Novel Methods of Filtering For FBMC/UFMC Based 5G Communication Systems

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Abstract— **It is expected that the 5G wireless technologies will come into effect by the year 2020. New Radio (NR) techniques will be implemented in 5G in order to overcome the limitations of OFDM based 4G/LTE. Two popular NR techniques are Filter Bank Multi Carrier (FBMC) and Universal Filtered Multi-carrier (UFMC) which are proposed for 5G. Both FBMC and UFMC have some merits as well as demerits. FBMC uses Filtering technique on each sub-carrier of OFDM. On the other hand UFMC decomposes the allotted band into sub-bands and applies the Filtering technique on each sub-band. This paper describes FBMC and UFMC for 5G which implement two different Prototype Filters. One of them is Binomial Filter for FBMC and the other one is Fractional-Powered Binomial Filter (FPBF) for UFMC. It was found that the Binomial Filter based FBMC can reduce the PAPR when the simulation results were compared with another popular Prototype Filter. PAPR reduction was about 0.81 dB in case of Binomial Filter based FBMC and at 256-QAM level. In the second case, sub-band interference of FPBF based UFMC was about 58 dB less than that of 60 dB Dolph-Chebyshev Filter based UFMC. PAPR was also minimum in case of FPBF based UFMC.**

Keywords— BER, 5G, OFDM, FBMC, FILTER, New Radio (NR), PAPR, UFMC

I. INTRODUCTION

Increased demand for Gbps data rate, incorporation of more applications and users, a new 5G radio propagation technique has been discussed and researched seriously for future wireless networks. Present LTE-A and Wi-Fi technologies will be merged with the 5G technologies for universal coverage, providing higher data rate and better user experiences. There are some restrictions of current LTE-A such as:

i. Simultaneous requirements of various distinct facilities for increased number of users,
ii. Insufficient bandwidth for allocating channels to customers,
iii. Huge population within a chain of high rise buildings, and
iv. Increased power requirements for huge number of mobile phones and other wireless devices.

5G communication services will have the facilities of higher Quality of Service (QoS) at greater ranges for massive Machine Type Communications (mMTC), Internet of Things (IoT), and other Ultra-Reliable and Low Latency Communications (uRLLC). 5G systems will have data rate at least ten times higher than that of 4G.

Multi-Carrier Modulation (MCM) is a popular and efficient air interface technique, where the available channel bandwidth is subdivided into several parallel sub-bands or sub-channels. Each sub-band has its own associated carrier. The most popular Orthogonal Frequency Division Multiplexing (OFDM) technique [1], the core modulation technique of 4G, is not efficient in 5G New Radio (NR) waveforms. As an alternative, different MCM techniques are now under research phases [2]-[4]. In this paper we have discussed two modulation techniques for 5G communications, one is Filter Bank Multi-carrier (FBMC) [5] and the second one is Universal Filtered Multi-carrier (UFMC) [6]. Discussions of other MCM systems are outside the scope of this paper.

Prototype Filters of MCM systems should have good time-frequency (TF) localization capabilities for a doubly-dispersive channels. Bad time localization increases ISI; on the other hand bad frequency localization increases ICI. In FBMC based techniques, Filtering is applied on each sub-carrier of conventional OFDM waveform. In UFMC based techniques, the whole frequency band is decomposed into several sub-bands and each sub-band is composed of a number of sub-carriers. Filtering is applied on each sub-band of UFMC. Sub-band based Filtering of UFMC can relax the requirements of global synchronization which in turn supports the inter-subband asynchronous transmission [7].

Different Prototype Filters and MCM/FBMC systems are discussed in [2], [8]-[13]. The unique feature of FBMC technique is its ability to provide improved frequency selectivity through the use of spectrally efficient Prototype Filters [14]. Some projects on FBMC, such as 5GNOW project, PHYDYAS project, have been mentioned in [15]. Detailed of PHYDYAS project findings are described in [10]. Prototype Filter described in [10] is based on the Filter-design method described in [16]. Prototype Filter described in [10] shows very good frequency localization that reduces the ICI more effectively.

On the other hand, some of the advantages of UFMC systems are robustness against multiple-user interferences, higher spectral efficiency, lower latency and better performance over OFDM [5]. The proposed Prototype Filter for UFMC, which can be found in the literatures, is Dolph-Chebyshev Filter [2].

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In this paper we have discussed two different Prototype Filters for FBMC and UFMC systems. We have introduced Binomial Filter as the Prototype Filter for FBMC and Fractional Powered Binomial Filter (FPBF) as the Prototype Filter for UFMC. We have compared the Binomial Filter and PHYDYAS Filter for FBMC systems. It was observed in our simulations that the PAPR of Binomial Filter based FBMC is better than the PAPR of PHYDYAS Filter based FBMC. It was also observed in our simulations that PAPR of FPBF based UFMC is better than the PAPR of Dolph-Chebyshev Filter based UFMC.

The paper is organized in the following way. Binomial Filter and FPBF are discussed in section II. Analysis of PAPR and BER for FBMC is done in section III. Analysis of PAPR and BER for UFMC is done in section IV. Finally conclusion is made in section V.

II. Prototype Filters for FBMC and UFMC Systems

Prototype Filter plays the most vital role in MCM systems. It was mentioned in section I that different Prototype Filters are proposed for different modulation schemes [2], [9]-[10], [13]. In this paper we have described two different Prototype Filters for two different MCM systems. For FBMC based system we have incorporated Binomial Filter and for UFMC based system we have incorporated Fractional-Powered-Binomial Filter (FPBF). FPBF is easily scalable through a single parameter. Weights for $(N+1)$-weight Binomial Prototype Filter can be calculated using (1)-(2):

$$C_L = \frac{N!}{L!(N-L)!} \quad L = 0,1 \ldots, N; \tag{1}$$

$$B_L = {C_L}\Big/{\sum_{L=0}^{N} C_L} \tag{2}$$

Coefficients of FPBF can be calculated using (3):

$$F_{FPBF} = [B_L]^\beta = \left[{C_L}\Big/{\sum_{L=0}^{N} C_L}\right]^\beta \tag{3}$$

The value of β in (3) is within the range 0~1. Fig.1 shows the impulse responses of three Prototype Filters (i.e. PHYDYAS, Binomial, and FPBF).

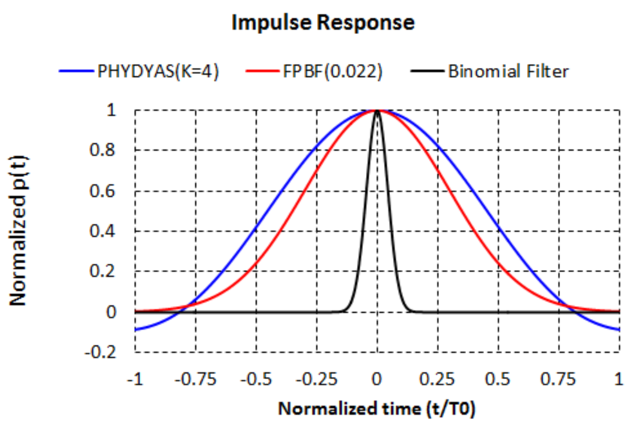


Fig. 1. Impulse responses of different Prototype Filters.

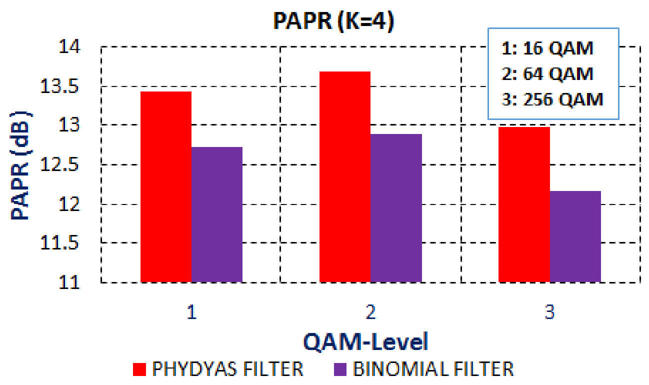


Fig. 2. PAPR of FBMC for two different Prototype Filters and three different QAM levels.

III. Reduction of PAPR in FBMC Through Binomial Prototype Filter

Though the FBMC based method described in the literatures has better PSD [14], it suffers from higher Peak to Average Power Ratio (PAPR) problem due to sub-carrier based Filtering and OQAM modulation [17]. Higher values of PAPR causes non-linearity in power amplifier. In this section we have investigated two different Prototype Filters for FBMC in order to compare PAPR/BER; one is the Prototype Filter described in [Bellanger 2], and the other one is the Binomial Filter described in section II. We have calculated the PAPR and BER for three different QAM-levels: 16 QAM, 64 QAM, and 256 QAM. We have taken the overlapping factor 4 and the number of FFT 512 in the simulations. In our simulation results it was observed that the PAPR of Binomial Filter based FBMC is better (Fig. 2) than the PAPR of FBMC described in [10]. Reduction of PAPR with Prototype Binomial Filter was much better with 256-QAM. Simulated BER performance was also better with Binomial Filter based FBMC (Fig 3). Power spectral densities (PSD) of FBMC with two different Prototype Filters are shown in Fig. 4, which shows that the reduction of out of band interference is better in Binomial Filter based FBMC. In the simulation results lowest PAPR was found as 12.17 dB with Binomial Filter (256 QAM). Simulation results indicate that the Binomial Filter can achieve lower PAPR with higher QAM level.

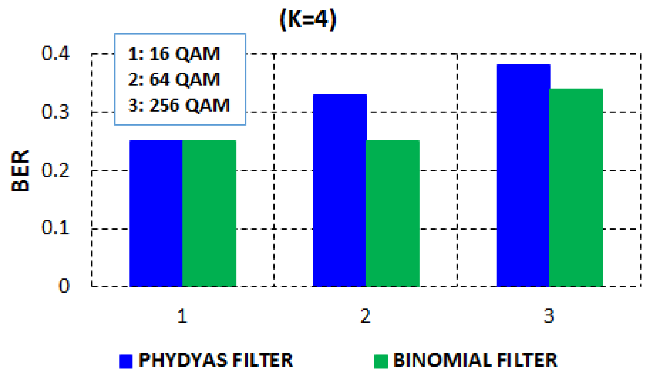


Fig. 3. BER of FBMC for two different Prototype Filters and three different QAM levels.

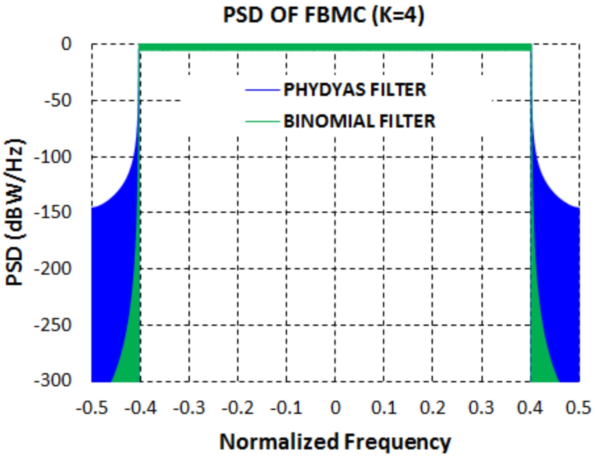


Fig. 4. PSD of FBMC for two different Prototype Filters (at 256 QAM).

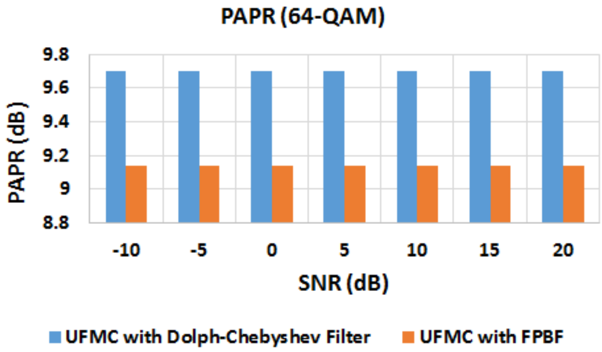
IV. Reduction of PAPR and BER in UFMC Through Fractional-Powered Binomial Filter (FPBF)

In section III, we have described the effect of Binomial Filter on FBMC. In this section we have described the effect of FPBF on UFMC. Binomial Filter has better time localization property. On the other hand FPBF has better time-frequency (TF) localization property. TF localization property of FPBF is also controllable through β of (3). In UFMC, FPBF performs better than Dolph-Chebyshev Filter. Some of the parameters used in MATLAB simulations of UFMC are as follows:

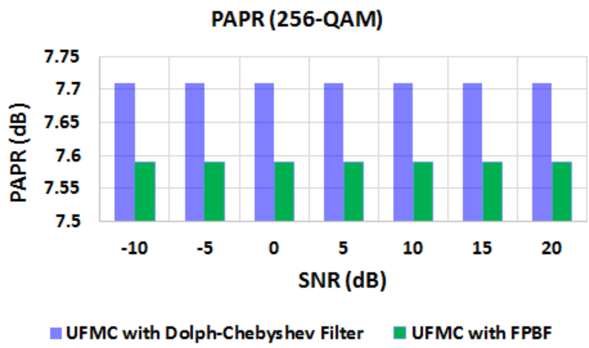
Filter length: 72;
Sub-band size= 24;
No. of sub-bands =12;
FFT size =512;
SNR: -10 dB~20 dB;
QAM level: 64 QAM and 256 QAM;
Side lobe attenuation of Dolph-Chebyshev Filter: 60 dB;
$\beta = 0.01$ (For FPBF with 64 QAM);
$\beta = 0.20$ (For FPBF with 256 QAM);

The simulation results of PAPR and BER for two different Prototype Filters of UFMC are shown respectively in Fig. 5 and Fig.6. It was observed that PAPR does not vary with the variation of SNR. Minimum PAPR was 7.59 dB at 256 QAM with FPBF based UFMC. BER in case of FPBF based UFMC was also identical to that of Dolph-Chebyshev based UFMC. Though in some cases FPBF based UFMC obtained better BER (Fig. 6).

PSD of FPBF based UFMC was also superior than that of 60 dB Dolph-Chebyshev Filter based UFMC (Fig. 7). In both cases of PSDs the value of SNR was 0 dB at 256 QAM level. It can be seen from Fig. 7 that the sub-band interferences as well as out of band interferences are minimized in case of FPBF based UFMC. Interference level within 4^{th}~24^{th} sub-bands (due to 1^{st} sub-band) was about 58 dB less in case of FPBF based UFMC in comparison to that of 60 dB Dolph-Chebyshev Filter based UFMC.



(a) *PAPR for 64 QAM.*



(b) *PAPR for 256 QAM.*

Fig. 5. PAPR vs, SNR of UFMC for two different Prototype Filters and different QAM levels.

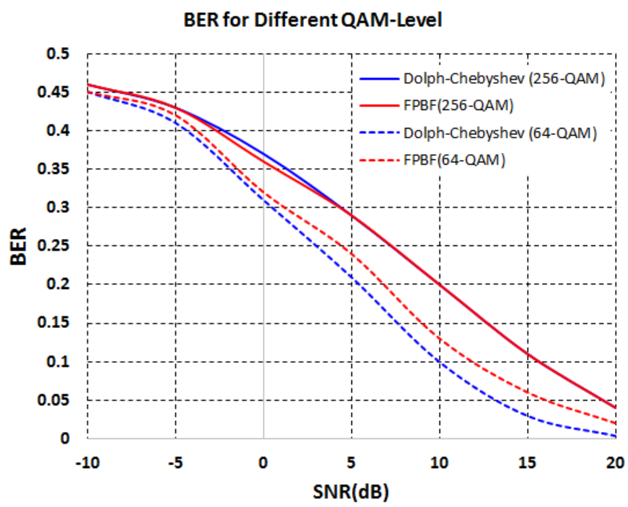
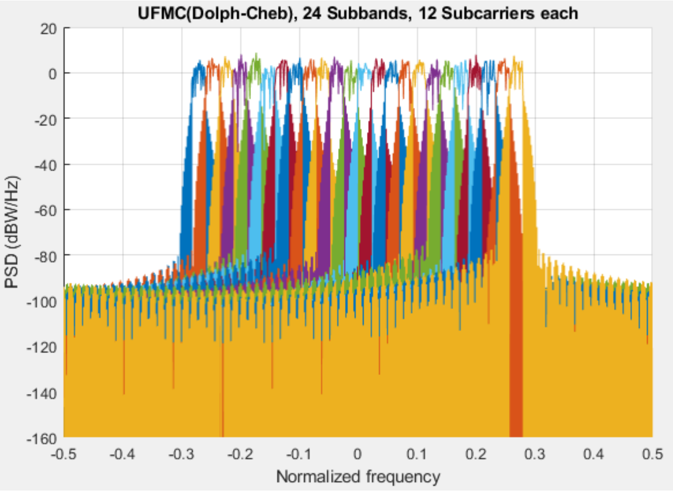


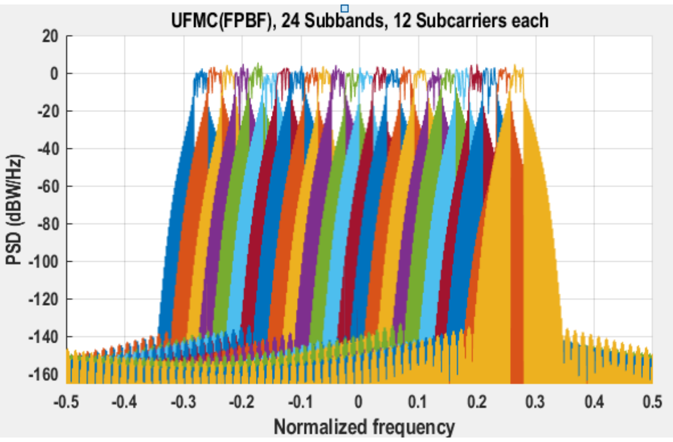
Fig. 6. BER vs. SNR of UFMC for two different Prototype Filters and two different QAM levels.

V. Conclusion

It is expected that the 5G wireless technologies will be implemented by the year 2020. This paper describes the incorporation of two different Prototype Filters based Mult-Carrier Modulation (MCM) systems. One of them is the FBMC based on Binomial Filter. It was observed through simulations that the Binomial Prototype Filter performs better than the PHYDYAS Prototype Filter. Reduction of PAPR is better in case of Binomial Filter with higher order of



(a) PSD of UFMC with Dolph-Chebyshev Filter.



(b) PSD of UFMC with FPBF.

Fig. 7. PSD of UFMC for two different Prototype Filters (256 QAM, SNR 0 dB).

modulation (at 256 QAM). PAPR with the Binomial Filter and 256-QAM was 12.17 dB. On the other hand PAPR for the identical case with the PHYDYAS Filter was 12.98 dB. Out of band interference of FBMC can also be minimized through Prototype Binomial Filter. Another Prototype Filter (FPBF) was compared with 60 dB Dolph-Chebyshev Filter in case of UFMC. It was observed that the FPBF can also reduce the PAPR of UFMC. PAPR of UFMC with FPBF (at 256-QAM level) was 7.59 dB. On the other hand PAPR for the identical case with 60 dB Dolph-Chebyshev Filter was 7.71 dB. Higher QAM level can increase the bit rate. It can be concluded that the described Binomial Filter and FPBF can be used as Prototype Filters respectively for FBMC and UFMC at higher QAM-level with reduced PAPR.

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