Research on Peak-to-Average Power Ratio Reduction for FBMC-Based 5G Transmission

Wenwan You, Junqi Guo(✉), Ke Shan, and Rongfang Bie

College of Information Science and Technology, Beijing Normal University, Beijing 100875, China
youwenwan@mail.bnu.edu.cn, guojunqi@bnu.edu.cn

Abstract. The pursuit of high-quality modulation has become an inevitable trend along with a continuous evolution of mobile communication technologies. The filter-bank based multicarrier (FBMC) modulation, which has aroused wide concern recently for its higher spectral efficiency than orthogonal frequency division multiplexing (OFDM), is considered as a promising candidate solution to the air interface problem in the fifth-generation communication (5G). Since performance of multicarrier transmission is inevitably and largely affected by peak-to-average power ratio (PAPR), research on PAPR reduction methods is essential. After presenting the architecture of an FBMC transmission system and analyzing structural characteristics of FBMC signals, this paper studies several PAPR reduction methods which are previously used in OFDM transmission, and then attempts to apply them to an FBMC transmission environment by giving theoretical derivation. Computer simulation under different cases also verify their feasibility and effectiveness on PAPR reduction of FBMC signal waveform.

Keywords: Filter-bank based multicarrier (FBMC)
Peak-to-average power ratio (PAPR) reduction · 5G

1 Introduction

The fifth generation mobile communication system (5G) has attracted more and more attention recently. Under a 5G scenario, the more stringent requirements are put forward for the multicarrier multiple access transmission [1]. Therefore, analysis of multicarrier technology for 5G mobile communication is of great significance. orthogonal frequency division multiplexing (OFDM), which is one of the key technologies for the physical layer of the fourth generation mobile communication (4G), has been widely used for signal transmission over multi-path fading channels [2]. However, competitive power of OFDM in the 5G scenario proves to be weak due to its sensitivity to carrier frequency offset (CFO) and large peak-to-average power ratio (PAPR) [3]. Filter-bank based multicarrier (FBMC), which employs specially designed filter banks with small out-of-band attenuation in an architecture of multicarrier modulation, has been considered as a promising candidate solution to the 5G air interface problem [4]. Compared with OFDM, the FBMC modulation scheme has a lower spectrum leakage, which makes it very suitable for cognitive radio (CR) applications in a 5G scenario. However, FBMC signals still suffer from large PAPR due to

K. Long et al. (Eds.): 5GWN 2017, LNICST 211, pp. 327–337, 2018.
https://doi.org/10.1007/978-3-319-72823-0_31

the superposition of multicarrier signals at the transmitter, which leads to performance degradation and attracts much research on PAPR reduction methods for FBMC-based 5G transmission. To the best of our knowledge, there are very few methods that can be effectively and actually employed for PAPR reduction in an FBMC transmission architecture. Some papers [2–4] introduce a tone reservation (TR) method and an overlapped selected mapping (SLM) technique, but they are not directly applicable to the FBMC scheme due to the fact that the overlap of time-domain symbols leads to a search with high computational complexity.

Based on the description of FBMC transmission architecture and analysis of structural characteristics of FBMC signals, this paper studies several PAPR reduction methods which are previously used in OFDM transmission, and then attempts to apply them to an FBMC transmission environment by giving detailed theoretical derivation. Computer simulation under different cases also verify feasibility and effectiveness of these PAPR reduction methods on the FBMC transmission scenario.

The organization of the paper is as follows. Section 2 briefly described the FBMC modulation and the structural characteristics of FBMC signals. In Sect. 3 traditional methods of reducing PAPR in an FBMC transmission system is introduced and improvement of the traditional algorithm is made. In Sect. 4 the algorithm mentioned in Sect. 3 is simulated. According to the simulation results, the performance of each algorithm is analyzed to find the algorithm which can reduce the PAPR effectively. Section 5 summarizes the results and concludes the paper with an overall evaluation of the discussed PAPR reduction schemes and next is the acknowledgement.

2 FBMC Transmission Architecture

2.1 System Principle

FBMC modulation is widely used in a multi-carrier modulation scheme. Similar to the OFDM system, multicarrier modulation is performed via IFFT, and then each sub-channel is filtered by a specially designed prototype filter which has a positive influence on the spectral characteristics of the transmitted signal. Through the analysis of FFT, a prototype filter which can be applied to FBMC system must have the following properties: (1) linear phase; (2) satisfies the Nyquist theorem to guarantee the mutual independence between the sub carriers; (3) small out-of-band attenuation. At present, many studies design a prototype filter based on an overlap factor [3]. The results show that this prototype filter under the conditions of the overlap factor $k = 4$ have better out-of-band attenuation performance than the FFT prototype filter [4].

In an FBMC system, the use of OQAM modulation is a good way to ensure the same code rate as the FFT filter bank. The cross-amplitude modulation signal is then transmitted in the system, in which there is a $T/2$ time delay between the imaginary and the real part of the input complex signal. Next, the imaginary part and the real part carry out the shift addition. The realization of the system block diagram is shown as below (Fig. 1).

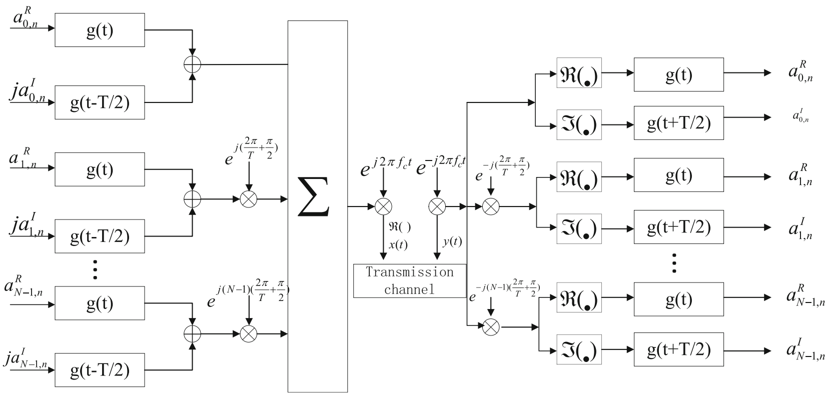

Fig. 1. The block diagram of realization of the system.

The structure of the FBMC system consists of a synthetic filter bank located at the transmitter and an analysis filter bank used by the receiver. The two filter banks are actually prototype filters after the shift. The status of the two filter banks in the system determines the unique nature of the FBMC signal. In the process of FBMC modulation, A prototype filter with a pulse response of P0 (represents the intensity of pulse response) and satisfying the Nyquist interval is applied to the sub carrier. Considering the superior performance of the prototype filter, the FBMC signal obviously has higher spectral efficiency than the OFDM signal. The following figure shows the basic architecture of the FBMC system (Fig. 2).

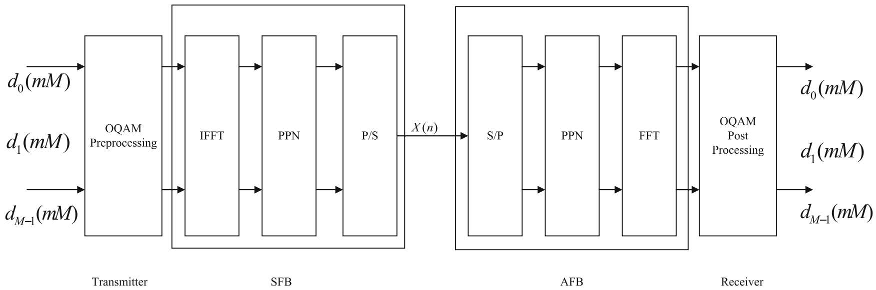

Fig. 2. The basic architecture of the FBMC system.

The figure shows that the FBMC system increases OQAM preprocessing module at the transmitter in order to separate the real and imaginary part of complex signals, then the synthetic filter bank, which includes IFFT processing module and PPN phase-multi structure, is employed to achieve frequency domain extension. Signals are then transmitted to the channel through the P/S transform. At the receiver, the received signal is first processed by the S/P transform. Next, the information flow is divided into multiplexed signals which then enter the analysis filter bank consisting of PPN phase-multi structure and FFT processing module. Finally, signals are demodulated through OQAM post-processing module. Since the carriers are orthogonal to each other in the system, the complete input signal can be restored at the receiver without being affected by subcarrier interference and inter-symbol interference.

The baseband signal $s[n]$ of discrete modulated in FBMC system can be expressed based on the complex modulation symbol $X_m[k]$ at the k^{th} subcarrier during the m^{th} time slot as follows:

$$s[n] = \sum_{m=-\infty}^{\infty} \sum_{k=0}^{N-1} (\theta_k \Re\{X_m[k]\} p_0[n - mN] + \theta_{k+1} \Re\{X_m[k]\} p_0[n - mN - \frac{\pi}{2}] e^{jk(n-mN)\frac{2\pi}{n}}) \tag{1}$$

$$\theta_k = \begin{cases} 1, & \text{k is even} \\ 0, & \text{k is odd} \end{cases} \tag{2}$$

where: $j = \sqrt{-1}$ and N represent the number of available subcarriers. The overlapping ratio of continuous symbol is closely related to the length of the prototype filter. For simplicity, the filter is designed with an impulse response of length $K * N$, which means that the symbol duration is stretched and there are K symbols overlapping in time domain to avoid loss of data rate.

2.2 Structural Characteristics of FBMC Signals

In order to make a comprehensive understanding of the FBMC system, we construct the FBMC signal and study its structural characteristics. In the FBMC signal, there is a $T/2$ time delay in the time domain between the imaginary part and the real part of the signal, where T represents the symbol width. After the input signal is modulated by the prototype filter, the adjacent modulation signal frequency difference is $1/T$. The modulated signal can be expressed in time domain as follows:

$$\widetilde{x}(t) = \sum_{n=0}^{N-1} \sum_{M=0}^{M-1} x_m^n(t) = \sum_{n=0}^{N-1} \sum_{M=0}^{M-1} [a_m^n h(t - mT) + jb_m^n h(t - mT - \frac{T}{2})] e^{jn\varphi_l} \tag{3}$$

where: N representing any positive integer. A_{mn} and B_{mn} respectively represent the real and imaginary parts of the signal input in the n^{th} sub carrier of the m^{th} data blocks. Obviously the impulse response of prototype filter is longer than T. Since the delay exists between the real and imaginary parts of the signal input, it will overlap between adjacent FBMC signal blocks.

In order to reflect signal PAPR more accurately, we oversample the signal with the sampling rate T/K, where $K = LN$ and L are over sampling coefficients. From the literature we know that when sampling coefficient $L = 4$, the sign changes can be described well [5]. The sampled signal can be expressed as follows:

$$x_m^n[k] = \begin{cases} (a_m^n h[k - mK] + jb_m^n h[k - mK - \frac{K}{2}])e^{jn(\frac{2\pi k}{TK} + \frac{\pi}{2})}, mK \le k \le mK + (A+1)K - 1 \\ 0, k < mK, k > mK + (A+1)K - 1 \end{cases} \tag{4}$$

where: A represents the number of overlapping data blocks with time domain signals $x_m[k]$; $h[k]$ represents the discrete time filters obtained by sampling, $h[k] = h[Tk/K]$.

3 PAPR Reduction for FBMC Transmission

This section will discuss methods of reducing PAPR in an FBMC transmission system. Through the study of some effective algorithms in a traditional OFDM system, we apply them to the FBMC environment and make some theoretical derivation.

3.1 Clipping

Note that the discrete amplitude of FBMC signals in time domain is limited to the threshold value $A_{\max}$. Clipping signal can be written as follows:

$$s^c[n] = \begin{cases} s[n], & |s[n]| \le A_{\max} \\ A_{\max} e^{j\varphi[s[n])}, & |s[n]| > A_{\max} \end{cases} \tag{5}$$

where: $\varphi(s[n])$ is the phase of complex signal. The limiter is characterized by limiting ratio, which is defined as follows:

$$CR_{dB} = 10\log_{10}(\gamma) \tag{6}$$

where: $\gamma = A_{\max}/\sqrt{P_s}$; P_s is the average energy of the transmitted signal. The mathematical model of the limiting amplitude is derived from the derivation of the Bussgang theorem for the non-memory nonlinear Gauss input [6]. The limiting signal can be expressed as:

$$s^c[n] = \alpha s[n] + d[n] \tag{7}$$

where: α describes the attenuation; $d[n]$ is a limited range of noise which is also known as Bussgang noise. Attenuation factor can be calculated in the following way:

$$\alpha = 1 - e^{-\gamma^2} + \frac{\sqrt{\pi}}{2}\gamma erfc(\gamma) \tag{8}$$

The energy of clipping noise is then calculated as follows:

$$P_d = (1 - e^{-\gamma^2} - \alpha^2)P_s \tag{9}$$

Since some literatures study clipping iteration scheme and clipping combined with filtering scheme [6], we consider to combine the two schemes. Let it be able to reduce the system PAPR significantly and to reduce the nonlinear distortion of the system as far as possible. In accordance with this idea, an additional signal processing module is added before the transmitter transmits the signal, then FBMC modulation is performed on a conventional symbol X, after that the PAPR of the resulting signal $s[n]$ is measured. If it is less than a predetermined limit, it can be transmitted. If the amplitude is larger, apply clipping to it. After the amplitude is limited, the signal s^c is demodulated. The demodulation of the symbol X^c uses a special selection and processing algorithm. Then the new symbol X^{new} is modulated, and the PAPR of the signal s^{new} is measured. Repeat this process until the desired PRPR has been reached. The iterative signal is used to form an analog signal.

3.2 Partial Transmit Sequence (PTS)

The main idea of the traditional PTS methods applied in OFDM is given as follows [7]: First, the original input data is divided into several equal sub blocks of the combination; Next, each block is multiplied by the same rotation vector; Finally, signals with the smallest PAPR are selected to transfer. For the FBMC system, we choose to use a P-PTS method [7] based on a two-step optimization structure to reduce the PAPR. Due to the overlap of the FBMC signal structure, we should consider several overlapping data blocks when we study the reduction of peak power.

The first step of this method is similar to the traditional Selected Mapping (SLM) method [2] used in OFDM. The difference between these two methods is that optimization of the phase rotation sequence of current symbol is determined by the prior overlap of the FBMC-OQAM symbol. In other words, all of the symbols that overlap with the current symbol need to be considered when selecting the optimized phase rotation sequence. In addition, since each FBMC-OQAM symbol is not generated until the time FT, we should calculate the value of PAPR during $[0, FT]$ instead of $[0, T]$ to select the optimal rotation vector. The second step is similar to S-PTS which is mentioned in the reference [7], the main idea of which is to divide the FBMC-OQAM symbol into segments, and then the intersection of some blocks are separated and multiplied by the different phase rotation factors. However, as the PTS scheme exists a certain complexity itself, just using the PTS method to reduce FBMC PAPR will lead to high computational complexity.

3.3 PTS-Clipping

Here we consider a practical combination of the two methods above, which can achieve better performance of PAPR reduction for FBMC transmission. On the one hand, we know that the main idea of the PTS scheme is to divide the raw data into several disjoint sub blocks. Note that there are three main methods for the segmentation of data blocks, namely, the random method, the interleaving method and the adjacent method [8]. Through comparing the performance of the three methods, we find that the method of random segmentation reaches the most satisfying PAPR performance [9]. After the split, each sub data block is then multiplied by a corresponding phase rotation sequence, and the phase of the signal is adjusted by the phase rotation factor. Through finding the optimal phase factor combination we can minimize FBMC PAPR. On the other hand, the main idea of the clipping scheme is to set a threshold value. The signal exceeding the threshold value will be cut, while the one which does not exceed the threshold value will keep the same original value or be amplified by small amplitude, so that PAPR can be effectively reduced in this way. However, the scheme draws into the nonlinear distortion which leads to performance degradation. Now we consider the combination of the two methods. Generally, the signal has been selected which has the minimum limit noise after the original signal is processed by the PTS method, then we apply the clipping operation. In this way, the system error will be reduced and PAPR reduction can also be guaranteed.

The implementation steps of the combined method "PTS-Clipping" are given below:

(1) Block the input signal data, divided it into V sub blocks;
(2) The sub blocks generated by (1) are multiplied by the corresponding phase rotation factor, and the generated signal is used as an alternative;
(3) Calculation (2) clipping noise power of V road signal respectively.

$$\widehat{P}_{v,Clipping} = \frac{1}{N}\sum_{i=1}^{n}(|x_k| - T_h)^2, \quad 0 \le k \le N, 0 \le v \le V; \tag{10}$$

(4) The signal with the minimum limiting noise power is selected from the V road signal, then apply clipping to it.

$$\widehat{x}_k = \begin{cases} T_h e^{j\varphi(x'_k)}, & |x'_k| > T_h \\ x'_k, & |x'_k|| \le T_h \end{cases} \tag{11}$$

(5) Observe the PAPR performance and bit error rate (BER) performance of the signal after the above steps.

4 Simulation Results

Here we give some simulation results of the three algorithms above to verify their feasibility and effectiveness on FBMC PAPR reduction.

4.1 Simulation Result of Clipping

Firstly we need to set up the simulation parameters, number of subcarriers $M = 512$ and overlap factor $K = 4$, then the length of the prototype filter $h[k]$ is $L = M * N - 1$, the clipping ratio is set to 4, which is equivalent to 6 dB. Through the MATLAB programming and using the complementary cumulative distribution function to describe the system's PAPR performance, simulation results are shown as follows (Fig. 3):

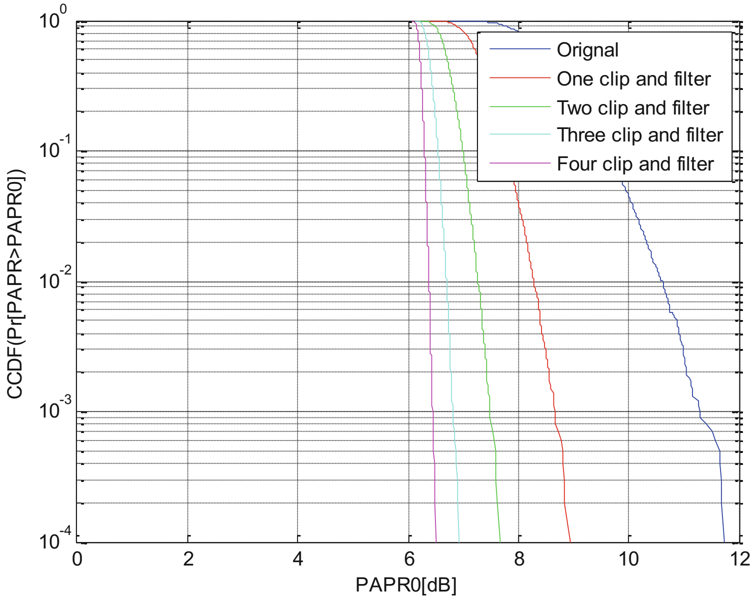

Fig. 3. Simulation results of clipping method

From the above figure, we can see the difference in the Complementary Cumulative Distribution Function (CCDF) curve between the signal PAPR after using the clipping method and the original signal PAPR. The PAPR performance of different clipping frequency is given, which demonstrates that clipping can effectively reduce PAPR. As the increase of the number of clipping, the performance of PAPR reduction is also improved.

4.2 Simulation Result of PTS

The simulation parameters are set as follows: the modulation mode is OQAM modulation, the number of sub carriers $M = 128$, the sub carriers are divided into 4 groups, the number of the rotation phase is 4, using random segmentation, simulation results are shown as follows (Fig. 4):

It can be seen from the above figure that the PTS is effective for reducing the peak-to-average power ratio of the FBMC system.

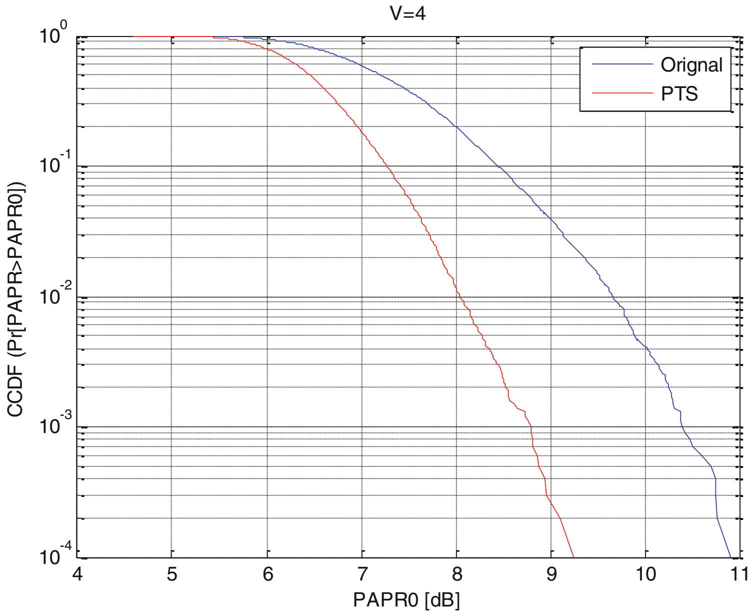

Fig. 4. Simulation results of PTS method

4.3 Simulation Result of PTS-Clipping

The simulation parameters are set as follows: number of subcarriers $M = 512$, the number of the rotation phase is 2, using 4 times oversampling. The simulation results are shown as below (Fig. 5):

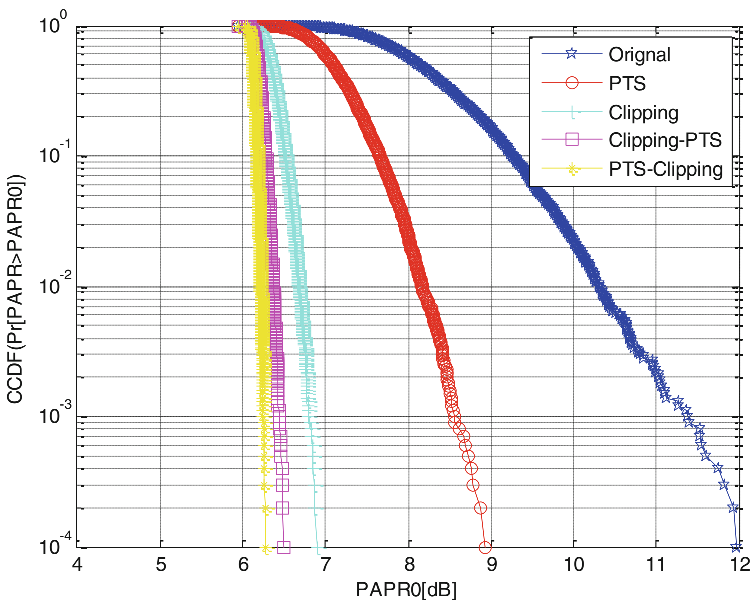

Fig. 5. Simulation result of PTS-Clipping method

From the figure we can see that using clipping method or PTS algorithm alone can only have a certain effect on PAPR reduction, but the combination algorithm has obviously better performance, which demonstrates that PTS-Clipping is a promising candidate solution to FBMC PAPR reduction.

5 Conclusion

In this paper, we have studied two methods for FBMC PAPR reduction which are clipping and partial transmit sequence (PTS), and then combined them together to present an improved method "PTS-Clipping". From the theoretical derivation and computer simulation, we find that: First, clipping method is undoubtedly the most simple method to operate in the FBMC system, but it will introduce nonlinear distortion which leads to BER performance degradation; Next, PTS method can effectively reduce FBMC PAPR, but we also find that the number of sub blocks greatly affect the computational complexity. Reduce the number of sub sequences will lead to poor PAPR performance; Finally, the combined method "PTS-Clipping" achieves better performance on PAPR reduction, which demonstrates that PTS-Clipping is a promising candidate solution to PAPR reduction for FBMC-based 5G transmission.

Acknowledgement. This research is sponsored by National Natural Science Foundation of China (No. 61401029), the Fundamental Research Funds for the Central Universities (No. 2012LYB46), Beijing Youth Excellence Program (YETP0296) and Beijing Advanced Innovation Center for Future Education (BJAICFE2016IR-004).

References

1. He, Z.: Research on key technology of ROF system based on FBMC. University of Science and Technology Beijing, Beijing (2015)
2. Lu, S.: Non distortion method for reducing peak to average power ratio of FBMC-OQAM signal. Huazhong University of Science and Technology, Hubei (2013)
3. He, X.: Research on channel estimation of multi-carrier system based on filter bank. Zhejiang University, Zhejiang (2013)
4. Guo, T.: Research on reducing peak-to-average power ratio in OFDM systems. Nanjing University of Aeronautics & Astronautics, Jiangsu (2007)
5. Qu, D., Lu, S., Tao, J.: Multi-block joint optimization for the peak-to-average power ratio reduction of FBMC-OQAM signals. IEEE Trans. Signal Process. **61**(7), 1605–1613 (2013)
6. Kollár, Z., Varga, L., Czimer, K.: Clipping-based iterative PAPR-reduction techniques for FBMC. In: Proceedings of VDE, pp. 1–7 (2012)
7. Bellanger, M., LeRuyet, D., Roviras, D.: FBMC physical layer: a prime. In: PHYDYAS (2010)
8. Farhang-Boroujeny, B.: OFDM versus filter bank multicarrier. IEEE Signal Process. **28**(3), 92–112 (2011)
9. Liu, K., Hou, J., Zhang, P., Liu, Y.: PAPR reduction for FBMC-OQAM systems using P-PTS scheme. J. China Univ. Posts Telecommun. **22**(6), 78–85 (2015)
10. Tao, Y., Liu, L., Liu, S., Zhang, Z.: A survey: several technologies of non-orthogonal transmission for 5G. China Commun. **12**, 1–15 (2015)

11. Zhuang, L., Weng, H.: Research on PAPR suppression algorithm for carrier aggregation in FBMC system. Sci. Technol. Engi. **16**(9), 221–225 (2016)
12. He, Y., Qu, D., Lu, S.: Sliding window tone reservation technique for the peak-to-average power ratio reduction of FBMC-OQAM signals. IEEE Wireless Commun. Lett. **1**(4), 268–271 (2012)