Performance Evaluation of UFMC and Comparison with OFDM

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ABSTRACT: The future cellular networks intends to achieve even higher data rates and for this reason, it needs to be more robust against inter channel interference (ICI) and inter symbol interference (ISI). Orthogonal Frequency Division Multiplexing (OFDM) has limitations that would not allow it to work efficiently for future requirements of cellular networks that include machine-to-machine (M2M) communication and Internet-of-things (IoT). OFDM technology suffers from the problem of high Peak to Average Power Ratio (PAPR) and lower spectral efficiency. Thus, to support the next generation wireless systems, other waveform models are getting attention. Among the techniques available, UFMC seems to be attractive due to high spectral efficiency and less complexity. In this paper, the performance of UFMC has been evaluated with different design factors such as number of sub bands, FFT (Fast Fourier Transform) size, filter characteristics and modulation and it is compared with OFDM, highlighting the merits of the candidate modulation scheme for emerging fifth generation (5G) Wireless Communication.

1. INTRODUCTION:

LTE-Advanced is a fourth generation (4G) mobile system that is currently being deployed worldwide. It has essentially been optimized to provide high data bandwidth to strictly synchronized devices like tablets and smartphones (1). However, in the near future, there will be a growing number of human-driven devices like smartphones. Besides the mobile data increase, the expansion and the creation of services and applications such as Internet of things (IoT), Vehicle to Vehicle (V2V) communication, Machine to Any (M2X) communication will impose new traffic requirements to the networks, so to meet these new requirements, the fifth generation (5G) cellular networks will be required (1,2).

Orthogonal Frequency Division Multiplexing (OFDM) (3,4) is the most popular multi-carrier modulation technique which is being used in 4th generation wireless communication. OFDM extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Rather than transmit a high-rate stream of data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at a low symbol rate. To prevent inter-symbol interference (ISI) caused by the propagation channel, OFDM systems insert a cyclic prefix (CP) before each symbol to be transmitted. However, OFDM suffers from several shortcomings regarding the previously mentioned requirements for the future 5G cellular network. OFDM suffers from a number of drawbacks including high peak-to average power ratio (PAPR) and frequency leakage caused by its rectangular pulse shape. It is also very sensitive to time and frequency offsets, requiring strict synchronization to avoid interference between users. Due to the use of cyclic prefix (CP), it suffers from Spectral efficiency loss (5). To overcome these limitations, several alternative candidates have been intensively studied in the literature over the past few years, such as Universal Filtered Multi Carrier (UFMC) (6, 7), Generalized Frequency Division Multiplexing (GFDM) and Filter Bank Multicarrier (FBMC) (8). In the paper, we have studied about the waveform UFMC and compared it with OFDM. UFMC (Universal filter multicarrier) is multi-carrier transmission scheme in order to overcome the ICI problem and improve the system performance. It is the compromise between OFDM and FBMC, it groups subcarriers to sub-bands, which are then filtered individually in order to reduce OOB power as compared with single subcarrier or the complete band.

This paper is organized in four sections. A brief introduction is given in Section 1. UFMC system model details would be discussed in Section 2. In Section 3, the simulation result of effect of different parameters on PAPR of UFMC and comparison between OFDM and UFMC is discussed and finally, Section 4, the last section, draws some conclusions.

2. UFMC SYSTEM:

Universal filtered multi carrier (UFMC) (6, 7) is a multicarrier modulation technique which combines the features of OFDM and FBMC (9).UFMC waveform is a derivative of OFDM waveform combined with post-filtering, where a group of carriers is filtered by using a frequency domain efficient implementation. In UFMC, first the total bandwidth is divided into sub-bands. Each sub band contains a number of subcarriers. Unlike self-subcarrier modulation in FBMC, a group of subcarrier modulation is performed in UFMC to reduce OOB. The subcarrier grouping reduces the length of the filter compared with FBMC and also reduces time to perform modulation. QAM type of modulation is used in UFMC. It has a good spectral efficiency due to the absence of cyclic prefix and decreased out-of-band emission due to filtering operation and has better time and frequency synchronization. Figure 1 shows the functional diagram of UFMC transceiver.

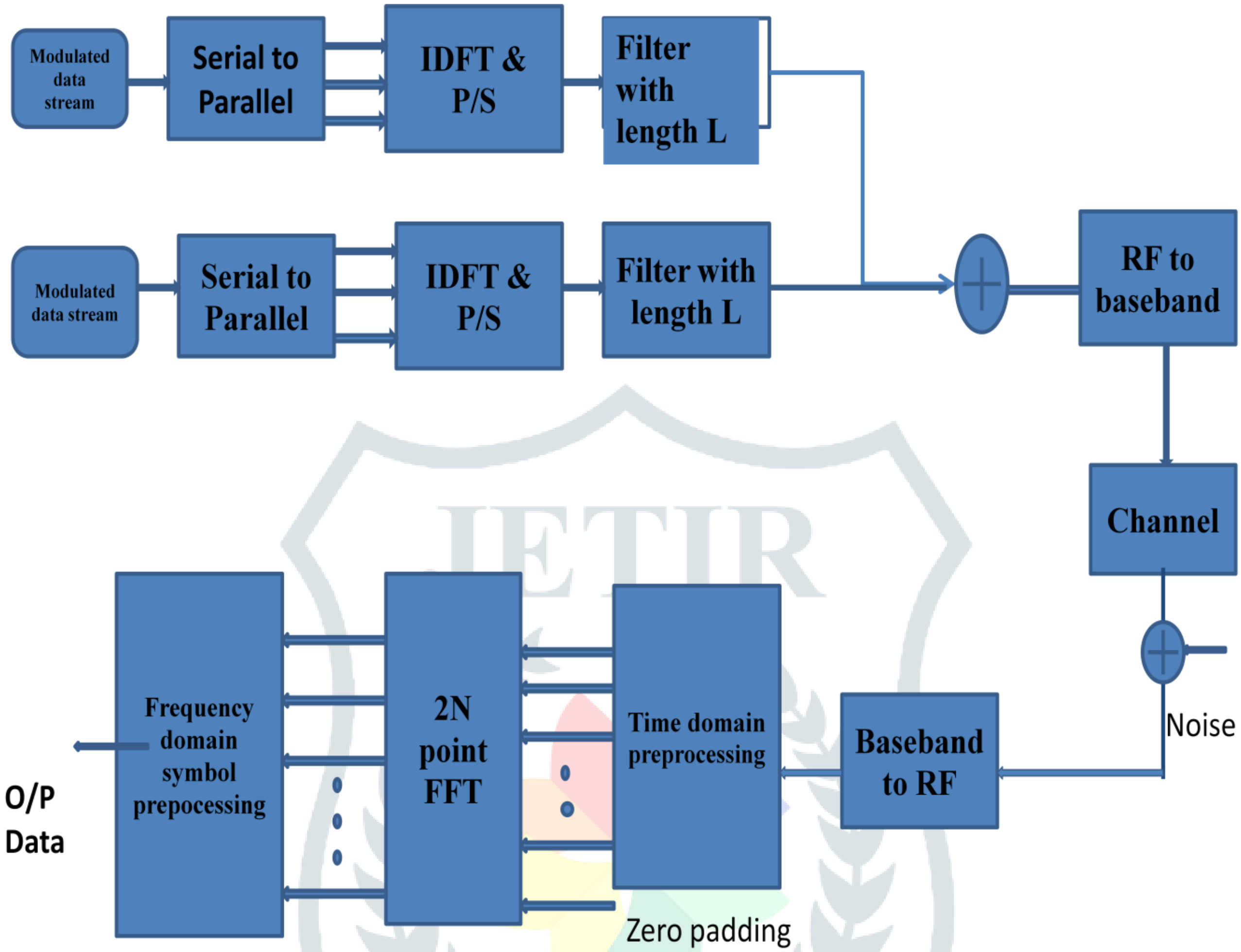

Figure 1: UFMC Modulation function block diagram.

In UFMC, full band of subcarriers (N) is divided into sub bands. Each sub-band has k subcarriers. Now, data bits are given to each sub band. The narrowband and closely-spaced individual sub bands undergo N-point Inverse Fast Fourier Transform (IFFT) to get time domain of each sub band from Frequency Domain of each sub band. IFFT operation ensures that the sub band carriers do not interfere with each other. The output of IFFT will be filtered with pulse shaping filter of length L. Band Filter filters each sub band and each sub band responses are summed. The filtering is done to reduce the out-of-band spectral emissions. A Chebyshev window with parameterized side lobe attenuation is employed to filter the IFFT output per sub band. The time series signal from modulation side is pre-processed for filtering interference and S/P converted, demodulation is performed by FFT of twice the number of total sub-carriers. The FFT converts data received in time domain into frequency domain. Equalization is used for equalizing the joint effect of the channel and the sub band filtering. The symbol demapper converts the symbols into bits and original data is retrieved (10-12**).**

In UFMC technology, the cyclic prefix can be rejected, so it has better spectral utilization than OFDM.UFMC technology is less sensitive to estimation errors of frequency and time shifts. The block-wise filtering provides flexibility to the system and may be used to avoid the main OFDM drawbacks. The length of the weighting window of the filter is a key parameter that affects the characteristics of the communication systems with the technology of UFMC. As side lobes decrease, the interference on adjacent subcarriers also decreases. The filter used in UFMC is Dolph-Chebyshev of length ‘L’. The length of the filter depends upon the size of sub-band that is the number of carriers in sub-band (12). Figure 3 shows the Chebyshev filter characteristics in time and frequency domain. The length of filter used is 43, 63 and 83 with side attenuation 60dB.

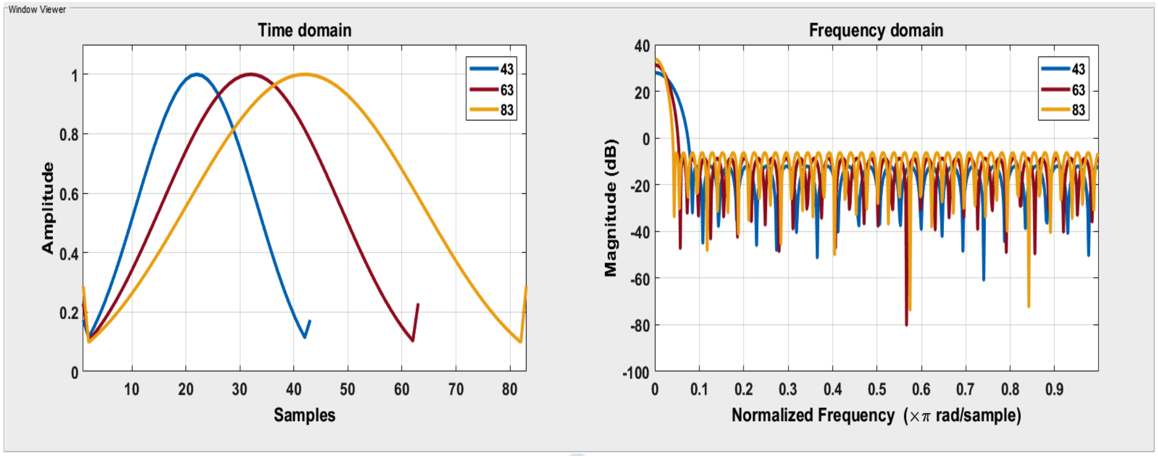

Figure 2.Chebyshev filter characteristics in time and frequency domain.

3. SIMULATION RESULTS:

In the following section, the performance of UFMC waveforms in terms of BER and PAPR is analyzed using MATLAB. The effect of different factors (number of subcarriers, filter length, side attenuation, and modulation order) on PAPR and BER of UFMC waveform has been studied. The comparison between UFMC and OFDM has been performed for different mapping techniques.

3.1 Different Factors Effecting PAPR in UFMC

PAPR is the relation between the maximum power of a sample in a given transmit symbol divided by the average power of that symbol. PAPR occurs when in a multicarrier system the different sub-carriers are out of phase with each other. It is the ratio of peak power to the average power of a signal. There are various parameters which can effect UFMC signal generation. In this section, we will study the effect of these parameters on the value of PAPR for UFMC systems.

Table 1: PAPR values with different Filter Length

Number of Sub Bands	Filter Length	Modulation Order	FFT Size	PAPR
10	30	16QAM	512	8.2822
10	43	16QAM	512	8.4112
10	63	16QAM	512	8.4575
10	83	16QAM	512	8.0589

Table 2: PAPR values with different FFT Size

Number of Sub Carrier	Filter Length	Bits Per Sub Carrier	FFT Size	PAPR
20	63	8	256	9.1335
20	63	8	512	8.5025
20	63	8	1024	7.7677
20	63	8	2048	7.4683

Table 3: PAPR values with different Modulation Order

Number of Sub Bands	Modulation Order	FFT Size	PAPR
30	4	512	9.4443
30	16	512	8.1156
30	64	512	10.1402
30	256	512	8.4995

Table 1 gives different values of filter length and the corresponding values of PAPR are also given. The parameters taken are size of FFT is 512, side attenuation of filter is 60dB and number of carriers is 20. Values are taken for each filter length 30, 43, 63 and 83. Filter length 83 shows slightly less PAPR in comparison to other lengths. The next factor of our observation is that how FFT size of the transmitter affects the PAPR of the system. Table 2 shows the values of PAPR corresponding to given different values of FFT size of transmitter. The parameters taken are size of FFT is 512, side attenuation of filter is 60dB and number of carriers is 20. The result shows that on increasing the FFT size, the value of PAPR decreases. The effect of increasing the modulation order on PAPR of UFMC is shown in Table 3. It is seen that 16 QAM modulation has the lowest PAPR among the order modulation order.

Table 4 shows the PAPR values for different values of side attenuation. The parameters taken are size of FFT is 512, filter length 43 and number of carriers is 20. Values are taken for side attenuation of 40, 50, 60dB. Filter with 40 dB side attenuation shows less PAPR in comparison to the other higher side attenuation values. The next Table shows how different number of sub carriers affects the PAPR of the system. In this, size of FFT is taken as 512 with filter length of 43 and side attenuation 60dB. The results show slightly less PAPR for the number of subcarriers 20.

Table 4: PAPR values with different Side Attenuation

Side Attenuation	Modulation Order(QAM)	FFT Size	PAPR
40	16	512	8.2379
50	16	512	8.3449
60	16	512	8.4112

Table 5: PAPR values with different number of Sub Carriers

Number of Sub Carrier	Number of Sub Bands	Modulation Order(QAM)	PAPR
20	10	64	8.5013
30	10	64	10.0724
40	10	30	9.585
50	10	30	9.9099

The BER analysis of UFMC using different modulation orders is shown in Figure 4. The bit error rate (BER) is the percentage of bits that have errors relative to the total number of bits received in a transmission. The parameters taken are size of FFT is 1024, number of subcarriers is 60 and number of sub bands is 10. The number of bits per symbol taken is 2, 4, 6 and 8. The results show UFMC has slightly better BER for 4QAM.

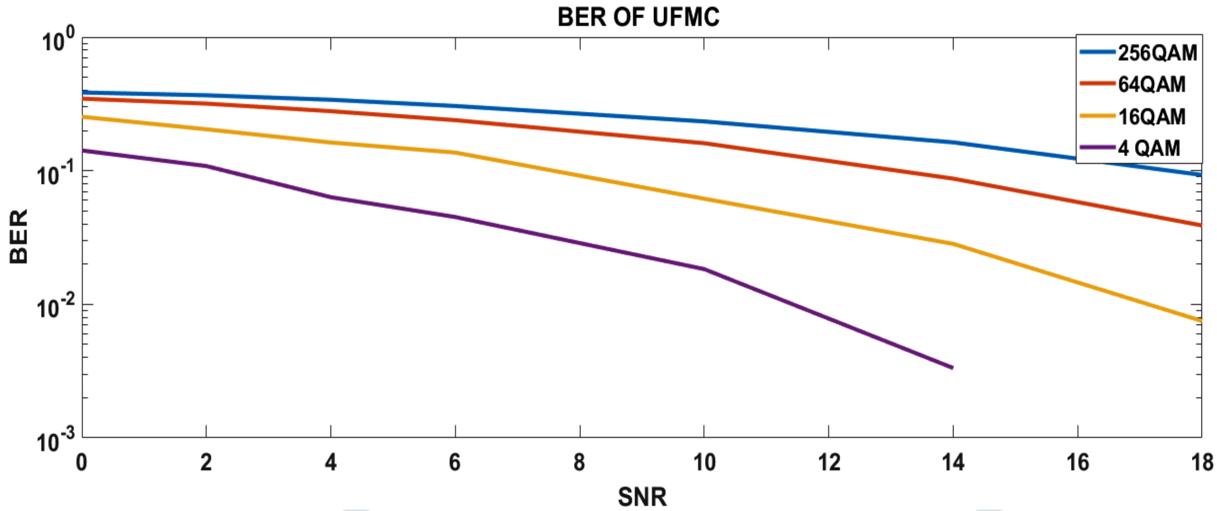

Fig 3.UFMC Bit Error Rate performance using different mapping techniques such as 4QAM, 16QAM, 64QAM, 256QAM.

3.2. OFDM versus UFMC

In this section, we examine the performance of the UFMC system and compare the results with that of the OFDM system. UFMC offers ways to overcome the known limitations of OFDM of reduced spectral efficiency and strict synchronization requirements, so this benefit makes UFMC suitable for 5G Communication.

3.2.1. Power Spectral Densities of UFMC and OFDM

Power Spectral Density helps to display the strength of the energy variation as a function. It shows that at which point the variations of frequency are weaker. Power spectral density of the UFMC transmit signal is designed to give low out-of-band leakage. Figure 4 and Figure 5 show the spectral densities of UFMC and OFDM schemes for 600 carriers. The overall band is divided into 10 sub bands, each sub band having 20 subcarriers with less side lobes. Because of filtered operation for each sub-band in UFMC, we can observe that the spectral re-growth is (-90 dB) which is very low as compared to that of OFDM (-40 dB). Hence, the UFMC scheme is more advantageous in comparison to OFDM as it provides higher spectral efficiency. UFMC has lower side lobes, so it allows better utilization of the allocated spectrum.

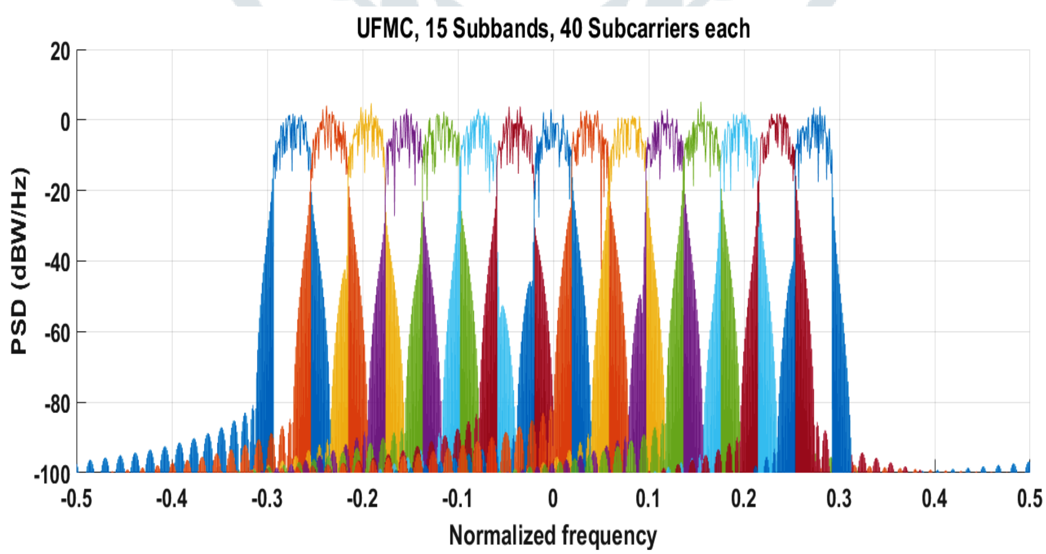

Fig.4. Power Spectral Density of UFMC

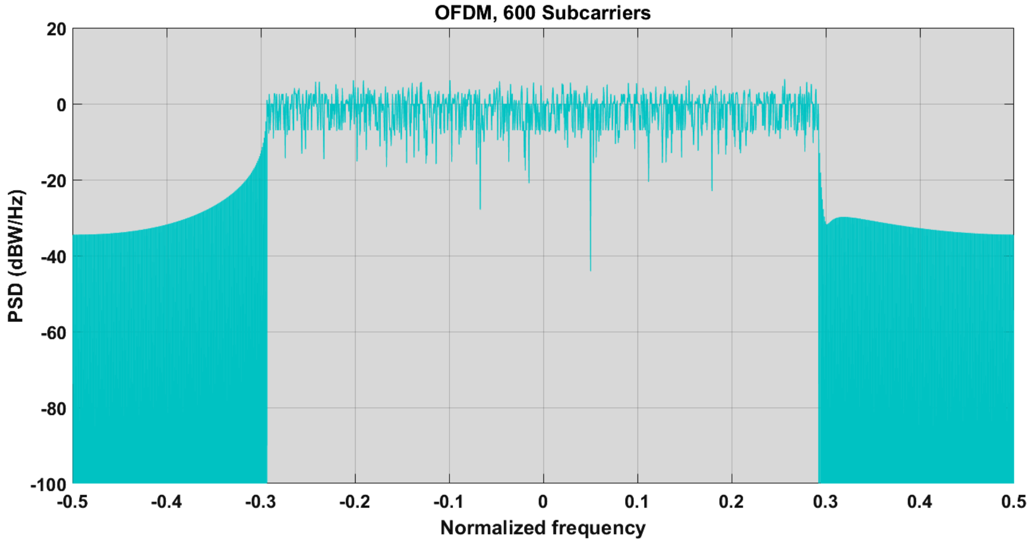

Fig.5. Power Spectral Density of OFDM

3.2.2 PAPR comparison of UFMC & OFDM

In this section, PAPR comparison between UFMC & OFDM is done by varying number of bits per symbol. Table 1 shows the comparison of PAPR values for UFMC and OFDM. The parameters taken are size of FFT is 512, number of subcarriers is 20 and number of sub bands is 10. The number of bits per symbol taken is 2, 4 and 6. The results show that at 2 bits per symbol, the PAPR is less for UFMC and OFDM. Table 2 shows the PAPR values with FFT size of 1024. The parameters taken are size of FFT is 1024, number of subcarriers is 60 and number of sub bands is 10. The number of bits per symbol taken is 2, 4 and 6.The results show that UFMC has slightly better PAPR than OFDM. The PAPR for UFMC and OFDM are notably very close for all conditions. PAPR can be reduced by different types of PAPR reduction techniques.

Table 6. Comparison of minimum PAPR values for FFT length 512

No of bits per symbol	PAPR of UFMC(dB)	PAPR of OFDM(dB)
2	8.2856	8.4377
4	8.4575	8.8843
6	8.9052	9.9269

Table 7. Comparison of minimum PAPR values for FFT length 1024

No of bits per symbol	PAPR of UFMC(dB)	PAPR of OFDM(dB)
2	7.7897	7.9483
4	7.7594	7.9418
6	9.6622	9.8098

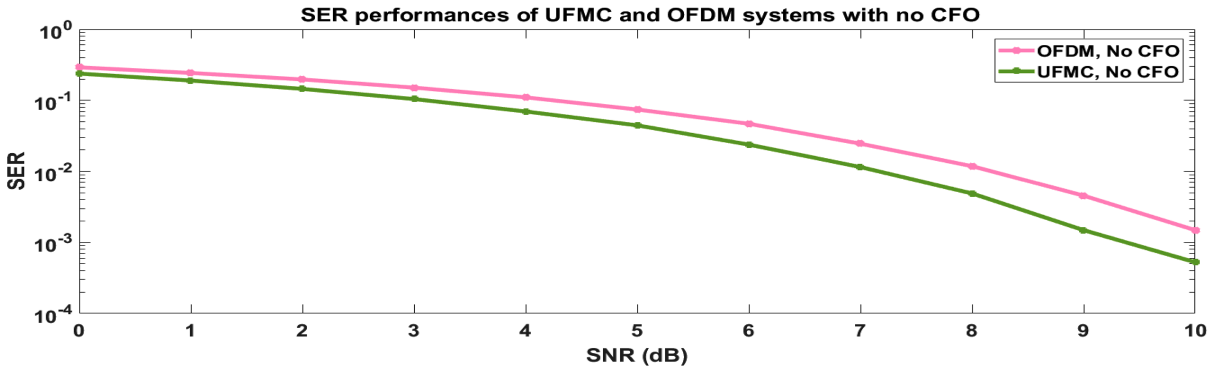

Fig 3 SER performance of UFMC and OFDM With no Carrier frequency offset

Figure 3 shows the symbol error rate (SER) of UFMC and OFDM systems versus SNR in no CFO scenario. In this figure, the UFMC system outperforms the OFDM system. UFMC scheme provides higher spectral efficiency compared to OFDM due to the absence of cyclic prefix samples which have to be discarded at the receiver.

In OFDM, the signal consists of a large number of independently modulated subcarriers. When they are added in phase, they can give a large PAPR but in UFMC, total bandwidth is divided into sub-bands. The maximum power decreases as the probability of number of subcarriers adding up in phase is less in UFMC. So, PAPR is low for UFMC when compared to OFDM. UFMC outperforms OFDM for both perfect and non-perfect frequency synchronization between the transmitter and receiver side. UFMC eliminates the cyclic prefix that is used in OFDM to combat inter-symbol interference, and hence increases the data transmission rate. Also, due to additional filtration, which reduces the Out-of-Band side lobe leakage, better spectrum and better ICI robustness is provided.

4. CONCLUSION

Using UFMC in 5G networks will enhance spectral efficiency of future mobile communication networks as compared to using OFDM technology. OFDM technique has some drawbacks like high PAPR and low spectral efficiency, which are addressed by UFMC. In this work, we comparatively analyzed the frequency responses of OFDM and UFMC and Performance analysis of UFMC in AWGN channel under different design parameters was carried out. From this, we found out that the UFMC has slightly low PAPR and low Power Spectral Density (PSD) when compared to OFDM. UFMC modulation has the advantages which OFDM offers but it also has the limitation of higher peak to average power ratio. By applying some PAPR reduction techniques, this can be reduced, making it more reliable and efficient for next generation wireless communication.

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