PAPR can cause non-linear distortion in power amplifiers, leading to spectral regrowth and reduced energy efficiency. Therefore, evaluating PAPR is essential for understanding power amplifier requirements and overall system power efficiency.

III. PROPOSED METHODOLOGY

A. Orthogonal Frequency Division Multiplexing

In an OFDM system, the transmitter first converts a high-speed serial data stream into parallel low-rate streams. Each stream is modulated using QAM or PSK, then converted from frequency to time domain using the Inverse Fast Fourier Transform (IFFT). A cyclic prefix is added to each OFDM symbol to prevent inter-symbol interference caused by multipath propagation. The time-domain signal is then converted to analog and transmitted over the air.

At the receiver, the reverse process is performed. The received analog signal is digitized and converted back into parallel streams. The cyclic prefix is removed, and a Fast Fourier Transform (FFT) is applied to recover the frequency-domain symbols. These are demodulated to retrieve the original data, which is then reassembled into the original serial stream [4]

Mathematical formulation of OFDM:

- The transmitted OFDM symbol is represented as an IFFT of input data symbol

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}$$

- where X_k is the symbol on the k^{th} subcarrier, and N is the number of subcarriers.

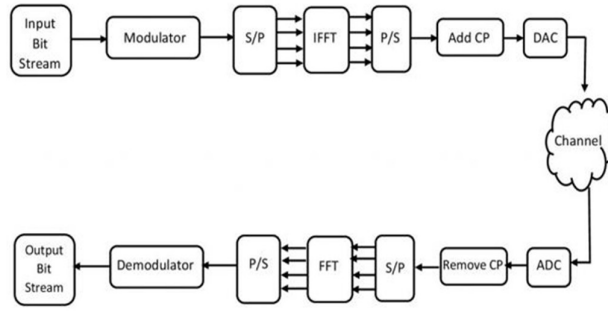


Figure 1. Block diagram of OFDM [4].

B. Filter Bank Multicarrier (FBMC)

Filter Bank Multicarrier (FBMC) is a spectrally efficient alternative to OFDM that reduces out-of-band emissions and eliminates the need for a cyclic prefix. It uses prototype filters per subcarrier to improve spectral localization and minimize interference. FBMC employs Offset QAM (OQAM), where real and imaginary parts are transmitted alternately to maintain orthogonality.

The modulation phase factor is given by

$$\theta(m, n) = e^{j\frac{\pi(m+n)}{2}} = j^{(m+n)} \quad \theta^*(m, n) = e^{-j\frac{\pi(m+n)}{2}} = -j^{(m+n)}$$

where m is the subcarrier and n is the symbol index.

At the transmitter, each subcarrier is filtered and modulated individually, then summed into a composite signal. The receiver uses an analysis filter bank to extract subcarriers and demodulate the OQAM symbols. FBMC offers high spectral efficiency and is suitable for dynamic spectrum scenarios like cognitive radio and 5G. However, it introduces complexity in equalization, symbol reconstruction, and MIMO processing due to the real-valued OQAM symbols and filter delay [5][6].

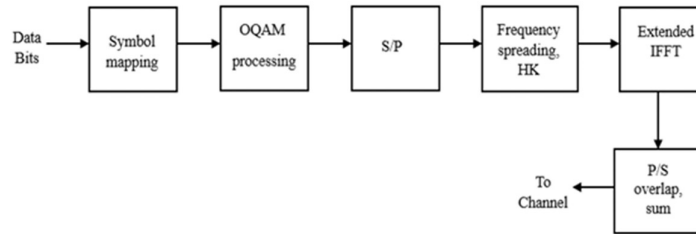


Figure.2. Block diagram of FBMC Transmitter [6]

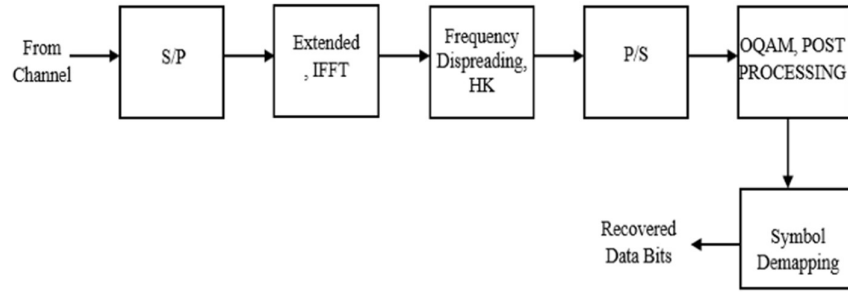


Figure 3. Block diagram of FBMC Receiver [6].

C. Universal Filtered Multicarrier (UFMC)

Universal Filtered Multicarrier (UFMC), also known as UF-OFDM, is a multicarrier modulation scheme proposed for 5G to balance spectral efficiency, complexity, and robustness. Unlike OFDM, which applies no filtering, and FBMC, which filters each subcarrier, UFMC filters groups of subcarriers (sub bands) using filters like Dolph-Chebyshev windows. This sub band filtering improves spectral containment and eliminates the need for a cyclic prefix.

Data is modulated (e.g., via QAM), passed through IFFT, grouped into sub bands, and filtered before transmission. At the receiver, the signal is filtered and FFT is applied to recover symbols. UFMC reduces inter-symbol and inter-carrier interference, supports low-latency communication, and is robust against synchronization errors. It offers better spectral efficiency than OFDM and lower complexity than FBMC, making it suitable for IOT and future wireless systems [6].

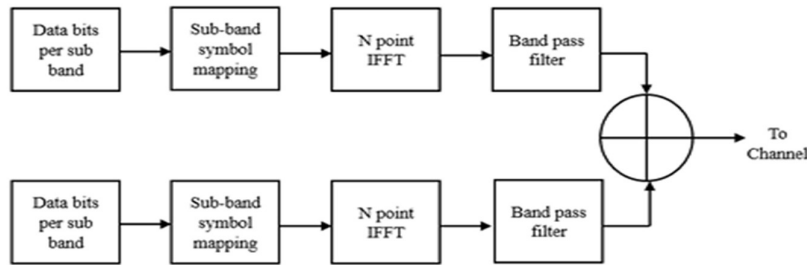


Figure 4. Block diagram of UFMC transmitter [5][6].

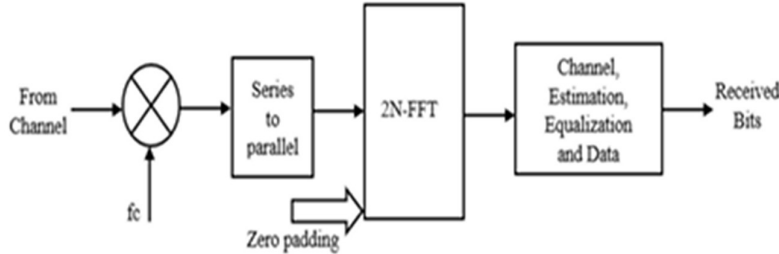


Figure 5. Block diagram of UFMC Receiver [5][6].

D. Simulation Setup And Parameters

- Define the simulation environment for OFDM, DFT's-OFDMF, W-OFDM, FBMC, and UFMC.
- Specify key parameters:
 - Number of subcarriers
 - Modulation scheme (e.g., QPSK, 16-QAM)
 - Channel model (e.g., AWGN, Rayleigh fading)
 - Filter types and lengths for FBMC and UFMC
 - Cyclic prefix length for OFDM variants
 - Bits for BER calculation.

IV. SIMULATION RESULTS AND DISCUSSION

A. SNR vs. BER Performance Comparison of OFDM Variant's and FBMC, UPMC For AWGN

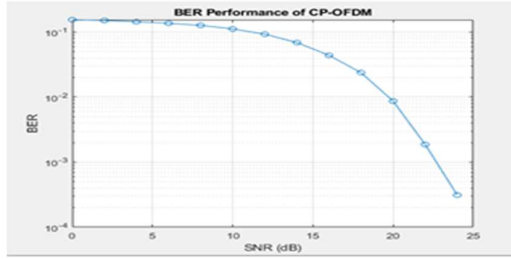


Figure .6. SNR vs BER Plot for CP-OFDM

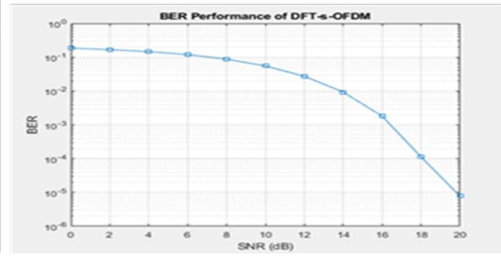


Figure .7. SNR vs BER Plot for DFT-s-OFDM

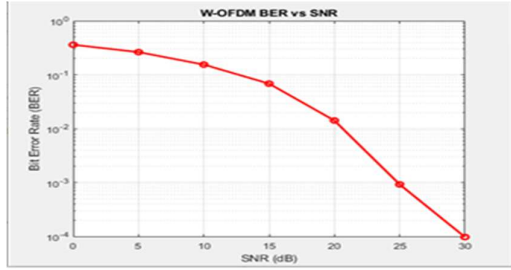


Figure .8. SNR vs BER Plot for W-OFDM

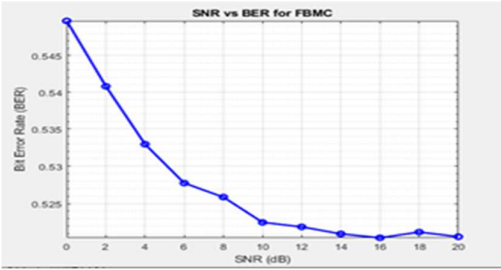


Figure .9. SNR vs BER Plot for FBMC

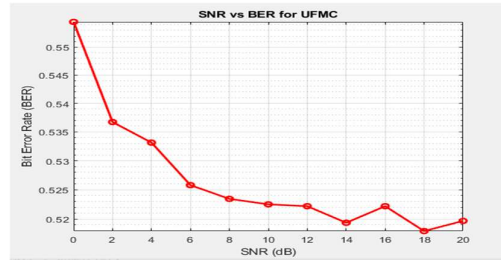


Figure. 10 SNR vs BER Plot for UPMC

Figures 6–10 show that BER decreases as SNR increases for all schemes. Among OFDM variants, DFT-s-OFDM performs best at low SNR due to reduced PAPR, while W-OFDM offers slight improvement over CP-OFDM; at high SNR, all three converge. Filter-based schemes outperform them—FBMC achieves the lowest BER across most SNR ranges thanks to superior frequency localization and no cyclic prefix, followed by UPMC, which provides strong spectral containment but slightly higher BER. Table 1 summarizes these SNR vs. BER comparisons.

TABLE I: SNR VS BER COMPARISON TABLE

Modulation Scheme	Low SNR (0–10 dB)	Medium SNR (10–20 dB)	High SNR (20–30 dB)	Overall BER Performance
CP-OFDM	Moderate BER, decreases slowly	Moderate decrease in BER	Steep drop after 20 dB	Average
DFT-s-OFDM	Best BER (low PAPR advantage)	Strong BER drop	Matches CP-OFDM at high SNR	Best at low/medium SNR
W-OFDM	Slightly better than CP-OFDM	Smoother BER reduction	Low BER like CP-OFDM	Better than CP-OFDM
FBMC	Poor at low SNR (>0.54 BER)	Best BER performance overall	Remains stable and low	Best overall
UPMC	Slightly better than FBMC at low SNR	Close to FBMC but slightly worse	BER stabilizes early	Second-best overall

B. SNR vs BER performance comparison OFDM Variant's for Rayleigh fading & AWGN channel

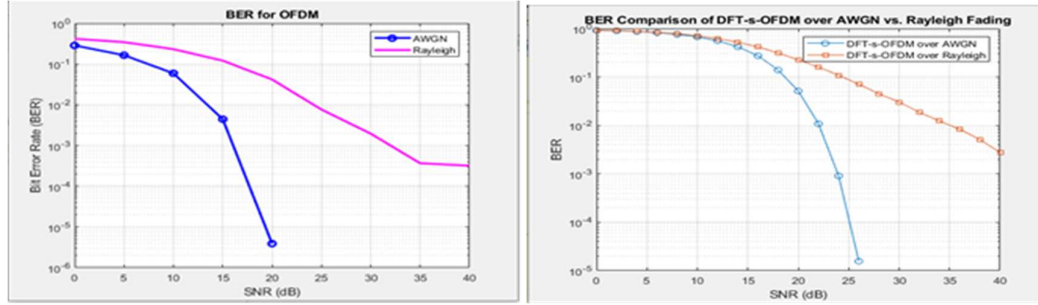


Figure .11. SNR vs BER Plot for CP-OFDM,DFT'S OFDM for Rayleigh fading and AWGN channel

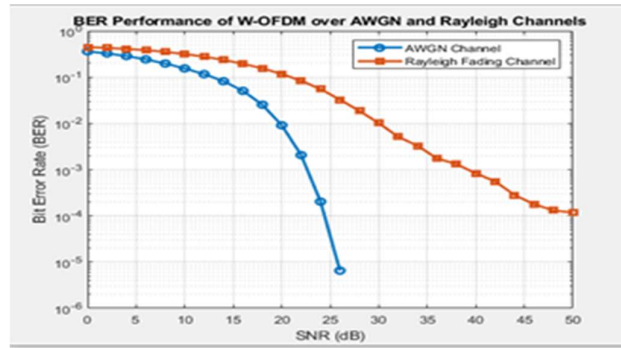


Figure.12 SNR vs BER Plot for W-OFDM For Rayleigh fading and AWGN channel.

From Fig 11 & 12 provides comparison of how Bit Error Rate (BER) varies with Signal-to-Noise Ratio (SNR) for two types of channels: AWGN (Additive White Gaussian Noise) and Rayleigh fading. In every graph, the BER decreases as the SNR increases, which is expected because a higher SNR means a cleaner signal with less noise. However, the rate at which BER improves depends on the modulation technique and the channel type [7][8].

In AWGN channel. all the modulation techniques perform better (lower BER) than in Rayleigh fading channels. This is because Rayleigh fading introduces more complex impairments like signal fading and multipath interference, making it harder to recover the transmitted data accurately.

DFT-s-OFDM, W-OFDM, and OFDM show significant improvement in BER with increasing SNR in both channels. Especially in AWGN, the BER drops sharply, which means these techniques are more efficient in noise-only environments [9].

TABLE II BER PERFORMANCE COMPARISONS OF OFDM VARIANTS (INCLUDING FBMC AND UFMC) OVER AWGN AND RAYLEIGH CHANNELS

Modulation Scheme	AWGN Channel	Rayleigh Fading Channel	Observation
CP-OFDM	BER drops rapidly after 10 dB, reaches $\sim 10^{-5}$ at 20 dB	BER drops slowly, $\sim 10^{-3}$ at 35 dB	Performs well in AWGN, degraded in Rayleigh due to multipath fading
DFT-s-OFDM	Best performance, BER $\approx 10^{-5}$ at 25 dB	BER drops gradually, reaches $\sim 10^{-3}$ at 40 dB	Best in AWGN due to low PAPR, slightly better than CP-OFDM in Rayleigh
W-OFDM	BER drops to $\sim 10^{-5}$ at 30 dB	Moderate improvement, BER $\approx 10^{-4}$ at 45 dB	Windowing helps reduce ICI, but Rayleigh fading still affects it
FBMC	Excellent performance, BER stays low and stable at high SNR	Still good, best in Rayleigh due to superior filtering	Best overall in Rayleigh, high robustness to multipath, but needs more computation
UFMC	Performs close to FBMC, slightly higher BER	Good in Rayleigh, better than OFDM variants	Sub-band filtering gives balanced performance in both channels

C. Power Spectral Efficiency Analysis of FBMC VS OFDM and UPMC VS OFDM.

The comparison of Power Spectral Density (PSD) between FBMC and OFDM shows that FBMC offers better spectral containment. FBMC has a sharper spectrum decay with minimal side lobes, reducing out-of-band radiation, unlike OFDM, which has broader side lobes and spectral leakage due to its sinc-shaped subcarriers. FBMC's improved frequency localization is due to well-designed prototype filters, making it more spectrally efficient and suitable for environments with strict interference control, like dynamic spectrum scenarios. Similarly, the PSD comparison between OFDM and UPMC shows that UPMC offers superior spectral efficiency, with sharp roll-offs and minimal out-of-band emissions, while OFDM has high side lobes leading to power leakage. UPMC's improved frequency localization makes it ideal for modern communication systems like 5G, which require efficient spectrum usage [10].

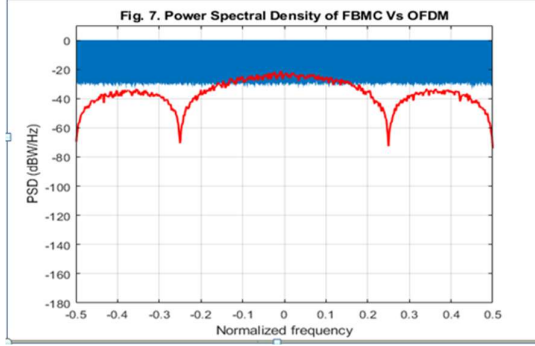


Figure .13. Power spectral density of FBMC Vs OFDM.

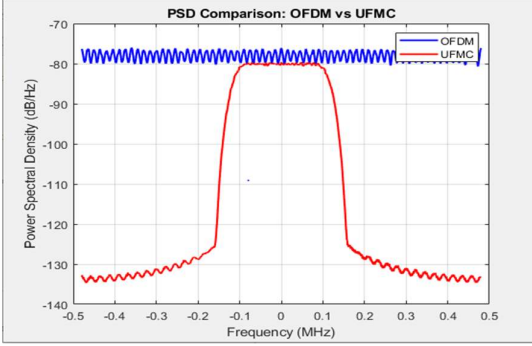


Figure .14. Power spectral density of UPMC VS OFDM

TABLE III: PSD COMPARISON OF OFDM, FBMC AND UPMC

Aspect	OFDM	UPMC	FBMC
PSD Shape	Flat in-band, high side lobes	Flat in-band, sharp roll-off outside band	Smooth and compact PSD
Spectral Leakage	High – significant side lobes outside main band	Low – side lobes decay quickly	Very low – minimal side lobes
Out-of-Band Emissions (OOBE)	High – spreads into adjacent channels	Lower – limited leakage into adjacent bands	Very low – excellent containment
Interference to Adjacent Channels	High – can cause interference	Reduced – less impact on neighbouring signals	Minimal – ideal for dense spectrum usage
Filtering Type	No filtering or windowing by default	Sub band-wise filtering (e.g., Dolph-Chebyshev)	Per-subcarrier filtering using prototype filter

D. Partial Transmit Sequence (PTS) Method for PAPR Reduction

TABLE IV: SAMPLE PAPR REDUCTION USING PTS (SIMULATED)

Modulation Scheme	PAPR without PTS (dB)	PAPR with PTS (dB)	PAPR Reduction (dB)	Notes
CP-OFDM	6.75	5.37	1.38	High gain due to large peaks
W-OFDM	9.04	6.92	2.12	Windowing + PTS synergize well
DFT-s-OFDM	4.62	4.27	0.35	Already low PAPR; moderate gain
FBMC	6.5	5.4	1.10	Less improvement due to smooth waveform
UPMC	9.6	6.20	3.40	Good results with sub band PTS

The Partial Transmit Sequence (PTS) technique is a method used to reduce the Peak-to-Average Power Ratio (PAPR) in multicarrier systems like OFDM by dividing the data block into sub-blocks and applying phase rotations to minimize signal peaks. The process involves transforming the data into the time domain using IFFT, partitioning it into sub-blocks, and multiplying each sub-block by a phase factor from a predefined set (e.g., $\{1, -$

$1, j, -j\}$). The sub-blocks are then summed, and the phase combination that results in the lowest PAPR is selected for transmission. PTS offers significant PAPR reduction without distorting the signal and can be applied to various multicarrier schemes like CP-OFDM, W-OFDM, UPMC, and FBMC. However, it comes with the drawbacks of high computational complexity and the need to transmit side information to the receiver. The technique is particularly effective for waveforms with high initial PAPR, such as UPMC and W-OFDM, making it a valuable tool for power-efficient 5G systems. Simulated results show that PTS achieves notable PAPR reduction, especially in UPMC and W-OFDM, with UPMC providing the best improvement of 3.40 dB [11][12].

V. CONCLUSION

This project presents a comparative evaluation of five multicarrier modulation schemes—CP-OFDM, W-OFDM, DFT-s-OFDM, FBMC, and UPMC—under AWGN channel conditions, considering Bit Error Rate (BER), Peak-to-Average Power Ratio (PAPR), and Power Spectral Density (PSD). Simulations show that CP-OFDM, though simple, suffers from high PAPR and spectral leakage, while W-OFDM offers modest spectral improvement with minimal BER gain. DFT-s-OFDM achieves the best BER and PAPR performance, making it suitable for uplink in mobile systems due to DFT precoding's energy spreading. FBMC and UPMC provide superior spectral containment but face BER limitations from filter complexity and synchronization issues, though their spectral efficiency makes them promising for future systems. Applying the Partial Transmit Sequence (PTS) technique reduced PAPR across all schemes, with significant improvement in CP-OFDM and W-OFDM and further optimization in DFT-s-OFDM and FBMC. Overall, DFT-s-OFDM offers the best BER-PAPR balance, FBMC and UPMC excel in spectral shaping, and PTS proves effective for general PAPR reduction.

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