
Review Article**A Comprehensive Review and Analysis on 5G based UPMC System****Divyasri Macha^{1,*}, Sruthi Vadlakonda², Kavya Durshanapally³, Nuneti Omkar⁴, Pinninti Kranthi Ranadev⁵ and Eegala Karthikeya⁶**¹⁻⁶ Student, Department of Electronics and Communication Engineering, Balaji Institute of Technology and Science, Warangal, Telangana, 506330, India.Corresponding Author: Divyasri Macha. Email: divyasrimacha2003@gmail.com

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Abstract: Wireless communication technology is pivotal in the advancement of mobile technology. Each user need an individual spectrum. Nonetheless, spectrum bands are finite. Consequently, the communication mechanism must be effective. The primary issues confronting Fifth Generation (5G) wireless networks encompass attaining superior spectrum efficiency, facilitating extensive connection, and enhancing throughput. A crucial factor in the design of the physical layer of the 5G wireless system to address these problems is the selection of an appropriate Multi-Carrier Modulation Scheme (MCM). The research indicates that the Universal Filtered Multi-Carrier (UPMC) approach is a superior contender for MCM, owing to its reduced complexity and enhanced frequency spectrum use. This project showcases simulations of the UPMC system over the Additive White Gaussian Noise (AWGN) channel. The performance of the UPMC system is evaluated for Peak-to-Average Power Ratio (PAPR), Power Spectral Density (PSD), and Bit Error Rate (BER).

Keywords: 5G, AWGN, OFDM, UPMC, PAPR, PSD, BER, SNR

1.Introduction

In recent times, wireless communication has grown more reliant on achieving high data transfer rates and fast transmission speeds. Wireless communication is becoming more popularity compared to high-speed conventional connections. With the growing demand for wireless applications and the exponential growth in the number of connected users [1], the present Wireless Communication Systems (WCSs) have reached their maximum capacity. To expedite the development of 5G wireless networks, it is essential to use solutions that utilize clever and efficient technology. Implementing a highly effective, dependable, and protected 5G network encounters several obstacles [1]. Wireless communication may degrade due to several factors, such as local scale fading, large scale fading, distortion, and HPA nonlinearities. In order to fulfill these requirements, a multiple carrier transmission is used instead of a single carrier transmission [2]. Recent estimates indicate that there is an anticipated 30% increase in data demand in the next years, beyond the capabilities of present technology to handle this growth. Hence, it is essential to cultivate WCSs of the future generation. The global deployment of 5G WCS is under underway. The medical profession, health sector, and educational sector are now seeing substantial increases in demand [3]. 5G mobile technology offers enhanced wireless speeds, improved security, and more accessibility.

The limits of 5G networks to provide an automated and immersive service are significant [4]. While 5G systems already surpass existing systems in some aspects, they will not be capable



of satisfying the requirements of future intelligent and automated concepts in a decade. The 5G network offers a greater range of features and a higher Quality of Service (QoS) compared to the 4G network. Key features of 5G include the incorporation of additional frequency bands, improved strategies for managing spectrum, and the integration of licensed and unlicensed channels [4-5]. 5G offers enhanced power efficiency, reduced overhead, and improved signal synchronization compared to existing technologies. Additionally, it facilitates the success of applications such as the Internet of Things (IoT)[6-9] and machine-to-machine communication.

For many years, multicarrier modulation (MCM) has played a crucial role in the development of broadband communication systems. MCM is a method of carrying several streams of information simultaneously in different frequency ranges. This technique has been shown to be very effective in transferring huge volumes of data and provides increased resistance to many types of signal degradation [10-11]. In the 4G technology LTE, data is transmitted by using a significant quantity of closely positioned orthogonal subcarriers [12]. The inclusion of a guard band is not a prerequisite for the segregation of distinct subcarriers. In the context of OFDM, a CP is appended to each symbol as additional bits. By introducing the CP, the interference between symbols is eliminated, resulting in circular convolution [13]. The presence of the CP leads to a reduction in spectral efficiency. OFDM also exhibits a high PAPR. The OFDM technology is not suitable for 5G owing to its significant limitations. There is a need for the implementation of new methods like UFMC [14]. A UFMC filter mitigates OoB emissions by selectively filtering a set of subcarriers. Thanks to the filter's broad frequency range and its quick reaction time, it can achieve a high level of spectral efficiency (SE) in brief bursts, since it covers several subcarriers within its bandwidth. In UFMC, the absence of a CP allows for the filters to be created with a total block length that is comparable to that of CPOFDM. UFMC does not have a need for CP, making it susceptible to slight temporal misalignments [15].

2. Universal Filtered Multi-Carrier (UFMC)

UFMC is a multi-carrier modulation technique designed to reduce OOB emissions and improve SE, making it ideal for 5G and beyond wireless communications. It applies filtering to groups of subcarriers (sub-bands), combining some advantages of OFDM and (FBMC) Filter Bank Multi-Carrier [16-20]. The primary operation of UFMC involves dividing the frequency band into multiple sub-bands, applying filtering to each sub-band, and then combining the filtered outputs for transmission.

- **Data Source (Input Bits):** The incoming data stream is divided into smaller data blocks for parallel processing across different sub-bands.
- **Modulation:** The data bits are modulated using a suitable modulation scheme like Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK). Each modulated symbol corresponds to a point in the complex plane.
- **Serial-to-Parallel (S/P) Conversion:** The modulated data is split into parallel streams, which will be assigned to different sub-bands for further processing.
- **Inverse Fast Fourier Transform (IFFT):** The parallel data streams are then transformed from the frequency domain to the time domain using the IFFT block. Each sub-band contains multiple subcarriers, and IFFT helps in creating the multi-carrier signal.
- **Filtering (Sub-Band Filtering):** Unlike OFDM, UFMC applies filtering to groups of subcarriers rather than the entire band. The filter is designed to reduce the OoB emissions of the sub-band and minimize inter-band interference. Filters, such as Dolph-Chebyshev filters, are typically used here for efficient spectral shaping.

- **Summation (Combining Sub-bands):** After filtering, all the sub-bands are combined to form the final time-domain signal that will be transmitted over the channel. The summation results in a signal that efficiently uses the spectrum with minimal interference between sub-bands.
- **Digital-to-Analog Conversion (DAC):** The digital signal is then converted to an analog signal for transmission.
- **Transmission Over Channel:** The final signal is transmitted over a wireless channel to the receiver.

In the receiver, a similar process occurs in reverse: Analog-to-Digital Conversion (ADC), sub-band filtering, FFT, demodulation, and decoding of the received bits. Filtering per sub-band allows UFMC to achieve better spectral containment and reduced latency compared to traditional OFDM. The elimination of the CP, as used in OFDM, improves SE and reduces overhead. UFMC improves spectral efficiency and robustness while reducing latency and OoB emissions compared to OFDM, making it more suitable for 5G and beyond systems.

The key steps in the UFMC signal generation process are:

- Modulation of data symbols across subcarriers.
- Grouping subcarriers into sub-bands.
- Applying filtering to each sub-band.
- Summing the filtered sub-bands to form the final UFMC signal.

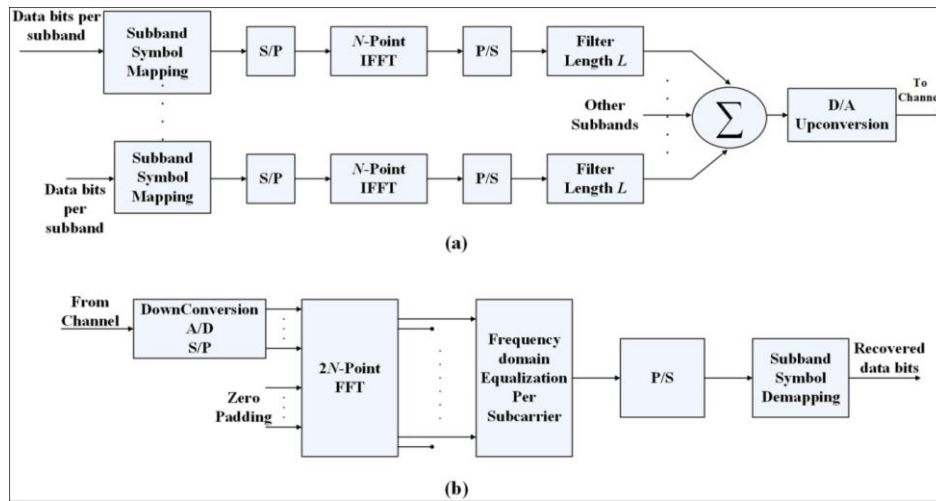


Figure 1: UFMC - Block Diagram

The transmitted UFMC signal can be represented as a summation of multiple filtered sub-bands. Consider a multi-carrier signal where data is divided into N subcarriers, grouped into M sub-bands. Each sub-band is filtered to reduce interference and OoB emissions. The UFMC signal in the time domain is given by:

$$x(t) = \sum_{m=0}^{M-1} \sum_{k=0}^{K-1} S_{m,k}(t) * h_m(t) \quad (1)$$

The subcarriers in each sub-band are modulated using QAM or PSK. The data symbols are modulated as:

$$S_{m,k}(t) = \sum_{n=0}^{N-1} d_{m,k}[n] e^{j2\pi f_{m,k}t} g(t-nT) \quad (2)$$

For each sub-band, a filter is applied to reduce inter-band interference and improve spectral containment. The filter is designed to confine the sub-band's spectrum and reduce OoB emissions. The filtered signal for sub-band m is:

$$x_m(t) = s_m(t) * h_m(t) \quad (3)$$

The UPMC signal is the summation of the filtered sub-band signals across all sub-bands:

$$x(t) = \sum_{m=0}^{M-1} x_m(t) \quad (4)$$

The filtering operation can be described in the frequency domain as a multiplication of the sub-band signal $S_m(f)$ with the filter response $H_m(f)$:

$$X_m(f) = S_m(f) \cdot H_m(f) \quad (5)$$

After modulating the data symbols and applying the sub-band filtering, the entire signal is transformed back into the time domain using the IFFT. The IFFT operation for M sub-bands and K_m subcarriers per sub-band is:

$$S_{m,k}(t) = IFFT[d_{m,k}] \quad (6)$$

This produces the time-domain signal that is filtered and transmitted.

Where $x(t)$ is the UPMC time-domain signal, $s_{m,k}(t)$ is the time-domain signal corresponding to the k^{th} subcarrier in the m^{th} sub-band, modulated by the data symbols, $h_m(t)$ is the filter applied to the m^{th} sub-band to control OOB emissions, M is the number of sub-bands, K_m is the number of subcarriers in the m^{th} sub-band, * denotes convolution, $d_{m,k}[n]$ are the modulated data symbols for subcarrier k in sub-band m, $f_{m,k}$ is the frequency of the k^{th} subcarrier in the m^{th} sub-band, $g(t)$ is the pulse shaping function (rectangular for UPMC), T is the symbol duration, N is the number of data symbols transmitted, $s_m(t)$ is the sum of all subcarrier signals in the m^{th} sub-band, $h_m(t)$ is the filter applied to the m^{th} sub-band, $x_m(t)$ is the filtered signal from the m^{th} sub-band, $S_m(f)$ is the frequency-domain representation of the sub-band signal, $H_m(f)$ is the frequency-domain representation of the filter for sub-band m.

Key Advantages:

- **Low latency:** UPMC reduces latency by eliminating CP and using shorter filters compared to FBMC.
- **SE:** Better management of OoB emissions allows for closer packing of users in frequency.
- **Flexibility:** UPMC can work with fragmented spectrum, making it ideal for IoT, M2M, and other 5G scenarios.

Challenges:

- **Complexity:** Filtering each sub-band adds some complexity compared to simpler OFDM systems.
- **Interference management:** UPMC can still suffer from inter-subband interference if not carefully managed.
- **Applications:** UPMC has been considered for various 5G applications, including massive IoT, V2X communications, and enhanced mobile broadband (eMBB).

Recently, there has been substantial development and extensive research to assess the

compatibility of the UPMC waveform for 5G communication networks [21]. Figure 2 visually illustrates the conceptual representation of the UPMC waveform. The shown diagram illustrates the division of the whole bandwidth into many sub-bands. Every sub-band consists of a certain quantity of orthogonal sub-carriers. The sub-bands undergo filtering in order to decrease the emissions that occur outside of the desired frequency range, known as OoB emissions. The filtering procedure also greatly decreases the length of the filter compared to other 5G solutions presented in the literature. In addition, sub-band filtering provides versatility in design and minimizes inter-symbol interference (ISI). Therefore, the UPMC waveform is considered the most favorable option for short-burst communications [22]. The UPMC waveform is known for its high SE, which is achieved by not using a CP. However, despite this advantage, the UPMC waveform still suffers from a significant downside in terms of spectral inefficiency. This limitation makes it impractical for the future 5G communication networks and beyond [23]. Hence, a thorough examination and enhanced design are necessary to address the issue of spectral inefficiency in the basic UPMC waveform.

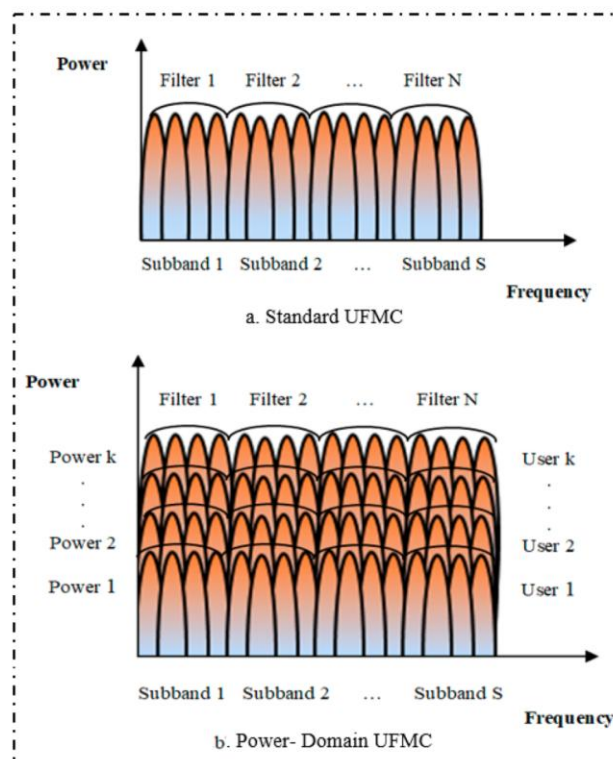


Figure 2: UPMC waveform and power-domain UPMC waveform

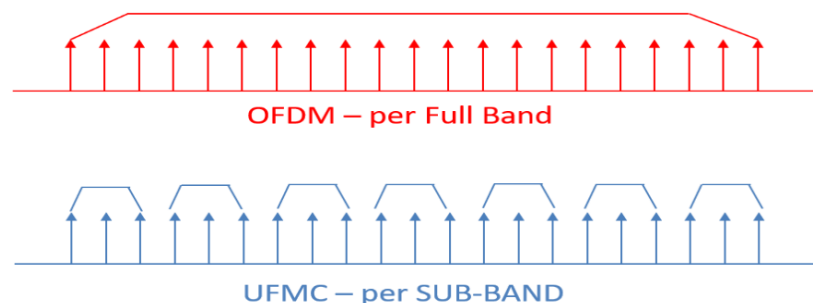


Figure 3: Filtering methods in UPMC**Table 1: OFDM vs UPMC [24]**

Parameter	OFDM	UPMC
SE	Lower (due to CP and OoB)	Higher (no CP, filtered sub-bands)
OoB Emissions	Higher (requires guard bands)	Lower (filtered sub-bands)
Filtering	None (uses CP)	Sub-band filtering
Latency	Higher	Lower
Robustness to Errors	Lower	Higher
Complexity	Lower	Slightly higher
Applications	4G, LTE, Wi-Fi	5G, IoT, M2M

3. 5G Support in UPMC

5G networks aim to support a wide range of applications and services, from enhanced mobile broadband (eMBB) to massive machine-type communications (mMTC) and ultra-reliable low-latency communications (URLLC). The UPMC technique is one of the modulation schemes proposed to address some of the key challenges in 5G [25-27].

Table 2: 5G in UPMC

Parameter	5G Requirement	UPMC Contribution
Improved SE	5G requires highly efficient use of spectrum to accommodate high data rates and dense user environments.	UPMC improves SE by eliminating the need for a CP, which is used in OFDM to combat ISI. By applying filters to sub-bands, UPMC reduces OOB emissions, allowing more efficient use of fragmented spectrum and closer packing of users in frequency. This is ideal for 5G, where spectrum is often non-contiguous.
Low Latency	5G targets ultra-low latency, especially for applications like URLLC, autonomous driving, and industrial automation [25].	UPMC eliminates the CP, reducing latency compared to traditional OFDM. Additionally, UPMC uses shorter filtering windows, which also contributes to lower latency, making it suitable for delay-sensitive applications in 5G [29].
Robustness to Synchronization Errors	5G must handle challenging environments, such as high mobility (e.g., V2X communications), where synchronization issues (timing and frequency offset) can degrade performance.	UPMC is more robust to synchronization errors compared to OFDM. The sub-band filtering in UPMC reduces inter-carrier interference (ICI) caused by timing and frequency misalignments, which makes UPMC a good fit for 5G use cases involving high mobility or distributed users.
Flexibility for Different Use Cases	5G needs to support a diverse set of applications, from eMBB (high data rates) to mMTC (massive IoT deployments) and URLLC [26] (low-latency, high-reliability communication).	UPMC can operate efficiently across different use cases: In eMBB, it provides high data rates and efficient spectrum use. For mMTC, UPMC can handle fragmented spectrum and support large numbers of low-power IoT devices. For URLLC, its low-latency characteristics and robustness to errors ensure reliable communication.
Support for Fragmented Spectrum	With 5G, the spectrum is often fragmented, especially when different frequency bands are aggregated (e.g., in IoT [28] or licensed/unlicensed spectrum scenarios).	UPMC can operate in fragmented spectrum environments by applying filtering at the sub-band level. This makes it possible to efficiently use non-contiguous bands and provide high performance in a spectrum-constrained environment, which is common in 5G.

Compatibility with Massive MIMO	5G uses Massive MIMO technology to enhance capacity and spectral efficiency.	UFMC, due to its low OoB emissions and efficient filtering, works well with Massive MIMO systems. It reduces interference between multiple users, improving overall system capacity, which is crucial in 5G's massive MIMO deployments.
Reduced Power Consumption	Power efficiency is important in 5G, especially for IoT devices that need to operate for long periods on limited battery power [27].	UFMC is more power-efficient than OFDM, as it doesn't require a CP and uses more localized filtering. This makes it suitable for power-sensitive applications, like IoT devices in the mMTC use case.
Lower Complexity than FBMC	The complexity of the modulation scheme should be manageable, even for edge devices with limited processing power.	UFMC offers a good trade-off between performance and complexity. While FBMC has excellent spectral characteristics, its complexity is higher. UFMC uses shorter and simpler filters than FBMC, making it more practical for 5G implementations where lower complexity is desirable.

UFMC is a promising candidate for 5G networks due to its flexibility, low latency, SE, and robustness to synchronization errors. It aligns well with 5G's diverse use cases, such as IoT, enhanced broadband, and low-latency applications, making it a potential modulation technique for next-generation wireless systems.

4.Simulation Results

This section covers the analysis and assessment of UFMC's performance assessments. MATLAB has been used to assess the efficacy of UFMC. Table 3 contains the simulation parameters.

Table 3: Simulation Parameters

Simulation Parameter	Value
Simulation tool	MAT Lab
No. of FFT points	512, 1024
No. of Sub-bands	10
Sub-band Offset	156
Filter Length	43
Modulation	16 - QAM
Filter	Dolph-Chebyshev filter
Sub-band Size	20

Figure 4 displays the Power Spectral Density (PSD) of UFMC. The spectrum depicts the overlaying of 10 UFMC sub bands, with each band consisting of 40 subcarriers that transmit 16QAM data symbols. The PSD of UFMC refers to the distribution of power over the frequency spectrum for a UFMC signal. UFMC is a multi-carrier modulation technique designed for 5G and beyond wireless communication systems, combining elements from both OFDM and FBMC. UFMC is often regarded as an enhanced version of OFDM that improves spectral efficiency and reduces OoB emissions by applying filtering to groups of subcarriers. The PSD of UFMC demonstrates a cleaner, more efficient use of spectrum with reduced interference outside the desired frequency band, making it a favorable modulation scheme for future communication systems.

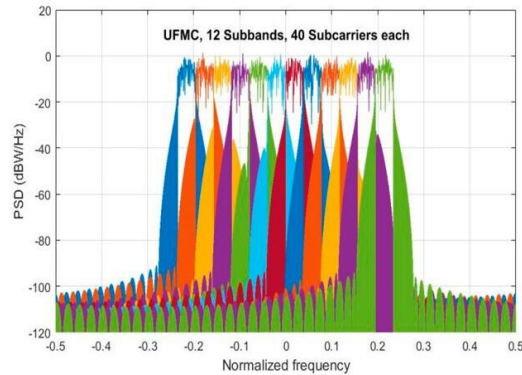


Figure 4: PSD of UPMC

The SE of UPMC refers to how efficiently the system uses the available bandwidth to transmit information. It is typically measured in bits per second per Hertz (bps/Hz). UPMC is designed to improve SE, especially in environments with stringent interference constraints, compared to traditional OFDM. The SE of UPMC is shown in figure 5. The SE of UPMC is higher than that of OFDM, primarily due to reduced OoB emissions and better spectral localization, making it a more efficient candidate for future wireless communication systems such as 5G and beyond. Its flexible filtering of sub-bands, reduced guard band requirements, and lower latency contribute to its higher spectral efficiency, offering more data transmission within a given bandwidth.

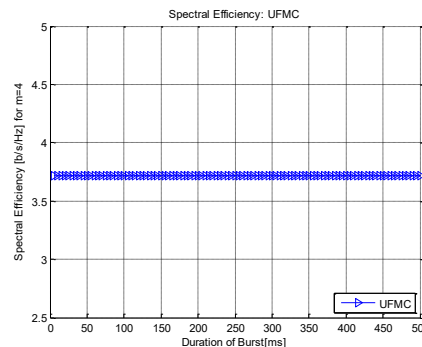


Figure 5: Spectral Efficiency

Table 4 and Figure 6 provide a comparison of the SNR and the BER for the UPMC system using the 16-QAM modulation scheme on an AWGN channel. The relationship between SNR and BER is fundamental in communication systems, including UPMC. This relation helps to evaluate the performance of UPMC in terms of data transmission accuracy and system reliability under varying noise conditions. The SNR-BER relationship in UPMC shows that higher SNR leads to lower BER, as with other communication schemes. The use of filtering in UPMC reduces interference, improving SNR and resulting in a lower BER compared to traditional OFDM. The performance of UPMC is particularly favorable in noisy and interference-prone environments, where its SE and filtering offer a clear advantage. Thus, UPMC achieves better BER performance for a given SNR compared to less spectrally efficient methods.

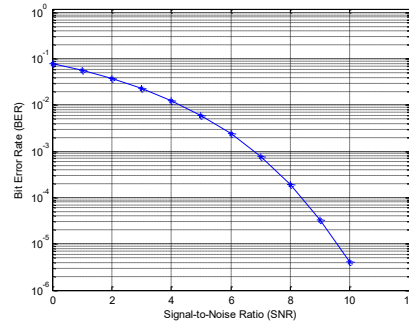


Figure 6: SNR vs BER

Figure 7 gives PAPR analysis of UPMC. The PAPR in UPMC refers to the ratio between the highest power peak of the transmitted signal and its average power. PAPR is a crucial parameter in multicarrier modulation schemes, as it affects the power efficiency of the system, especially when using power amplifiers. PAPR is defined as the ratio of the peak power to the average power of the transmitted signal. Power amplifiers (PAs) are usually operated in the linear region for efficiency. However, if the PAPR is too high, the signal peaks may drive the PA into the non-linear region, causing signal distortion (clipping) and spectral regrowth (interference with adjacent bands). High PAPR reduces the power efficiency of the system because the PA must be operated with a backoff (reduction in power) to avoid clipping. This means that the average transmit power must be reduced, limiting the range and coverage of the transmission. PAPR is the ratio of peak power to average power in a transmitted signal. High PAPR is a problem in UPMC due to the superposition of multiple subcarriers, which can result in power peaks that distort the signal and reduce power efficiency. While UPMC's filtering improves spectral efficiency and reduces out-of-band emissions, it does not inherently reduce PAPR compared to other multi-carrier schemes like OFDM. Various PAPR reduction techniques are used in UPMC to improve power efficiency and reduce signal distortion, ensuring more reliable and energy-efficient communication.

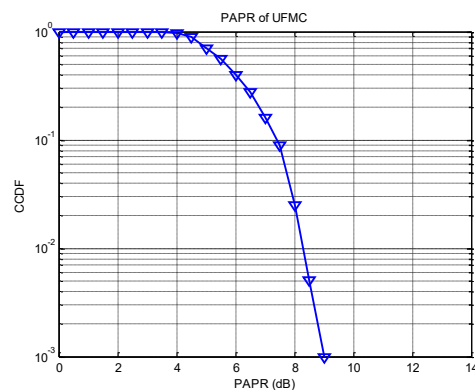


Figure 7: PAPR analysis of UPMC

Table 4: UPMC: PAPR Analysis

No. of FFT points	Modulation	PAPR (dB)
512	4QAM	9.0473
512	16QAM	8.2379
512	64QAM	8.6229

512	256QAM	8.0416
1024	4QAM	7.7732
1024	16QAM	8.2967
1024	64QAM	9.6202
1024	256QAM	7.5373

5. Conclusion

OFDM is a method used in 4G technology that has some drawbacks, including a high PAPR and poor spectrum efficiency. The UFMC addresses these limitations. UFMC offers superior spectral efficiency for 5G networks compared to LTE-Advanced networks that use OFDM technology. UFMC does not need the use of a CP. UFMC enables higher data transmission speeds, resulting in enhanced protection against inter-symbol interference. This article examines the PSD, SE, PAPR, BER and SNR of UFMC. The UFMC waveform has superior spectrum efficiency, making it a more suitable choice for 5G communication. Sub-band filtering is used in UFMC to decrease the OoB Emission. QAM modulation may be used to provide MIMO compatibility in a UFMC transmission. UFMC waveform is used for asynchronous transmissions in 5G cellular networks.

6. Future Scope

The UFMC system, as reviewed and analyzed in this study, stands as a promising candidate for future wireless communication technologies, especially in the context of 5G, 6G, and beyond. Despite its numerous advantages, including low OoB emissions and improved SE over conventional OFDM, several areas remain open for exploration. One significant direction is the integration of UFMC with emerging 6G technologies such as terahertz communications, massive MIMO, and intelligent reflecting surfaces, where its filtering flexibility can be leveraged for performance optimization. Furthermore, the application of artificial intelligence and machine learning for dynamic filter design, adaptive modulation, and intelligent resource allocation in UFMC systems could offer breakthroughs in efficiency and reliability. Practical challenges such as hardware implementation, real-time processing, and energy-efficient designs also present key opportunities for future research. Additionally, UFMC's potential in IoT and IIoT networks, due to its robustness to synchronization errors and latency tolerance, warrants deeper investigation. Lastly, security enhancements and comparative evaluations with newer waveforms like OTFS and GFDM will be crucial in determining its long-term viability and standardization prospects.

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