Performance Optimization of Peak to Average Power Ratio in FBMC Waveforms

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Abstract: High spectral efficiency and low computational complexity are requirements of the 5G wireless communication systems. They must also offer low PAPR (peak to average power ratio), low latency, and high throughput. In 5G it is not possible to realize all of these requirements through a single technique. One of the efforts is to look for a suitable technique for 5G. Therefore, a suitable technique Filter Bank Multicarrier (FBMC) emerges. But it has a high complexity, high Peak to Average Power (PAPR) and high out of band (OOB) leakage which results in inter-carrier interference and inter-channel interference. Also, due to high PAPR, mobile batteries are depleted more rapidly. So, a PAPR reduced method is needed. In this paper, a method of Pruned DFT Precoded FBMC to optimize the PAPR for different number of subcarriers has been studied. The performance evaluation in terms of bit error rate (BER) and spectral efficiency of OFDM, FBMC and Pruned DFT Precoded FBMC has been done in this paper. In DFT Precoded FBMC, a DFT spreading matrix is multiplied with FBMC waveform and is transmitted only some part especially half of the DFT precoded matrix and the rest remain zero. Monte Carlo simulation with one tap equalizer is used to validate our results.

Keywords: 5G, FBMC, DFT, PAPR, TDL

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I. INTRODUCTION

As we try to build a waveform with certain required features, the others one fall, and this is why we are improving the engineering of the waveform to provide better features than what existed in the previous generation. Therefore, Filter Bank Multicarrier (FBMC) [1-2] comes into play because of its flexible time and frequency resources. Additionally, it is synchronization dependent compared to OFDM. A OFDM waveform is a Sinc function in frequency domain, so even though the others are orthogonal, the peak occurs at the zero of the neighbouring subcarriers, however, slight offsets cause a severe penalty because of Inter Channel Interference (ICI), with guard interval being small, and channel impulse response extending beyond the Cyclic Prefix (CP), ICI and ISI are present, resulting in performance degradation. FBMC has greater resilience than OFDM, and it has better spectral efficiency because it produces circular pulses. FBMC has a high complexity, high out-of-band leakage, and a high PAPR. This high PAPR calls for power amplifiers with high linear (gain) ranges. But to increase the efficiency of a power amplifier its gain becomes nonlinear, resulting in a distorting of the FBMC signal. Thus, a PAPR reducing technique is needed. Several techniques have been proposed to reduce the PAPR in OFDM, such as selective mapping [3] or partial transmission sequences [4]. Those methods can also be applied to FBMC as in [5-7]. All of these techniques however need highly sophisticated computational capacities. The drawbacks of these systems explain why they are not used in practical systems. For the uplink, 4G LTE uses Single Carrier - Frequency-Division Multiple Access (SC-FDMA) [8], a precoded OFDM system based on DFT. Additionally, the same technique will be used in the Fifth Generation (5G) of wireless communication systems (in addition to CP-OFDM) [9]. In Discrete Fourier Transform spreading based generalized frequency division multiplexing (Pruned DFT Precoded FBMC), simply combining FBMC and a DFT, as in SC-FDMA [10-12]. Ihalainen et.al [10] propose precoding by a filter bank rather than a DFT to improve the performance.

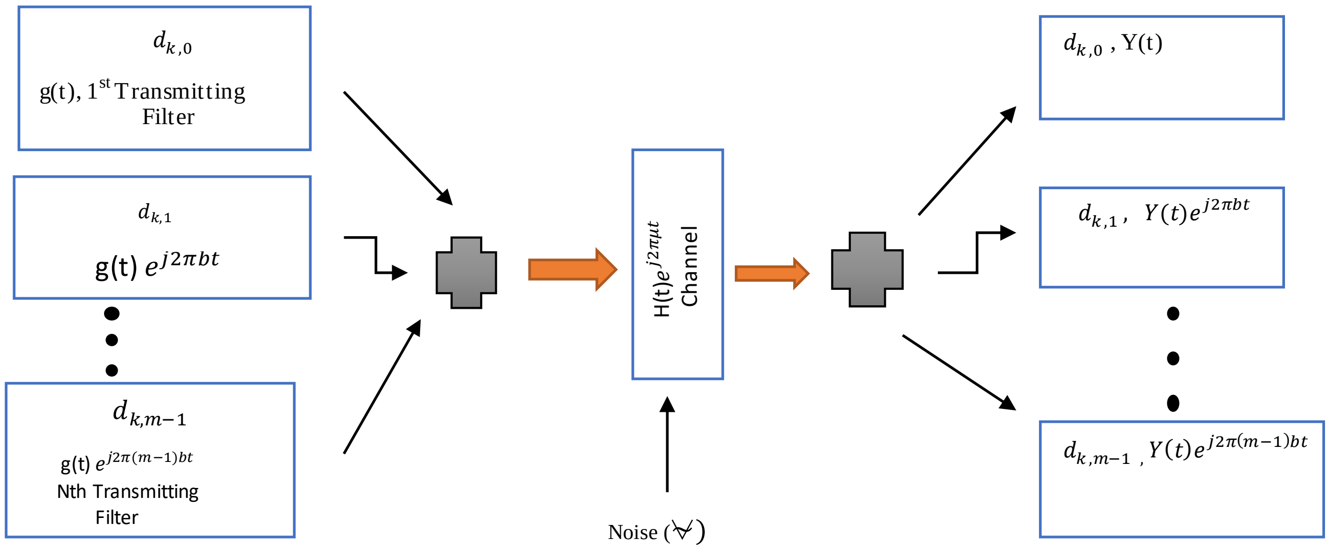

Fig.1. A Gabor System Multicarrier Communication

To optimize the PAPR of FBMC, a new modulation scheme is proposed called Pruned DFT Precoded FBMC with one-tap scaling. In this paper, for different number of subcarriers (64, 128, 512, 1024) of OFDM, FBMC PAPR value is calculated. Thereafter a method named Pruned DFT Precoded FBMC with one tap scaling is used to reduce the PAPR value of FBMC. In addition to this, the performance evaluation of BER, spectral efficiency of OFDM, FBMC and pruned DFT precoding FBMC in real-time doubly selective TDL-A channels has been done. This TDL Channel [13] is a Tapped Delay Line mode that was introduced by the Third Generation Partnership Project (3GPP). The results obtained by author are validated by the Monte Carlo simulation. On account of good time localization, the Hermite filter is used to simulate FBMC and DFT Precoded FBMC [14]. This paper is organized as section II talking about FBMC. A mathematical description of FBMC is given in section III. A PAPR reduction method "Pruned DFT Precoded FBMC" is given in section IV. About Prototype filters are given in section V. Result is presented in section VI. Finally, the Conclusion and Reference are given in sections VII, VIII respectively.

II.FBMC

An FBMC signal is a combination of OFDM with single-carrier block transmission with frequency-domain equalization (SC-FDE). This waveform foundation is taken from Gabor's proposal in which a function can be expanded into a series of elementary functions which are constructed out of the translational and modulatory modulation (transition in time and frequency domain) of a single building block. Below is the mathematical representation of transmitted FBMC waveform, f(t) as

$$f(t) = \sum_{n,m \in z} C_{m,n}\, g_{m,n}(t) \quad (1)$$

where elementary function $g_{m,n}$ is given by

$$g_{m,n}(t) = g(t-na)\, e^{2\pi imbt} \;,\; m,\, n \in Z \quad (2)$$

Equation (2) represents shifting and modulating copy of the fundamental building block g(t) [15], where g(t) is a time and frequency transforming function [14]. A schematic showing Gabor's proposed FBMC signal transmission is shown in Fig.1.

Fig. 2 shows a cyclic prefix added to each OFDM symbol subcarriers and Fig.3 is shown blocks of FBMC. There is one CP in front of it, thereby it helps to have a better spectral efficiency even than OFDM.

CP	Time Slot# 1	CP	Time Slot#2	CP

Fig.2. OFDM Subcarriers with CP

CP	Time Slot#1	Time Slot#2	CP

Fig.3. FBMC Subcarriers with CP

In FBMC it has a circular pulse shape. In OFDM all the frequency components will be present in 1 to N so that in each symbol duration it has processed samples, whereas in the case of FBMC it has taken the whole block together. If there are M number of time blocks and N subcarriers, then M times number of one sample is to be processed.

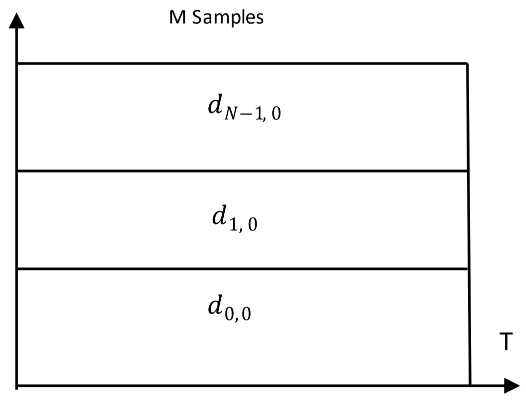

Fig.4(a). OFDM

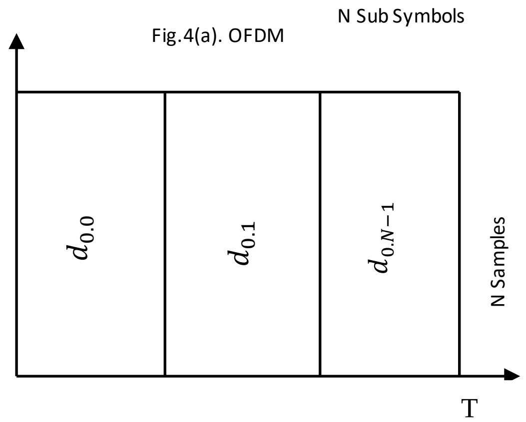

Fig.4(b). SC-FDE

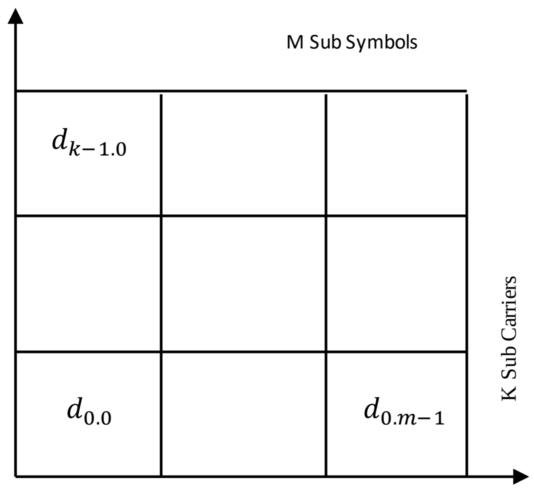

Fig.4(C). FBMC

In Fig. 4 (a) we have separated sub-carriers associated with OFDM and that subcarrier existed for time duration and each subcarrier has a different carrier frequency. Fig. 4 (b) shows SC-FDE (Single Carrier Frequency Division Equalizer) in which a single carrier covers the entire band. It is a kind of small duration of the symbol because bandwidth is large so in one case it is Frequency Division Equalizer (FDE). It is more of Time Division Multiplexing (TDM) architecture. Fig. 4 (c) combines both FDM, TDM because it is a block-based system so there are M blocks in a time domain and there are N subcarriers in the frequency domain.

III. MATHEMATICAL DESCRIPTIONS OF FBMC [1][14][16]

Let M be the number of Time slots, N be the number of subcarriers. In the system model, the basis transmitted signal in Equation (1) can be represented by

X = $\sum_{l=0}^{MN-1} a_l^N d_l^{-N} = \sum_{l=0}^{MN-1} d_l^{-N} * l^{th}$ column vector (3)

Where, $a_l^N = A_N d^{-N}$,MN – Number of Gabor's atom, a_l^N - Pulse Shape, d_l^{-N} - Data Symbol

The FBMC signal is presented in matrix form given below, which is more convenient than that shown by (3)

$X_{MN*1} = A_{MN*MN}\, d_{MN*1}$ (4)

The received signal Z after frequency selective fading channel and CP removal can be given as

Z = HAd + ∀ (5)

where ∀ - Noise, H – Circular channel matrix which represent convolution operation.

Equation (5) can be expanded as

Z = $W_{MN}\ \Lambda\ W_{MN}^{H}$Ad + ∀ (6)

where W_{MN} represents MN order IDFT matrix, Λ - diag {ĥ (0), ĥ (1), ĥ (2) ……ĥ(MN-1)} is diagonal channel frequency matrix, A - Hermite filter coefficient and d - data symbol.

To recover data symbol d from received signal Z by using the two-stage receiver. In a two-stage receiver, the channel is first equalized, followed by FBMC self-interference equalization. A channel equalized vector can be expressed as follows

Y = $W_{MN}\ \Lambda_{eq}\ W_{MN}^{H}$ Z + ∀ W_{MN}^{H} (7)

Where

Λ_{eq} =
- Λ^{-1} for Zero Forcing Frequency Domain Equalization (ZF FDE)
- $[\Lambda^{H}\Lambda + \frac{\sigma_v^2}{\sigma_v^2} I_{MN}]$ ^ (-1) Λ^{H} for minimum mean-squared error (MMSE) FDE

Self-interference equalized vector can be given as

d = A_{eq}Y (8)

where

A_{eq} =
- A^H for Matched filter equalizer
- A^{-1} for zero forcing Equalizer
- $[R_v + A^H A]^{-1} A^H$ for biased MMSE equalizer
- ®FBMC^{-1} $[R_v + A^H A]^{-1} A^H$ for unbiased MMSE equalizer

®FBMC= diag { [$\frac{\sigma_v^2}{\sigma_d^2}$ I + A^H A]^(-1)A^HA} is bias correction matrix.

R_v is noise correlation matrix after channel equalization.

IV. PRUNED DFT PRECODED FBMC

Here precoding of FBMC with DFT spread matrix is performed similarly as that in DFT-Spread-OFDM or SC- FDMA. In DFT-Precoded FBMC [1] there is DFT precoding then subcarrier mapping matrix is followed by FBMC. This precoding is done before the FBMC transmitter as illustrated in Fig. 5. Here, the data symbol(d) is multiplied with the precoding matrix P_{MN*MN}(where P = $P_m P_c$ in which P_c is DFT spreading matrix and P_m is permutation matrix to implement subcarrier mapping) to obtain precoded data symbol [16]. The subcarrier mapping can be either (Localised Frequency Division Multiple Access) LFDMA or (Interleaved Frequency Division Multiple Access) IFDMA. In this paper, LFDMA is used. P_m is the identity matrix for LFDMA. In equation (4) if we put precoded data symbol(đ) so that the received signal as given in Equation (6) is modified as.

$$Z = W_{MN} \wedge W_{MN}^H A \, đ + ⩔ \quad (9)$$

In Pruned DFT [14], only half of the DFT matrix transmits and the rest half is set to zero. This is done to preserve the spectral efficiency up to the expected level as compared to FBMC. This is the overall architecture of Pruned DFT precoded FBMC. In DFT Precoded FBMC, as in SC-FDMA, performs poorly in real scenario [17-19] and does not produce a good trade-off between relevant factors such as Spectral efficiency, Latency, Robustness to a doubly selective channel. In the paper number of cyclic prefixes is set to zero for efficient utilization of channel bandwidth and no spectral efficiency loss.

V. PROTOTYPE FILTERS

In designing the FBMC waveform mostly the PHYDYAS filter is used [20]. The PHYDYAS filter has poor time localization. So, in this paper a Hermite filter is used. It has good time-frequency localization [21]. It is represented as

$$p_{Herm}(t) = \sqrt{(F} \; e^{-2\pi (tF)^2} \sum_{i=\{0,4,8,12,16,20\}} \alpha_i \; H_i\{2\sqrt{\pi t F}\} \quad (10)$$

Where α_i is given in [22-23].

Also, the Hermite pulse is zero outside the interval when the overlapping factor(O) does not exceed 1.5.

$$P_{Herm.Trunc}(t) = \begin{cases} P_{Herm}(t) & \text{if } -\frac{1.56}{2F} \leq t \leq -\frac{1.56}{2F} \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

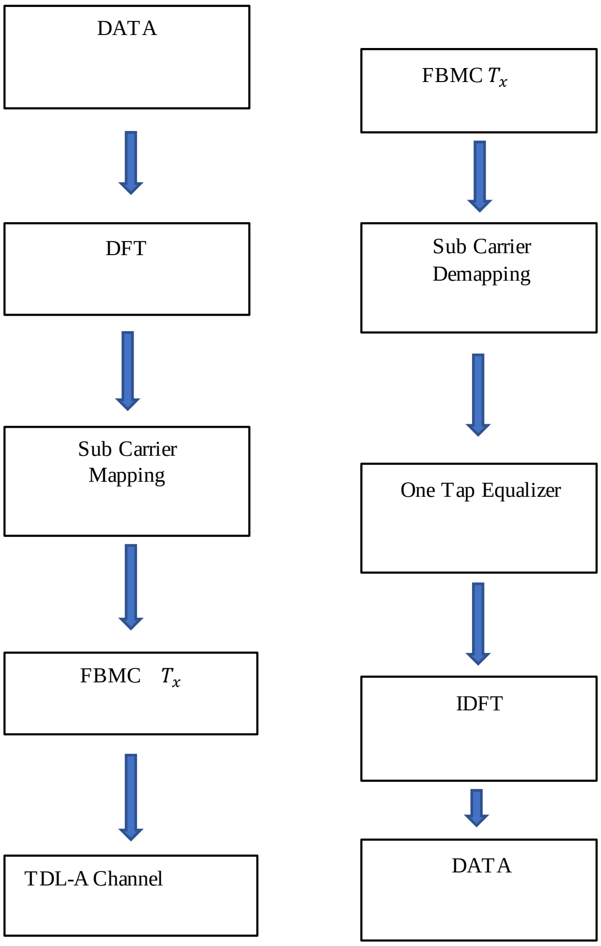

Fig.5. Block diagram of Pruned DFT Precoded FBMC

In pruned DFT precoded FBMC a Hermite Truncel filter is used. The reason for this is that it provides a good trade-off between out of band (OOB) emission, latency, and robustness to a doubly selective channel. In FBMC only real data value is transmitted. But in Pruned DFT Precoded FBMC real value data is changed into complex value because of DFT precoding in the only frequency domain [14].

TABLE I. SIMULATION PARAMETER

S.No.	***Simulation Parameter***	***Values***
1	QAM_order	16
2	Number of subcarriers (N)	64,128,512,1024
3	Power delay profile	300 ns
4	Carrier frequency	2.5 GHz
5	Number of Monte Carlo repetitions	150
6	Velocity in km/h	250
7	Number of multipath propagations for the WSSUS process	50

TABLE II. PAPR (dB) VALUE AT DIFFERENT SUBCARRIERS

S.No.	Waveforms	PAPR (dB) for N=64	PAPR (dB) for N=128	PAPR (dB) for N=512	PAPR (dB) for N=1024
1	OFDM	5.67	6.36	7.55	7.79
2	FBMC	5.58	6.31	7.56	7.77
3	Pruned DFT Precoded FBMC	3.94	4.31	4.85	4.87
4	Difference in PAPR of FBMC and Pruned DFT Precoded FBMC	1.64	2.02	2.71	2.9

VI.RESULT

It is found that the PAPR of FBMC and OFDM is approximately the same for the different number of subcarriers. A method named Pruned DFT Precoded FBMC has been identified to reduce the PAPR of FBMC. All the simulation parameters are considered as per that given in Table 1. It is observed from Fig. 6-9 for the different number of subcarriers (64, 128, 512, 1024) the PAPR of Pruned DFT Precoded FBMC is significantly reduced as compared to FBMC. In simulating FBMC, the Hermite filter is used and in Pruned DFT Precoded FBMC Hermite truncel.46 filter has been used. Moreover, the number of Cyclic Prefix (CP) for pruned DFT Precoded FBMC can usually be set to zero as there is no spectral efficiency loss.

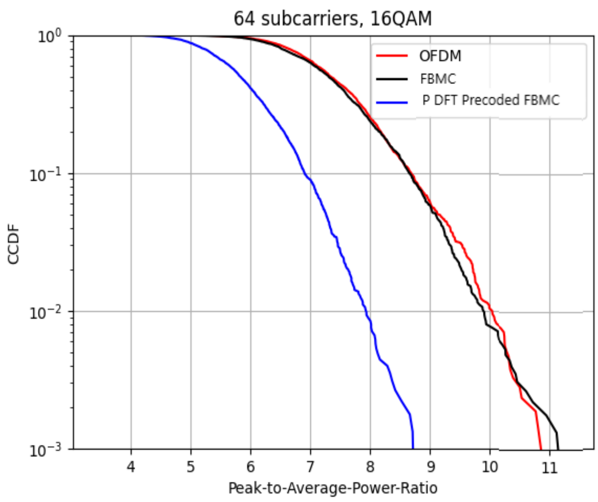

Fig.6. PAPR Vs CCDF for 64 Subcarriers

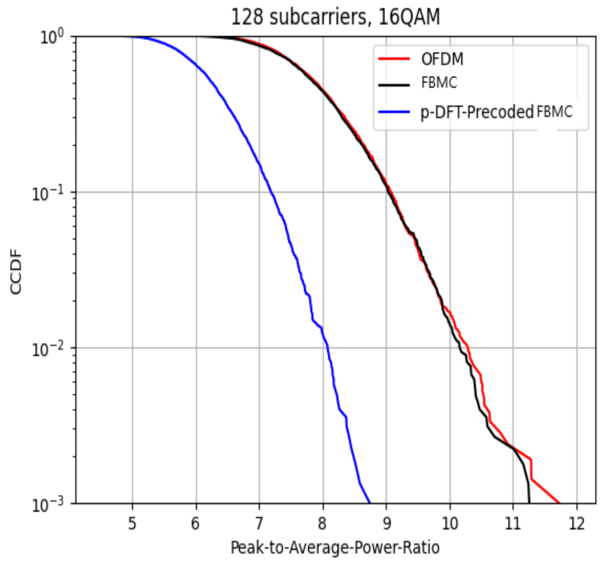

Fig.7. PAPR vs CCDF for 128 Subcarriers

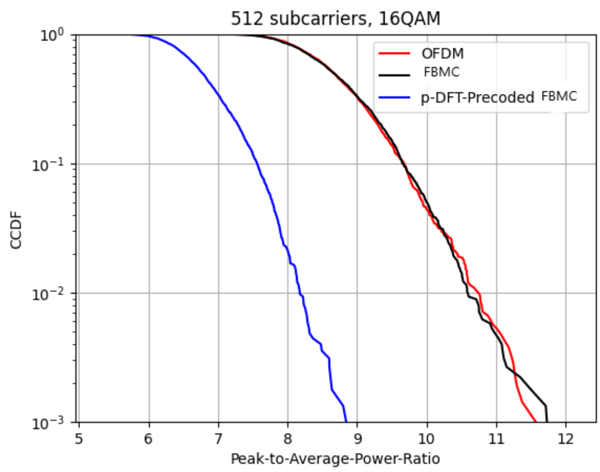

Fig.8. PAPR vs CCDF for 512 Subcarriers

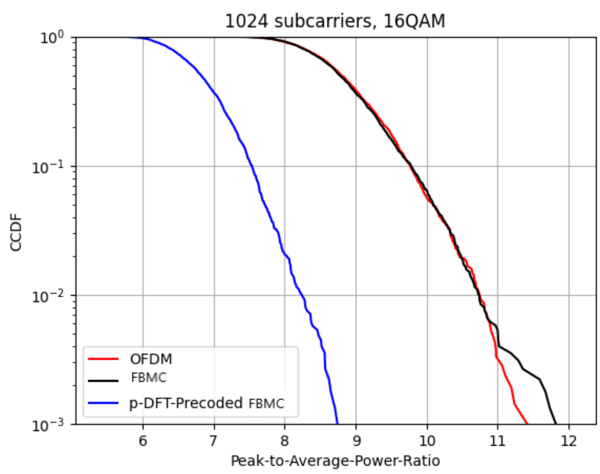

Fig.9. PAPR vs CCDF for 1024 Subcarriers

It is shown in Fig. 10-13 that as SNR is increasing, the BER is decreasing for FBMC and Pruned DFT Precoded FBMC. But here as the number of subcarriers is increasing the BER is reduced more for Pruned DFT Precoded FBMC as compared to FBMC. In simulating bit error rate performance, the

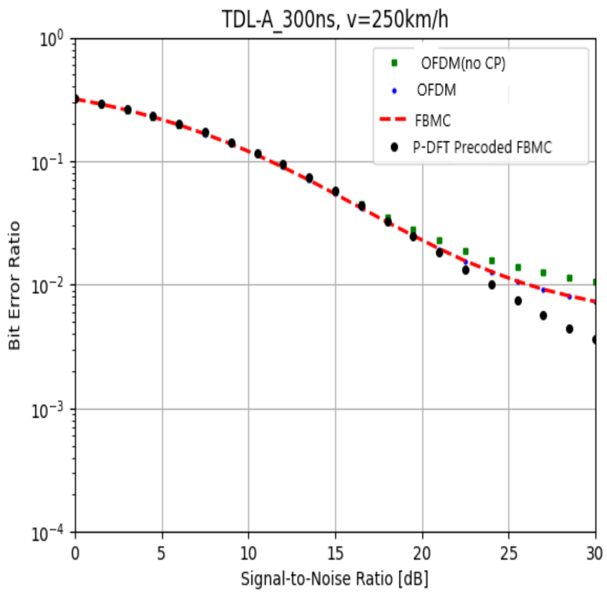

Fig.10. BER vs SNR for 64 Subcarriers

channel used is (Tapped Delay Line) TDL-A. This channel is defined in Technical Report 38.901[24] of 3GPP. The TDL mode is defined for the frequency range 0.5 GHz to 100 GHz in Non-Line of Sight (NLOS) transmission.

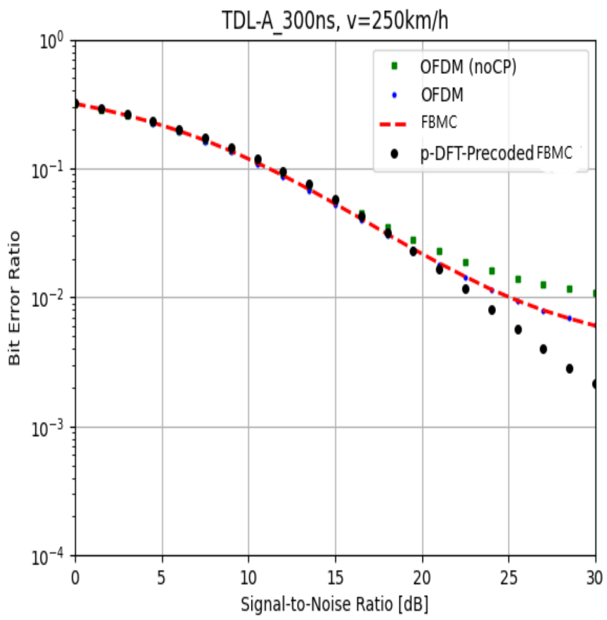

Fig.11. BER vs SNR for 128 Subcarriers

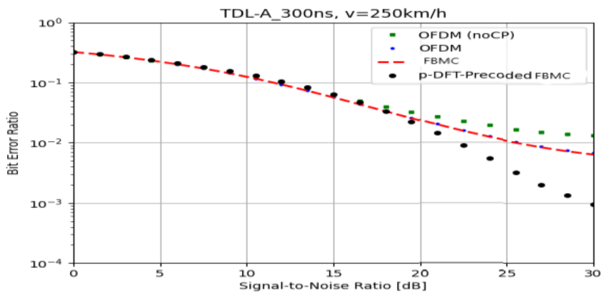

Fig.12. BER vs SNR for 512 Subcarriers

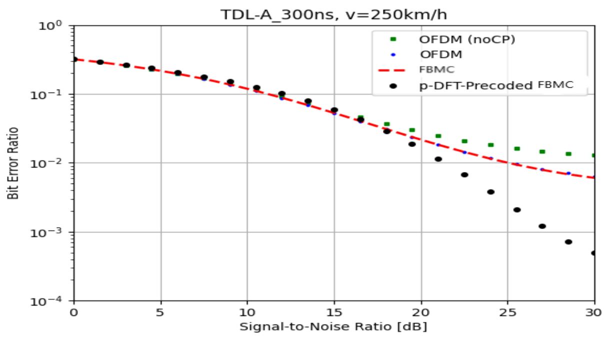

Fig.13. BER vs SNR for 1024 Subcarriers

In the simulation studies, it is found that very small difference in the PAPR value of the OFDM and FBMC waveforms. When we use a method Pruned DFT Precoded FBMC the PAPR value is reduced by 1.64dB for N= 64, 2.02dB for N= 128, 2.71dB for N= 512, 2.9dB for N= 1024. From the above observation, it is concluded that as the number of subcarriers is increases, the PAPR value is also increased. Also, the difference in PAPR of FBMC and Pruned DFT Precoded FBMC increases as the number of subcarriers is increased. It means Pruned DFT Precoded FBMC is significant for the higher number of subcarriers. Table II. illustrates the PAPR value at different subcarriers.

TABLE III. BIT RATE AND SPECTRAL EFFICIENCY OF OFDM, FBMC, AND PRUNED DFT PRECODED FBMC

S.No.	No. of Subcarriers(N)	Parameters	OFDM	FBMC	Pruned DFT precoded FBMC
1	64	Bit rate	3.58 Mbps	3.84 Mbps	3.84 Mbps
		Spectral Efficiency	3.73 bits/sec./Hz	4 bits/sec./Hz	4 bits/sec./Hz
2	128	Bit rate	7.16 Mbps	7.68 Mbps	7.68 Mbps
		Spectral Efficiency	3.73 bits/sec./Hz	4 bits/sec./Hz	4 bits/sec./Hz
3	512	Bit rate	28.67 Mbps	30.72 Mbps	30.72 Mbps
		Spectral Efficiency	3.73 bits/sec./Hz	4 bits/sec./Hz	4 bits/sec./Hz
4	1024	Bit rate	57.34 Mbps	61.44 Mbps	61.44 Mbps
		Spectral Efficiency	3.73 bits/sec./Hz	4 bits/sec./Hz	4 bits/sec./Hz

In table III it is shown that as the number of subcarriers is increased, the bit rates increases but the bit rates of FBMC and Pruned DFT Precoded FBMC are the same over the same channel bandwidth. The Spectral efficiency of FBMC and Pruned DFT Precoded FBMC are the same and is found to be 4 bits/sec/Hz. Also, the spectral efficiency of FBMC and Pruned DFT precoded FBMC is 0.26 bits/sec./Hz more than that in OFDM. From Table III, it is observed that there is no change in spectral efficiency as the number of subcarriers is increased for OFDM, FBMC, and Pruned DFT Precoded FBMC. All the simulations have been performed in Python 3.

VII. CONCLUSION

Reducing the PAPR value is important for various 5G waveforms for proper amplification and to increase the mobile battery backup. From the result, we conclude that as the number of subcarriers increases the PAPR value increases but by using the method Pruned DFT Precoded FBMC there is a significant reduction in PAPR. This method has less complexity than other PAPR reduction methods. Also, this method is approximately similar to that of SC-FDMA, a method to reduce the PAPR value of OFDM in 4G Uplink. This PAPR reduction method is a more robust system in doubly-selective channels, requires no CP, and has considerably lower out of band emissions. So, it is applicable in real-time communication equipment.

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