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# PERFORMANCES COMPARISONS OF PAPR REDUCTION SCHEME FOR FBMC/OQAM AND OFDM SYSTEMS

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## Abstract
Multi-carrier transmission scheme such as OFDM (Orthogonal Frequency Division Multiplexing) has some disadvantages of large PAPR (Peak-to-Average Power Ratio) compared to a single carrier transmission scheme. Similar to other multicarrier systems like OFDM, a fundamental drawback of FBMC/OQAM(Filter Bank Multicarrier with Offset QAM) systems is the large PAPR of the signal. In this paper, we consider the signal structure of the FBMC/OQAM and verify whether the conventional PAPR reduction scheme for OFDM system is still effective to FBMC/OQAM or not. Theoretical analysis and simulations show that there needs to be some modification of the conventional PAPR reduction in consideration of the overlapping structure of the FBMC/OQAM signal.

**Keywords**: PAPR reduction, FBMC, OQAM, OFDM.

## Introduction
The FBMC/OQAM (Filter Bank Multicarrier with Offset QAM) has attracted increasing attention as the transmission schemes for 5G mobile communication recently, due to its high spectral efficiency and low leakage power between band sidelobe [1-2]. However, a fundamental drawback of FBMC/OQAM systems is the high PAPR (Peak-to-Average Power Ratio) of the signal which is similar to other multicarrier systems such as OFDM. In general, the high PAPR degrades the output signal of a high-power-amplifier (HPA) when the signal passes through a nonlinear HPA region because the nonlinearity of HPA leads to both in-band distortion and out-of-band radiation. There have been various PAPR reduction techniques for OFDM among which TR (tone reservation), PTS (Partial Transmit Sequence), DFT (Discrete Fourier Transform) attracted much attention [3]. Due to the similarity between the FBMC/OQAM and OFDM systems, it is natural to consider these techniques to reduce the PAPR of FBMC/OQAM signals. However, FBMC/OQAM signals have a somewhat different signal structure compared with the OFDM signals. Therefore, it is not a good solution to apply the PAPR reduction techniques for the OFDM systems to FBMC/OQAM systems directly.

In this paper, we analyze the PAPR reduction scheme considering the signal structures of OFDM and FBMC/OQAM and derive a design rule for PAPR reduction scheme for FBMC/OQAM.

## SYSTEM MODEL
### Signal Model for OFDM
We are more concerned with the reduction of the PAPR of the continuous-time FBMC/OQAM signal. However, most existing PAPR reduction schemes are only implemented for discrete-time signals. To approximate the true PAPR of the signal, we assume that the FBMC/OQAM signal is over-sampled with the discrete-time signals. It is known that PAPR of the discrete-time signal is approximately same as that of the continuous-time signal when the oversampling coefficient $L \geq 4$ [5].

At the transmitter, the *m*th discrete time-domain OFDM signal is the sum of *N* independent modulated symbols which are mapped on each *k*th subcarrier and is modeled as [4]

$$S_{ofdm}^{m}[n] = \sum_{k=0}^{N-1} c_k^m e^{j\left(\frac{2\pi}{F}\right)kn} \quad (1)$$

where $n$ is the index for time-domain sample and $c_k^m$ is the complex data modulated symbol of *k*th subcarrier. The OFDM signal is sampled with sampling period $T/F$, where $F = LN$ and $L$ is the oversampling factor and we assume $L$=4.

In general, the PAPR is defined as the ratio of the maximum instantaneous power and its average power [5] and the PAPR of (1) is given as

$$\mathrm{PAPR}_{ofdm} = \frac{\mathrm{Max}\,|S_{ofdm}[k]|^2}{E\left[|S_{ofdm}[k]|^2\right]} \qquad (2).$$

**Signal Model for FBMC/OQAM**

In this section, we model the FBMC/OQAM signal and consider its PAPR. At the transmitter of the FBMC/OQAM system, the *m*th discrete time-domain signal is also the sum of *N* independent modulated symbols which are mapped on each *k*th subcarrier and is modeled as [4].

$$S_{fbmc}^{m}[n] = \sum_{k=0}^{N-1} d_n^m[k] \exp^{jn\left(\frac{2\pi k}{F}+\frac{\pi}{2}\right)} \qquad (3)$$

where $d_k^m$ is the complex data modulated symbol of *k*th subcarrier and can be expressed as

$$d_n^m[k] = a_n^m h[k-mF] + jb_n^m h[k-mF-F/2] \qquad (4)$$

where $a_k^m$ and $b_k^m$ are real and imaginary parts of the *m*th symbol on the *k*th subcarrier, respectively. The *m*th FBMC/OQAM symbol consists of data block $\boldsymbol{d}^m = [d_0^m, d_1^m, \ldots, d_{N-1}^m]^T$ whose component is mapped on each subcarrier.

The real and imaginary components of the symbols are staggered in time-domain by $F/2$. Also, $h(t)$ is the continuous time filter used at the FBMC/OQAM system, which is given as

$$h(t) = 1 + 2\sum_{i=1}^{K} H_i \cos\left(2\pi \frac{it}{KT}\right) \qquad (5)$$

where $h[k]$ is the discrete-time filter obtained by sampling the continuous time filter $h(t)$ and $H_i$ is the frequency response of $h(t)$. Also, *K* is the overlapping factor and assumed as *K*=4. It is assumed that $h(t)$ has the length of $T_h$ in time domain. Apparently, the signals of adjacent data blocks overlap with each other due to the fact that the filter length is $T_h > T$ [4]. Then, the symbols are passed through a bank of transmission filters and are modulated with *N* subcarrier modulators. Similar to OFDM signal, the PAPR of the FBMC/OQAM signal is given as [6]

$$\mathrm{PAPR}_{fbmc} = \frac{\mathrm{Max}\,|S_{fbmc}[k]|^2}{E\left[|S_{fbmc}[k]|^2\right]} \qquad (6).$$

## Papr Reduction Schemes

There have been several approaches to overcome PAPR problem in OFDM system. The simplest method is clipping techniques [7] which deliberately clips the OFDM signal before amplification. It can reduce PAPR, but may cause both in-band and out-of-band interference due to its nonlinear process and consequently destroy the orthogonality among subcarriers. Another method is coding technique which uses the codewords that minimize the PAPR without distortion and out-of-band radiation. However coding-based PAPR reduction technique requires the transmission of side information such as Partial Transmit Sequence (PTS), Tone Reservation (TR), DFT-Spreading, etc.

**PTS (Partial Transmit Sequence)**

The partial transmit sequence (PTS) technique partitions an input *m*th data block of *N* symbols into *V* disjoint subblocks $\boldsymbol{x}_v$, $v = 1,2,\ldots,V$, where $\boldsymbol{x}_v$ is PTS. Then each partitioned subblock is multiplied by a corresponding weighting factor $\mathrm{b}_v = e^{j\emptyset v}$ which represents the phase rotation. The phase rotation vector is chosen so that the PAPR can be minimized and index for the optimum phase rotation vector is transmitted to receiver as the side information. The OFDM system has a signal structure in which adjacent data blocks do not overlap. Therefore, the conventional PTS scheme optimizes phase rotation vectors for each data block independently. However, the PAPR of the

FBMC/OQAM segment is affected by multiple adjacent data blocks due to adjacent data blocks overlap. Consequently, it is not a good solution to adopt conventional independent PTS scheme directly to FBMC/OQAM. It is necessary to optimize PTS considering the overlapped data subblock of FBMC/OQAM system.

**DFT-Spreading**

The DFT-spreading technique is the method using Fourier matrix as a spreading code. The OFDM system becomes equivalent to the single carrier system because the DFT and IDFT operations virtually cancel each other. In this case, the transmit signal will have the same PAPR as in a single carrier system. The DFT-spreading scheme allocates a spreading code to $N_s$ parallel data symbols in OFDM system. However, the filter length of FBMC/OQAM system should satisfy the constraint of $T_h > T$. Therefore, it is not a good solution to allocate a spreading code to $N_s$ parallel data symbols similarly to the OFDM system and is necessary to design the spreading code in consideration of the filter length.

## Simulation Results And Discussion

The most common performance evaluation method of the PAPR scheme is the CCDF (Complementary Cumulative Distribution Function), i.e. $\mathrm{CCDF}(\chi_0) = \Pr(X > \chi_0)$, which represents the probability that the random variable exceeds a certain threshold $\chi_0$.

In this section, we compare the PAPR performances of OFDM signal and FBMC/OQAM signal. When we assume the data sequences $d_k^m$ are independent, identically distributed (i.i.d.) random variables, the CCDF of PAPR is given in (7) because the random variable can be modeled as Gaussian random variable using the central limit theorem.

$$\mathrm{CCDF}(\mathrm{PAPR}_0) = \Pr(\mathrm{PAPR} > \mathrm{PAPR}_0) = 1-(1-e^{\chi_0})^N \quad (7)$$

Simulations is conducted in two forms. The first is a form that applies a conventional PTS scheme in OFDM signal and the second is a form that applies a conventional DFT-spreading scheme in FBMC/OQAM signal. In the simulations we assume 256 FFT size and 16-QAM for the OFDM system and FBMC/OQAM system for comparison. The subblock size is 16 in the PTS scheme.

**Figure**:

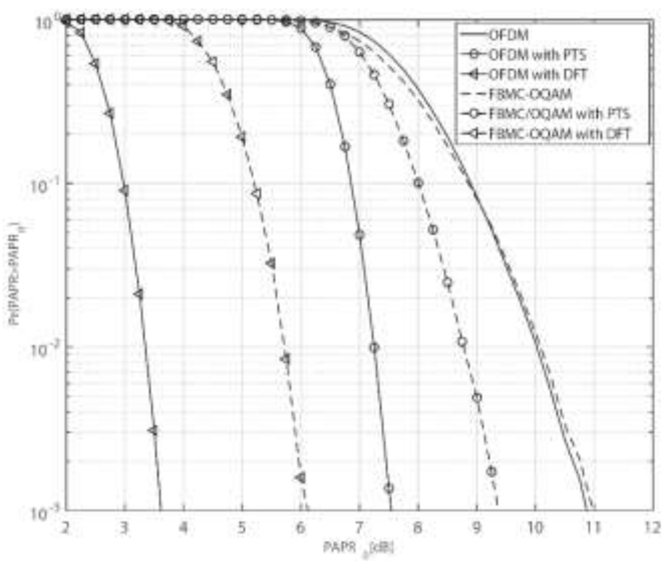


***Fig. 1 CCDFs of OFDM signal and FBMC/OQAM signal***

In the DFT-spreading scheme, we assume the DFT size is 64 and spread symbols are matched with subcarrier placed in the regular interval (256/64=4). Fig. 1 shows CCDF of OFDM and FBMC/OQAM signals through simulations. The curve "OFDM" and "FBMC/OQAM" represents the similar PAPR at CCDF. The PAPR of the PTS scheme with CCDF of $10^{-3}$ increases in almost 1.9 dB in FBMC/OQAM. The PAPR of the DFT-spreading scheme with CCDF of $10^{-3}$ increases in almost 2.5 dB in FBMC/OQAM. As shown in the simulation results we can draw the conclusion that when the filter length of FBMC/OQAM system is larger than symbol duration, FBMC/OQAM system has a structure of overlapped data block. For these reason, the performance of the conventional PAPR reduction schemes for the FBMC/OQAM system is not effective than that of the schemes for the OFDM system.

## Conclusion

In this paper, we discussed the PAPR reduction schemes of OFDM and FBMC/OQAM system. For the FBMC/OQAM system which is the candidate of the transmission scheme for the 5G mobile communication, we verify whether the conventional PAPR reduction scheme is still effective or not. Through computer simulation, we have a conclusion that there needs to be some modification of the conventional PAPR reduction in consideration of the overlapping structure of the FBMC/OQAM signal.

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