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RESEARCH ARTICLE

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Performance Analysis of Various Modulation Schemes for 5G Technology

Prathyusha V[1*], E.Sreenivasa Rao[2]

[1]Research Scholar, Department of Electronics and Comm. Engg.,University college of Engineering, Osmania University, Hyderabad-500007.

[2]Professor & HOD, Department of Electronics and Comm. Engg., Vasavi college of engineering, Hyderabad.

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Abstract

The upgrade to 4G was necessary due to the rapid growth of wireless applications. 5G had been launched with significant capacity, minimal latency, enhanced dependability, and higher quality of services (QoS). 4G Technology uses orthogonal frequency-division multiplexing (OFDM), a communication technique that effectively eliminates inter-symbol interference (ISI) and enhances the SNR, resulting in reliable long-distance communications. However, it suffers from a drawback of inefficient spectrum utilisation. However, the enhanced data ratecan be achieved by utilising a spectrum. 5G implemented various strategies to optimise spectrum use in present situations. One of the newer types of waveforms includes the filtered -OFDM), universal filtered multicarrier (UFMC), as well as filter bank multicarrier (FBMC). The research study aims to conduct a comparative analysis of the recommended 5G modulation techniques, namely FBMC and UFMC, compared to OFDM, the modulation technology employed throughout 4G communications. We evaluate the essential characteristics of these modulation approaches to assess the advantages of every option. The evaluation encompasses the characteristics of Power Spectral Density (PSD), Bit Error Rate (BER), Spectral Efficiency (SE) and Peak-to-Average Power Ratio (PAPR). The research has been executed via MATLAB.

Author's e-mail: prathyusha.velijala@gmail.com, e.sreenivasarao@staff.vce.ac.in

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Introduction

The proliferation of mobile devices within contemporary society has significantly increased the burden placed on preexisting communication networks. To accommodate the continuously growing mobile traffic, it is increasingly imperative for these networks to enhance their data rates and stability. The implementation of 4G technology resulted in notable enhancements in data transmission speed and network dependability. The OFDM modulation technology employed in 4G networks exhibits a remarkable capacity for achieving exceptionally high data transmission rates. Nevertheless, the employment of cyclic prefixes and guard bands as a means to mitigate excessive side lobes leads to a reduction in spectral effectiveness by around 16% compared to the ideal conceptual performance. OFDM has been widely recognised as a suitable option for communication between points in the context of 4G networks.[2] However, it is essential to acknowledge that OFDM does have certain limitations.

i. The OFDM technique necessitates precise synchronisation with a user node and the Base Station (BS).[3] However, achieving this synchronisation is challenging due to the dynamic nature of the mobile network, namely the Doppler shift experienced by numerous users.[4] The problem can be addressed by utilising multi-user cancellation methods.[5-8] However, the implementation of such methods might be complex and challenging. One of the primary characteristics, namely simplicity, of Orthogonal Frequency Division Multiplexing (OFDM) would be compromised.

ii. The OFDM technique incorporates carrier aggregating,[9] which refers to the suboptimal performance of sub-carrier filtering in the IFFT/FFT filtering bank. The inadequate performance of sub-carrier filtration results in the generation of egress noise on the consumers. This phenomenon can be mitigated using side-lobe suppressing strategies.[10-11]

However, it should be noted that the implementation of these methods introduces intricacy to the transmitter system and results in a reduction in the efficiency of bandwidth. In order to obtain accurate results, the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform(IFFT) must be precisely aligned. Nevertheless, the phenomenon of propagation of multiple paths results in the occurrence of overlaps among multi-carrier symbols at the receiver's end. The demodulation process of the signal may encounter difficulties due to the presence of ISI.This issue can be resolved.

i. The utilisation of this technique in OFDM remains attributed to the increase in the length of the guard band and symbol frequency.[12]

ii. The notion of utilising further processing, namely a bank of filters, in conjunction with the FFT while maintaining the symbol duration and timing described in reference[13] is employed in implementing FBMC technology.

Numerous modulation schemes have been suggested as potential solutions to address the limitations of the OFDM approach. Despite the considerable success and several advantages of OFDM, a range of novel 5G waveform concepts have the potential to offer supplementary benefits to the emerging mobile system, given specific scenarios and conditions. The prospective demand encompasses the need for high-speed data transfer, minimal latency, and energy-efficient communications. Various modulation schemes for implementing 5G technology are currently under consideration. The techniques above encompass FBMC, UFMC, and OFDM.

FBMC presents itself as a viable alternative to OFDM. It achieves a more efficient reduction of both ingress noise and egress noise by utilising high-quality filters. Furthermore, it can mitigate the issue of synchronisation. The previous communication system employs CP- OFDM, which suffers from a reduced spectral efficiency (SE) caused by including a cyclic prefix (CP), elevated levels of out-of-band radiation, and heightened susceptibility to narrow- band disturbances. In order to attain the desired outcome, sub-channels of FBMC were devised, exhibiting efficient spectrum management capabilities.

Additionally, this approach will eliminate the potential for cognitive dissonance and enhance self-efficacy. The filter bank of FBMC has been developed to meet reception requirements alongside selectivity by providing adequate band isolation, which includes adequate out-of- band attenuation of the sub-filters. FBMC achieves spectral separation of all the assigned sub- channels if an unoccupied sub-channels exists between the assigned sub-channels. Consequently, users can optionally synchronise prior to the communication of the sub-carrier. The concept suggested for future networks has a high dynamism and vitality. FBMC also can perform spectrum detection and transmission functions concurrently on a single device.[14- 17]

Literature Review

Ravindran and Viswakumar (2018) compared the CP-OFDM waveform used in different 4G systems and the UFMC and FBMC waveforms used in 5G systems based on offset-QAM. Thepresent 4G multicarrier technology, CP-OFDM, has many issues. In the context of OFDM, using a CP mitigates the impact of multipath propagation, hence reducing both ISI and ICI. However, it should be noted that including a CP also decreases the effective use of the available spectrum. Furthermore, the CP-OFDM exhibits a high PAPR and a notable out-of-band (OOB) emission compared to neighbouring sidebands.

In their study, Wang et al.[19] examined the effectiveness of the Bayesian compressive sensing (BCS) approach for estimating the MIMO channel in FBMC/OQAM systems. The BCS channel estimating technique proved to be a reliable method for precisely measuring the channel impulse response. Subsequently, the criteria for terminating the iterative process were enhanced, resulting in the development of an improved FBMP algorithm. The simulation results indicated that the suggested strategy outperformed standard compressive sensing methods, as reflected by reduced MSE and BER values.

Essiben et al.[20] published performance studies of multicarrier modulation systems such as FBMC, F-OFDM, and UFMC. Simulation evidence suggests that FBMC may be a superior alternative to OFDM. The FBMC is the most optimal option because of its efficient design and the values obtained from PAPR and PSD. Nevertheless, the research emphasized that a comprehensive performance evaluation requires the computation of the Rayleigh and Rician Fading Channel, the BER in Additive White Gaussian Noise (AWGN), and the complementary cumulative distribution function.

Venu et al.[21] compared two 5G modulation techniques, FBMC and OFDM. The simulation findings indicate that FBMC modulation outperformed OFDM modulation regarding BER, PAPR, SE, and Spectral Density. Hence, FBMC proves to be a superior communication technique compared to OFDM.

Adoum et al.[22] state that future-generation networks must achieve several key objectives. These include providing a significantly higher level of data transfer per user, optimal energy efficiency, improved spectrum efficiency, and extremely low latency. Therefore, it is recommended to provide new waveforms, access techniques, and modulation approaches to facilitate these technological developments. This research concisely describes the many kinds of waveforms used in 5G, B5G, and 6G technologies. The transmission technologies used in 5G, OFDM include GFDM, FBMC, UFMC, and IM. The research stressed the need for future mobile networks' radio interfaces to be adaptive and optimize the use of current frequency resources in order to meet these requirements.

Abbas et al.[23] found that OQAM encountered imaginary inter-symbol/inter-carrier interference, posing challenges for signal processing tasks such as Channel Estimation (CE). This study investigated channel estimation techniques using different channels and prototype filters. Additionally, a comparison was provided between several estimation methodologies and alternative FBMC approaches. The comparative analysis of the research facilitated comprehension of the most effective strategy for channel equalization about MSE, BER, and Signal-to-Noise Ratio (SNR), as well as the previously or currently used approaches for channel equalization. Moreover, this research provided a prospective assessment based on the scrutinized technologies.

Table 1: Displays a fundamental examination of FBMC and OFDM, as referenced in.[24]

Property	OFDM	FBMC
Cyclic Prefix Extension	Cyclic prefix is required in OFDM and this sacrifices the Bandwidth	Cyclic prefix not required and this conserves the bandwidth
Sidelobes	Large and interfering sidelobes	Low sidelobes
Synchronisation	For correct detection, multiple access interference (MAI) cancellation should be performed at the receiver	MAI is repressed due to excellent frequency localisation of the subcarriers
Doppler Effect	Highly sensitive to carrier frequency offset	Less sensitive and hence performs significantly with the increase of the user mobility
MIMO Systems	High flexibility while adopting MIMO techniques	Limited flexibility
Spectrum Sensing	Degraded spectrum sensing performance due to spectral leakage problem in OFDM	High spectrum sensing resolution
Computational Complexity	It has very low complexity	It has high complexity

In this analysis, we compare the FBMC and UFMC modulation strategies about the established OFDM approach.

Design Aspects of Various Techniques

OFDM:

OFDM is a transmission technique that utilises multiple carriers, with each frequency band divided into distinct sub-channels. Multiplexing systems commonly employ numerous filters to mitigate interference between sub-carriers, ensuring they do not overlap and maintaining a minimum frequency gap. In contrast, OFDM employs signal processing methodologies to address this concern effectively effectively. Additionally, the sub-carriers in OFDM possess orthogonality properties, hence obviating the requirement for several filters. The OFDM system comprises a transmitter and receiver, as shown in Figure 1. They employ various modulation techniques to assign the signal to an appropriate constellation. They subsequently transformed the serial data into a parallel data stream upon which OFDM is used. The system comprises a set of N subcarriers responsible for carrying the symbols. The OFDM transmitter incorporates an IFFT block.

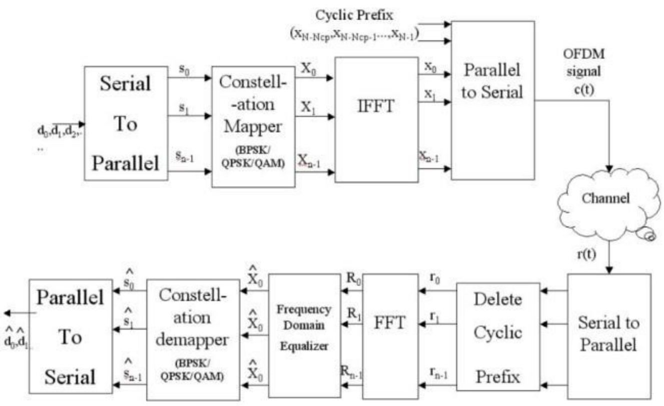

Fig. 1: OFDM Model

The addition of a CP to the output signal is employed as a means to mitigate ISI. Subsequently, the data undergoes processing to provide a sequential output that is transmitted across the respective communication channel. Upon reaching the receiver, the data undergoes a conversion process to parallel input, and subsequently, the PC is eliminated. The given data is subsequently subjected to FFT. The expression for the frequency domain output in the k^{th}receiver sub-carrier can be obtained by

$$F(K) = \sum_{n=0}^{N-1} f(n) \exp\left(\frac{-j2\pi kn}{N}\right) \quad ......(1)$$

UFMC

The UFMC modulation scheme is widely regarded as an extension of Filtered OFDM and FBMC modulations, encompassing their fundamental principles and characteristics. In the context of wireless communication systems, filtering is employed in many modulation schemes. Specifically, in filtered OFDM, the whole band has been subjected to filtering. On the other hand, in the FBMC, every single sub-carrier undergoes individual filtering. Lastly, inUFMC, sub-carrier groupings, referred to as sub-bands, are filtered. The utilisation of sub-carrier grouping enables the reduction of filter length compared to FBMC.

Furthermore, it is worth noting that UFMC cancan utilise QAM, a modulation technique compatible with current MIMO schemes. The complete set of sub-carriers (N) has been divided into sub-bands. Each sub-band has characteristics defined by a predetermined quantity of sub- carriers, and it is not mandatory to utilise all sub-bands for a specific transmission. A discrete IFFT is calculated for everyevery sub-band, including zero values for the carriers that have not been allotted. The signal in each sub-band undergoes filtration using a filter of length L, and the resulting responses from the various sub-bands are combined using summation.

Filtering is employed in order to decrease the spectral emissions that occur beyond the desiredfrequency range. Various filters can be created for each sub-band, but a uniform filter is employed throughout this particular instance throughout all sub-bands. A Chebyshev window with a parameterised side-lobe attenuation has been used for filtering the output of the IFFT in each sub-band. The UFMC modulation transmitter scheme has been depicted in Figure 2. The following illustration shows the fundamental UFMC receiving processing, that depends on FFT, similar to OFDM. The application of sub-band filtration results in the expansion of the receiving time window to the length that is the next power-of-two for the subsequent FFT operation. Each alternative frequency value is associated with a sub-carrier major lobe. Pre- sub-carrier equalisation is commonly employed in standard situations to equalise the combined impact of the channel's bandwidth and sub-band filtration. In this particular instance, solely the sub-band filter has become subjected to equalisation, as the absence of channel effects precludes their inclusion in the model. The procedure at the receiving end is depicted in Figure3.

The utilisation of UFMC has been seen as favourable when compared to OFDM due to its ability to provide improved spectrum efficiency. The utilisation of sub-band filtering offers advantages such as the reduction of guard intervals between sub-bands and the decrease in filterlength. These characteristics render this technique appealing for applications involving short bursts. The aforementioned characteristic also renders it appealing when compared to FBMC, considering with significantly greater filter length.

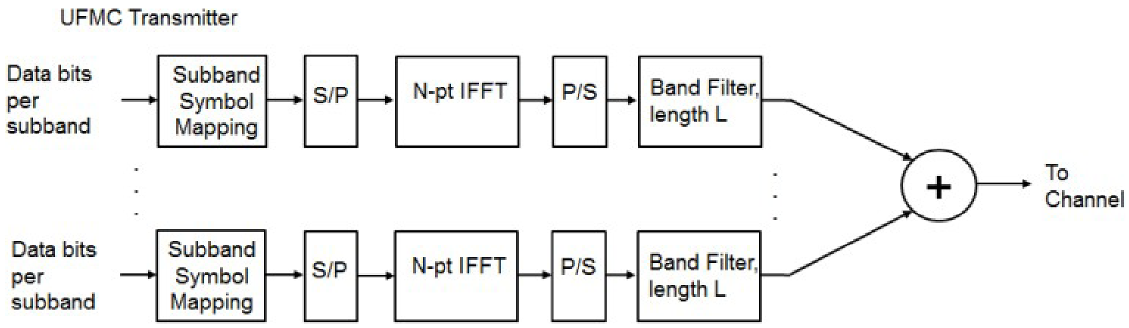

Fig. 2: UFMC Transmitter

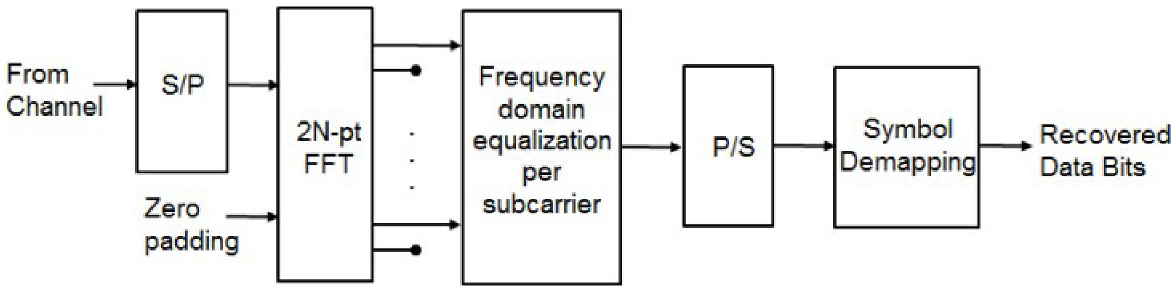

Fig. 3: UFMC Receiver

FBMC

FBMC is a technique employed in multi-carrier systems to filter every sub-carrier in a modulated signal. The prototype filter is employed by the zero frequency carrier and serves as the foundation for the remaining sub-carrier filters. The filters exhibit a distinctive attribute known as the overlapping factor, denoted as K, that reflects the quantity of multi-carrier symbols which overlap inside the temporal domain. FBMC is a category of multi-carrier systems in which the IFFT and FFT can be employed as multicarrier modulators and demodulators, correspondingly. The final result of the IFFT can be described mathematicallyas

$$x(n) = \sum_{j=0}^{M-1} X_j(mM) e^{i2\pi \frac{j(n-mN)}{M}} \quad \ldots (2)$$

where M - IFFT size and data samples of M , where mM ≤ n ≤ (m + 1)M

$X_j(mM)$ - input of the IFFT for 0 ≤ j ≤ M - 1.

"m" represents the symbol index, and the collection of "M" samples represents the multi-carrier symbol. The following multi-carrier symbols are unlikely to overlap in the temporally domain, therefore make note of this. FFT operations are carried out by FBMC in the receiver, and the FFT's output is outlined as.

$$K(nM)\ \frac{1}{2}\frac{2-j(nM+M-1)}{2n=mM}\frac{1}{2n=mM}\frac{2-j(n-mN)}{M} \quad \ldots\ldots(3)$$

The synthesis and analysis of filters used by BMC consist of an OQAM/FBMC system. The prototype filters have the capability to ascertain stop-band attenuation, ISI, and ICI. The over- sampling factor (K) represents a parameter that determines the specific attributes of prototype filters. It should be noted that the attributes of a prototype filter pertain to the proportion between the length of time of the filter's impulse response along with the symbol period of a multi-carrier system. Moreover, the over-sampling factor refers to the quantity of frequency coefficients that are inserted within the coefficients of FFT filter. The conceptualization of the prototype parameters is based on the Nyquist criteria. In addition, the strength of the 'background noise' serves as a crucial factor in the construction of the prototype filter. This parameter quantifies the interference power resulting from the lack of orthogonality among the carriers, extending beyond the adjacent sub-channel.[14]

The execution of the filter bank necessitates an expansion in the IFFT and FFT algorithms. The polyphase network (PPN) may effectively decrease the complicated calculations generated bythis procedure.[21] The aforementioned method is often referred to as PPN-FFT.[22] FBMC employs a non-usage of CP in order to minimise the impact of interferences. The capacity of FBMC may be enhanced with the use of OQAM.[24]

The current implementation of FBMC utilises the technique of frequency spreading. The system employs an IFFT of length N*K, wherein N represents the number of sub-carriers. The symbols overlap with each other with a delay period of N/2. This particular design decision facilitates the analysis of FBMC modulation and enables effective comparisons against various modulation techniques. In order to get maximum efficiency, OQAM processing was used. The transmission of data with complicated symbols involves a sequential transmission of both the real and the imaginary components, with a delay of half the symbol time applied to the transmission of the imaginary part.

Figure 4 illustrates the transmitter configuration, whereby the input data bits are mapped to thedesignated data symbol before undergoing OQAM processing. The conversion from serial to parallel will be executed before the extended IFFT process. In the context of FBMC, the filterbank technique is used as an alternative to the FFT method often utilised in OFDM. Each data block elongates the temporal frame, overlapping the multicarrier symbol. Interference between symbols may be mitigated by ensuring the channel filter adheres to the Nyquist criteria. It is important to note that the spreading process should be performed before the execution of the extended IFFT operation. The data element is distributed over many inputs of the IFFT, and this process is often referred to as weighted frequency spreading. Subsequently, the process of converting parallel data to serial data is accomplished inside the FBMC transmitter prior to transmitting the information as a symbol to the

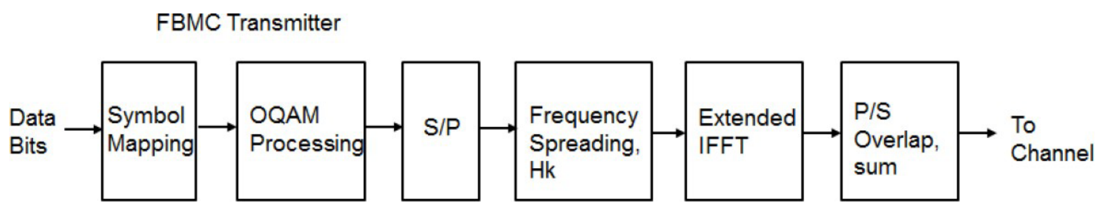

Fig 4: FBMC Transmitter

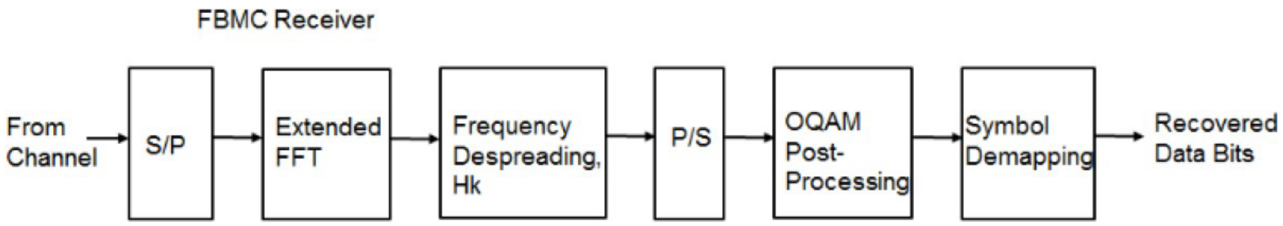

Fig. 5: FBMC Receiver

receiver over the channel. Several factors influence the transmission of information in a channel. It is essential to acknowledge that allocating separate sub-channels to various users does not require synchronisation. The sub-channel equaliser is responsible for compensating for time offset, phase, amplitude distortion, and frequency offset. Implementing either time- or frequency-domain channels is contingent upon the receiver's filter bank architecture.

The FBMC receiver, as seen in Figure 5, currently undergoes serial to parallel translation prior to the execution of the FFT process. The use of a weighted dispreading procedure facilitates the retrieval of data items. Prior to OQAM processing, parallel-serial transformation was carried out once again. Following this, the received symbol undergoes damping and acquires the transmitted symbol.

Simulation Results

The implemented work includes the evaluation of potential physical layer contenders for 5G technology. The 5G standard is still fully developed; it employs several modulation methods. This analysis examines and contrasts modulation schemes, including OFDM, FBMC, and UFMC. The comparison entails modelling these modulations across several parameter sets. The acquired findings include spectral efficiency, bit error rate vs signal-to-noise ratio, peak- to-average power ratio, and power spectral density. The execution is carried out via MATLAB.

The following parameters tabulated in Table 2 are used in this research to calculate various measurements.

S. No	Parameter Properties	Values
1	Length of the FFT	512
2	Bits/Sub-carrier	5
3	Cyclic prefix length in OFDM	43
4	Filter Length in UFMC	43
5	Stop band attenuation in UFMC	40
6	Spreading Factor in FBMC	4

In the context of FBMC, the transmitter is responsible for broadcasting the data symbols. These symbols are then processed by the OQAM modulator, generating both even and odd symbols. The symbols are subjected to upsampling with a multiplication factor of K. Afterwards, these symbols are enhanced with protected bits and processed through prototype filtering. The transmitter would eliminate a 1/2 delay created by the filter and subsequently calculate the IFFT length for the transmitted symbol. The transmitted symbol represents the combined value of the delayed real and imaginary signals.

Adding Additive AWGN on the channels is used to imitate noise circumstances. Now, the recipient will do an FFT operation in combination with match filtering and prototyping filtering. This measure will reduce the impact of interference. Subsequently, the recipient will eliminate $K - 1$ elements and establish a protective buffer zone. Afterwards, OQAM post-processing is performed, followed by down-sampling methods, which decrease the data by 2K. Finally, we separate the imaginary component (which represents the Kth sample after the fundamental component) and the fundamental component (which represents the Kth sample after the imaginary component) of the information signals. Prior to the de-mapping operation, the data would be normalised using the up-sampling rate.

Power Spectral Density(PSD):

The PSD quantifies the signal's intensity within a specific time interval, indicating the potential range of bandwidth within which the transmission of bits may be accomplished without errors. A comparison was made between the PSD of FBMC and UFMC about OFDM. The simulation generates two graphs, each corresponding to a similar reference. The PSD quantifies the signal's intensity throughout a specific time interval, indicating the potential bandwidth withinwhich the transmission of bits may be accomplished without errors.

An effective modulation's PSD is maximised when the intensity is near the normalised frequency. Figure 6 displays the spectrum density of FBMC represented by the red-shaded area, whereas the blue-shaded portion

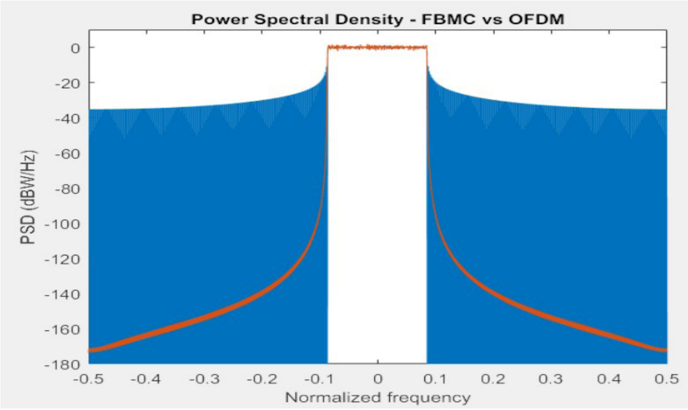

Fig. 6: PSD of FBMC versus OFDM

represents the PSD of OFDM. The graph clearly illustrates that the PSD of FBMC is significantly higher than the OFDM.

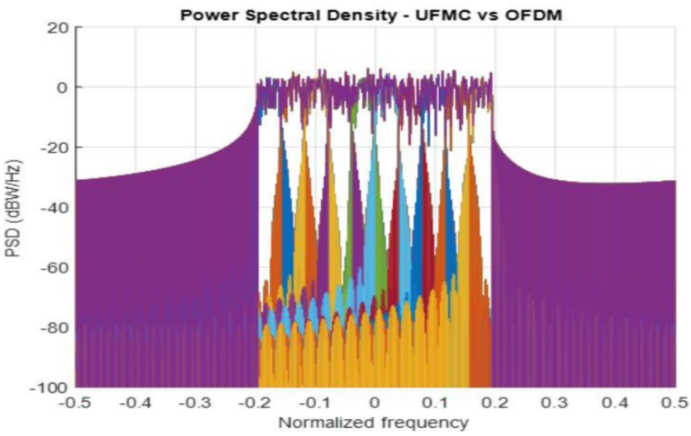

Fig. 7: PSD of UFMC versus OFDM

Figure 7 displays the PSD for UFMC within the centre-darkened area, whereas the blue area represents the PSD of OFDM. The graph clearly illustrates that the PSD of UFMC is significantly higher than the OFDM. Therefore, it is evident that FBMC and UFMC represent superior alternatives to OFDM. Therefore, choosing the two options becomes more prudent for 5G. Among all 5G modulation schemes like OFDM and UFMC, the FBMC exhibits the spectral density most similar to the normalised frequency.

Spectral Efficiency:

Spectral efficiency, also known as spectrum bandwidth efficiency, quantifies the number of bits that may be carried within a given bandwidth. The data rate refers to the maximum amount of data delivered within a specific bandwidth in a communication network.

The curve in Figure 8 represents the spectrum efficiency of three modulation techniques: UFMC, OFDM, and FBMC.

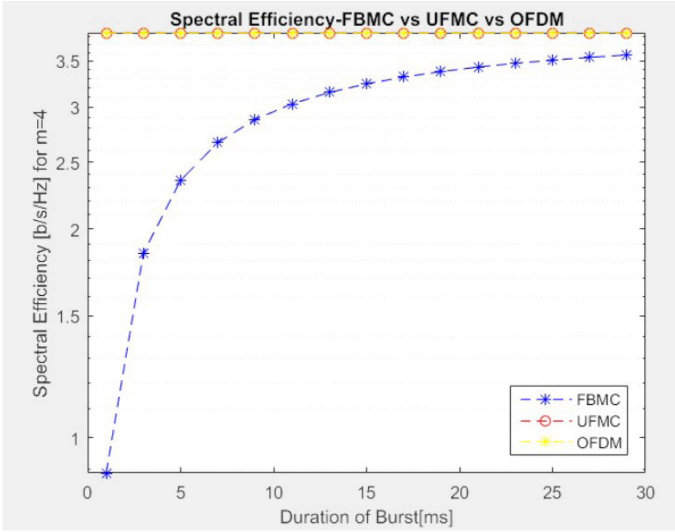

Fig. 8: Spectral Efficiency of OFDM Vs FBMC Vs UFMC

The graph has been constructed by systematically altering the burst length, ranging between 0 – 30. Due to the identical number of cyclic prefixes and filter length, all OFDM UFMC systems overlapped with one other within the specified bursts. The spectral efficiency of FBMC is shown to rise as the length of bursts rises. If the length of bursts becomes more extensive, it is more significant than any previous two.

PAPR:

The PAPR has been calculated by squaring the peak amplitude and dividing it by the square of the RMS value of power. This is crucial throughout signal processing operations. The system's efficiency is inversely proportional to the PAPR. Modulation approaches utilising numerous inputs exhibit a greater PAPR, while those with a sole input exhibit a reduced PAPR. All three possess a high PAPR, which constitutes a disadvantage in these cases. FBMC (10.11dB) exhibits the highest PAPR amongst these, with OFDM(8.88dB) and UFMC (8.23dB) following in that order.

BER:

BER, or bit error rate, is the frequency of errors in bits occurring during a specific period. The unit of measurement is not specified, and the performance metric is often expressed as a percentage. Variations in the SNR impact the efficiency of the constellation. The simulation of BER vs SNR was constructed based on data from Figures 9, 10, and 11. The SNR range used in the simulation ranged from 0 – 15 dB. The performance of FBMC surpasses those of other approaches. It is approaching 0 from a value of 5 dB.

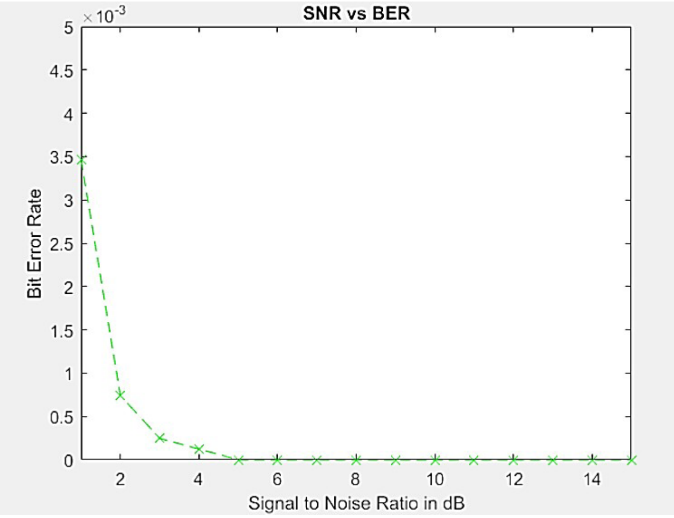

Fig. 9: BER Vs SNR in FBMC

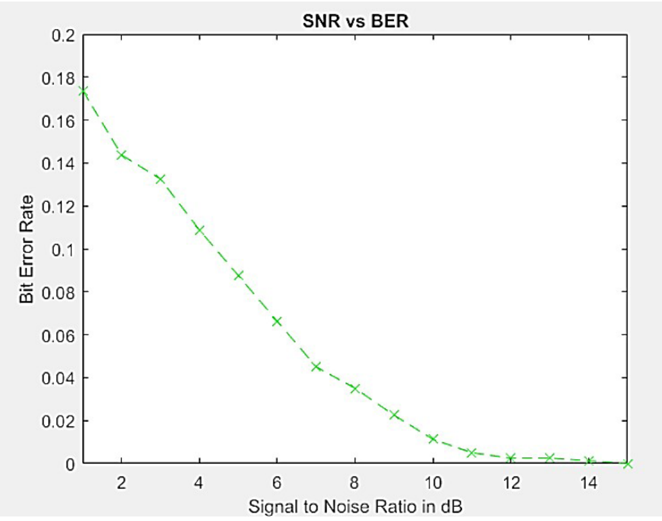

Fig.10: BER Vs SNR in UFMC

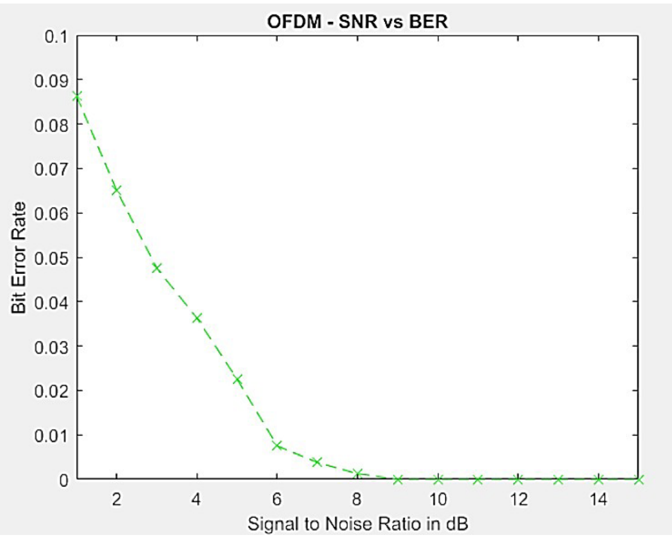

Fig. 11: BER Vs SNR in OFDM

Conclusion

FBMC possesses superior spectrum efficiency compared to OFDM. However, it is accompanied by a longer filter delay caused by filtration per sub-carrier basis. FBMC necessitates adaptation for MIMO processing as a result of the OQAM processing. Simulation outcomes for the specified parameters illustrate the efficiency assessment of various modulation methods, namely FBMC, UFMC, and OFDM, as applied in 5G communications.

This facilitated the assessment of the effectiveness of modulation approaches by considering characteristics such as Spectral Density, BER, PAPR, and Spectral Efficiency. This could be improved by implementing modulation methods across several wireless communication channels. The addition of the MIMO feature allows testing the system's capacity to accommodate many users. One crucial factor for enhancing spectral efficiency in the development of 5G technology is the utilisation of a waveform that offers superior spectral control. FBMC is an alternative method that surpasses OFDM regarding features by constructing a sub-carrier waveform using prototype filters.

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