UFMC System Performance Analysis for 5G Cellular Networks

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Abstract: Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique, which is used as a dominant waveform for the 4G communication systems. But OFDM cannot meet the demands in 5G. Universal filtered multicarrier (UFMC) has been paid more attention in the 5G communication system because of its low out of band emission (OOBE) and compatibility for multiple input multiple output (MIMO) communication. In this paper performance of UFMC is analyzed in terms of power spectral density (PSD), Bit error rate (BER) and peak to average power ratio (PAPR). Extensive comparison of UFMC and OFDM is included to illustrate the advantages of UFMC. PAPR performance of UFMC is evaluated for various design parameters including FFT size and side lobe attenuation.

Keywords: OFDM, UFMC, PSD, BER, PAPR

1. Introduction

OFDM is a multicarrier modulation technology which is used in broadband wireless communication systems [1]. OFDM was the dominant technology used in 4G networks since it has high spectral efficiency because it uses orthogonal subcarrier signals. OFDM is easily implemented by using IFFT and FFT at the transmitter and receiver respectively. OFDM mitigates inter symbol interference (ISI) and combats the effect of multipath reception [2]. However OFDM cannot meet the 5G wireless communication demand because it has high OOBE. OOBE in OFDM is because of the use of rectangular window in time domain, which leads to sinc pulses in frequency domain. These sinc shaped spectrum causes strong OOBE which in turn causes severe adjacent channel interference (ACI) [3]. Subcarriers in OFDM remain orthogonal only in case of perfect synchronization conditions. So Strict synchronization is required in OFDM to avoid interference between the users since it is very sensitive to time and carrier frequency offsets (CFO). The frequency offset may be because of oscillator frequency mismatch between transmitter and a receiver or due to the Doppler shift resulting from the mobility. Performance degradation in OFDM occurs because of inter carrier interference (ICI). ICI occurs because of CFOs which destroy the orthogonality between subcarriers. To reduce OOBE of OFDM and to meet the requirement of 5G network scenario filter based waveforms were proposed in the literature. Another drawback of OFDM is that it has high PAPR [4].

Filter based waveforms reduces OOBE with different filter designs. Filtering reduces the subcarrier side lobe levels, so filter based waveforms do not require complex synchronization and transmission of additional training signal [5]. Based on the filter granularity filter based waveforms are divided as subcarrier filtering and sub band filtering [6]. Subcarrier filtering is used in filter bank multicarrier modulation (FBMC) and Generalized frequency division multiplexing (GFDM). FBMC is proposed in [7]. Sub carrier filters used in FBMC reduces OOBE and hence reduces ICI. Spectral efficiency of FBMC is higher than that of OFDM. Because of the use of filter banks in FBMC subcarriers in FBMC are not orthogonal to each other. So offset-QAM (OQAM) modulation was proposed to solve this problem [8]. FBMC uses OQAM modulation due to which it is not suitable for MIMO applications [6]. Another drawback of FBMC is that long filters used in FBMC causes problems in short data transmission in applications such as machine to machine communication. GFDM is a subcarrier filtering based waveform in which filtering is applied in block wise manner to avoid inter burst tails. Increased decoding latency and use of complex receivers are the drawbacks of GFDM [9].

UFMC collects the advantages of OFDM and FBMC [10]. UFMC uses sub band filtering; these sub bands consist of number of subcarriers. OOBE in UFMC is much lesser than OFDM because of the filters used. Sub band filtering reduces the filter lengths in UFMC which makes it suitable for short data transmission. UFMC is compatible MIMO techniques because of QAM modulation used at the transmitter. UFMC outperforms the OFDM for both perfect and non-perfect synchronization between user equipments (UEs) and base stations (BSs) [11] . In [12] author has used novel pulse shaping approach to reduce the spectral leakage in to nearby sub bands. In [13] anti-interference filter is used in UFMC system, where in band distortion and out of band distortions are taken in to consideration. In [14] BER performance of UFMC with different side lobe attenuation, different width of sub band and different modulation constellations are analyzed. PSD comparison of OFDM and UFMC is analyzed in [15]. In this paper we will make comprehensive comparison of OFDM and UFMC in terms of PSD, BER and PAPR.

Remaining part of the paper is structured as follows. Section II describes system model. Section III explains the simulation results and conclusion is given in section IV.

2. System Model

UFMC transmitter block diagram is as shown in Fig. 1. As shown in block diagram total bandwidth B is divided in to number of sub-bands K. Each subband has N subcarriers. N Subcarriers are passed through modulator, modulation can be QPSK, 4-QAM, 16 QAM or 256 QAM. Complex QAM modulated symbols are passed through IDFT, so that subcarriers are orthogonal to each other, which avoids the OQAM modulation which is required in FBMC. Each subband is filtered using Dolph-Chebyshev filter which has the side lobe attenuation of 40dB. Length of the filter is chosen depending on the number of FFT points used, which is approximately equal to the 8% of the length of IFFT and almost equal to the length of cyclic prefix(CP) used in OFDM.

Filtering is used in UFMC to reduce the OOBE and subsequently to minimize ICI. The filtered signal of each subband is summed to obtain the UFMC signal. In [6] zero prefix [ZP] is used in UFMC to avoid ISI. In which case length of the filter used should be less than or equal to the length of ZP. Due to the addition of ZP extra time overhead will be added but performance in multipath environment improves. In the system model shown below CP is not added so the spectral efficiency is better than OFDM. Base band UFMC signal is as given below where K is the number of sub bands. L is the length of the filter and N is the number of points in FFT.

$$x_k = \sum_{i=0}^{K-1} \sum_{l=0}^{L-1} \sum_{n=0}^{N-1} d_n^i \, g[l] e^{\frac{j2\pi k(n-1)}{N}} \qquad (1)$$

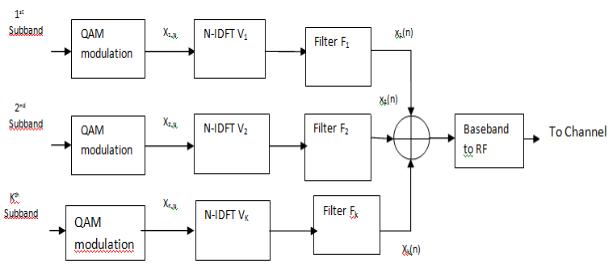

Fig. 1.UFMC Transmitter

Sub-band filtering used in UFMC results in broader spectrum, so length of the filter reduces, which makes UFMC suitable for short burst transmission. Implementation complexity of UFMC is considerably lesser than that of OFDM. UFMC receiver is shown in Fig. 2. In UFMC filters are used only at the transmitter. Length of the received symbol in UFMC is length of the FFT (N) + length of the filter (L) -1. At the receiver N-L-1 zeros are added, data symbols from UFMC are recovered by applying 2N point FFT. Since all the odd sub carriers contain ISI only even bits of 2N point FFT are considered to recover the data

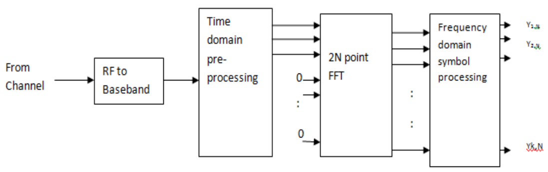

Fig. 2 UFMC Receiver

3. Simulation Results

In this section we examine the performance of UFMC and OFDM system. To evaluate the performance of UFMC we developed a simulation model using MATAB. Simulation parameters are shown in Table 1.

A. PSD comparison

Filter based waveforms are used to reduce OOBE and thereby to support asynchronous transmission. So it is necessary to compare the OOBE of UFMC and OFDM.

Comparison of Power spectral density of UFMC and OFDM is shown in Fig. 3. It is apparent from the figure that UFMC has less OOBE than OFDM. With UFMC OOBE improves by 50dB. High OOBE in OFDM is because OFDM uses rectangular pulse in time domain. So if the orthogonality between the subcarriers is lost in OFDM because of carrier frequency offset ICI of OFDM increases which degrades the performance of OFDM.

Frequency shift in the channel produces interference between subcarriers. UFMC is more resistances to interference, since side lobes in UFMC is much lesser than OFDM.

Table 1 Simulation parameters

Simulation Parameter	Parameter value
UFMC System	
Number of subbands	10
Number of subcarriers in each subband	12
Number of FFT points	512
Modulation	4-QAM
Filter type	Dolph-Chebyshev filter
Filter side lobe attenuation	40dB

For comparison 120 subcarriers are chosen in OFDM with number of FFT points as 512 and modulation as 4-QAM.

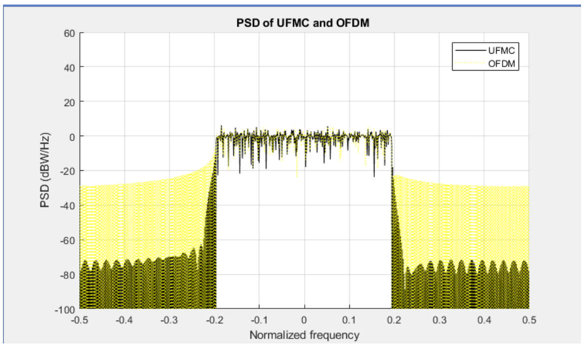

Fig. 3 PSD of UFMC and OFDM

Fig. 4 shows the superimposition of spectrum of 10 UFMC subbands with 6 subcarriers in each subband carrying 4-QAM data symbols.

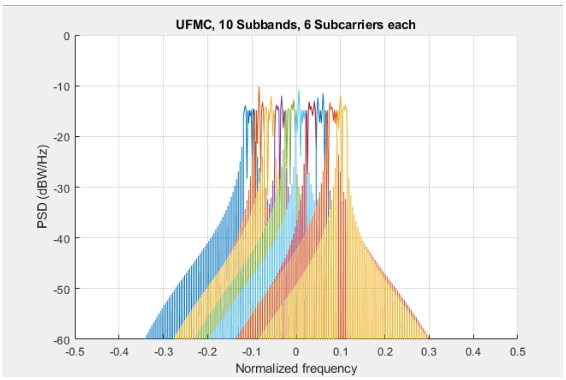

Fig. 4. PSD of UFMC

Fig.5 shows the time domain and frequency domain characteristics of the subband filters used in UFMC for filter length of 43 and sidelobe attenuation of 40dB and 60dB. Dolph chebyshev filters are used here because in this filter for a given side lobe attenuation width of the main lobe is minimized. Filter length and side lobe attenuation both can be varied depending on the application. Side lobe attenuation produces trade off between side lobe level and main lobe width. As side lobe attenuation decreases from 60dB to 40dB main lobe width in frequency domain decreases and side lobe level increases.

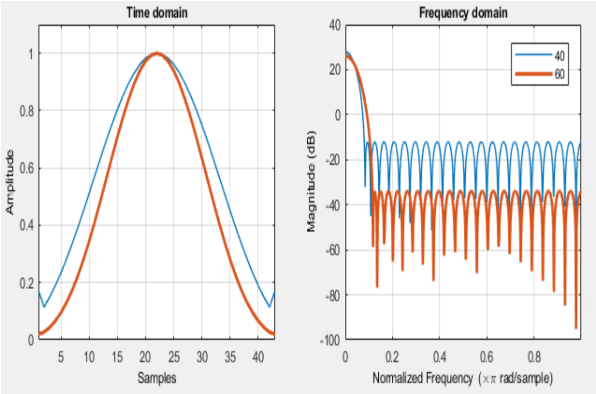

Fig. 5. Characteristics of Dolph-Chebyshev filter

B. BER comparison

Along with less OOBE BER Performance of UFMC is also good. Fig. 6 shows comparison SNR versus BER plot UFMC and OFDM for 4-QAM modulation scheme in AWGN channel. BER graph can also be plotted for 16-QAM modulation. BER performance of UFMC is almost same as that of OFDM for all the modulation scheme . As the modulation order increases spectral efficiency increases but BER performance decreases. From the graph it is clear that even though CP is not used in UFMC BER performance of UFMC is same as that of OFDM.

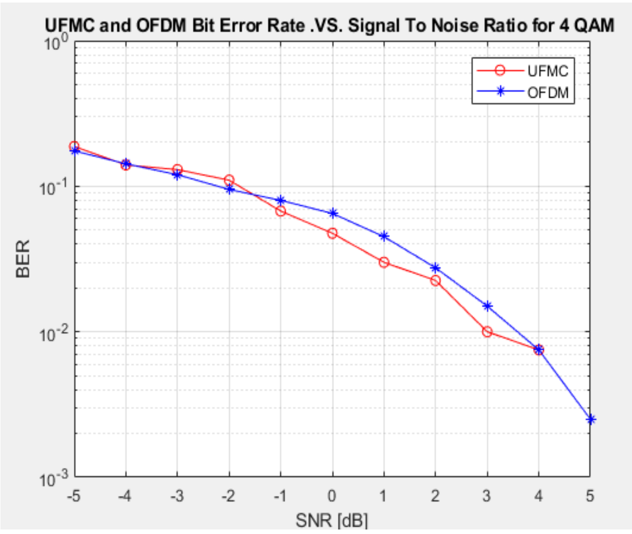

Fig. 6. BER vs SNR comparison of UFMC and OFDM

Table 2 and 3 shows the BER variation with varying side lobe attenuation for 4-QAM modulation and 16-QAM modulation. From the table it is clear that by increasing the side lobe attenuation BER performance improves. It is obvious that as the modulation order increases from 4-QAM to 16-QAM BER increases. Simulation is carried for 512 point FFT SNR of 2dB. For 4-QAM modulation BER of OFDM is 0.008333. When the modulation order increases to 16-QAM BER of OFDM increases to 0.24167.

Table 2. Comparison of BER of UFMC for SNR of 2dB for 4-QAM modulation

Side lobe attenuation in dB	BER
5	0.03333
10	0.01667
20	0.0167
40	0.008333

Table 3. Comparison of BER of UFMC for SNR of 2dB for 16-QAM modulation

Side lobe attenuation in dB	BER
5	0.13333
10	0.1125
20	0.1048
40	0.10417

C. PAPR comparison

In this section we compare the PAPR of OFDM and UFMC for different number of FFT points and filter side lobe attenuation. PAPR is the ratio of the peak of squared amplitude and mean power. It is obvious that QPSK, QAM and Single carrier Frequency division multiple accessing (SC-FDMA) offers lowest PAPR because they use single carrier. PAPR increases in multi carrier transmission. Table 4 shows the variation of PAPR as the number of FFT point increases. It is clear from the table that as the number of FFT points increases PAPR increases both in OFDM and UFMC. Table 5 shows the variation of PAPR of UFMC as the side lobe attenuation increases. Simulation is carried for 512 points FFT with 4-QAM modulation for which OFDM gives the PAPR of 8.3503dB. PAPR of UFMC decreases with increase in the side lobe attenuation.

$$PAPR(y(t))_{dB} = 10log_{10}\left(\frac{\max(|x(t)|^2)}{E|x(t)|^2}\right) \qquad (2)$$

Table 4. PAPR with variation in FFT size

Number of points in FFT	PAPR of UFMC	PAPR of OFDM
512	8.071	8.3503
1024	8.3262	8.4671
2048	9.8825	8.98

Table 5. PAPR with variation in filter side lobe attenuation

Side lobe attenuation	PAPR of UFMC
40	9.04 dB
60	9.0029 dB
80	8.4377 dB

4. Conclusion

UFMC is the better waveform candidate for 5G communication because it has better spectral efficiency than OFDM and FBMC. Sub band filtering used in UFMC reduces the OOBE. QAM modulation used in UFMC makes it compatible with MIMO transmission. In this work fair comparison of UFMC and OFDM is made under a common frame work. UFMC has less OOBE compared to OFDM. BER performance of UFMC is almost same as that of OFDM. PAPR of UFMC is less than OFDM for 512 and 1024 FFT points. Therefore UFMC waveform is expected to be used for asynchronous transmission in 5G cellular networks.

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