Hybrid PAPR Reduction Scheme with Partial Transmit Sequence and Tone Reservation for FBMC/OQAM

Han Wang[1], Yani Cui[1], Wencai Du[1,2], and Lingwei Xu[3]
[1] College of Information Science & Technology, Hainan University, Haikou 570228, China
[2] City University of Macau, Macau 000853, China
[3] College of Information Science & Engineering, Ocean University of China, Qingdao 266071, China
Email: hanwang1214@126.com; cyn0213@163.com; wencai@hainu.edu.cn; gaomilaojia2009@153.com

Abstract —As a particular type of multicarrier technique, the filter bank multicarrier with offset quadrature amplitude modulation (FBMC/OQAM) has attracted increasing attention as a potential technology for 5G. However, the intrinsic shortcoming of high Peak to Average Power Ration (PAPR) for FBMC/OQAM should be alleviated. In this paper, a new method that combines Partial Transmit Sequence (PTS) with Tone Reservation (TR) is proposed for the PAPR reduction in FBMC/OQAM system. The union algorithm used PTS to process FBMC/OQAM signal to reduce PAPR, then the result is further processed by clipping to reduce PAPR. Simulation results show that the proposed method provides better performance of reducing PAPR than other two conventional methods.

Index Terms—FBMC/OQAM, Peak to Average Power Ration (PAPR), Partial Transmit Sequence (PTS), Tone Reservation (TR), Hybrid

I. Introduction

Multicarrier modulation techniques have been widely used in many communication systems and are considered as a suitable candidate for future wireless systems. OFDM is certainly one of the most famous and accepted type of multicarrier schemes in some digital communication systems. However, the insertion of Cyclic Prefix (CP) in OFDM transmission symbol sacrifices spectral efficiency. Moreover, the use of rectangular pulse shaping on each subcarrier will lead to high out of band radiation. To overcome the disadvantages of OFDM system, the filter bank multicarrier with offset quadrature amplitude modulation (FBMC/OQAM) has drawn increasing attentions by many researchers [1]-[3]. As a potential candidate multicarrier modulation scheme for the future 5G technique [4]-[7], FBMC/OQAM utilizes well time frequency localization (TFL) property pulse shaping based filter bank, which has a theoretically higher spectral efficiency [8], [9] as well as robustness to frequency offset and Doppler spread. Besides, CP is not required in the FBMC/OQAM system, which can provide higher data rate than CP-OFDM [10], [11].

Multicarrier communication systems suffer from a high PAPR problem. A high PAPR means that, in order to avoid distortions in the transmitted signal, linear amplifiers with large input backoff need to be used. Otherwise Bit Error Rates (BER) performance will deteriorate and nonlinear distortion will be introduced. FBMC/OQAM has its root in the pioneering works of Chang [12] and Saltzberg [13] who introduced multicarrier techniques over two decades ago. Similar to OFDM system, one of the main defects for FBMC/OQAM system is the high PAPR of transmitted FBMC/OQAM signals. In OFDM system, various methods have been proposed to tackle the PAPR problem [14]-[16], including the selective mapping (SLM), Partial Transmit Sequence (PTS) and Tone Reservation (TR) schemes.

Recently, several PAPR reduction schemes for FBMC/OQAM system have been studied [17]-[24]. In [17], [18], the overlapped SLM (OSLM) scheme and Alternative Signals (AS) scheme have been proposed to reduce the PAPR of FBMC/OQAM signal, these two schemes jointly consider the current data block and the previous data blocks to acquire the optimal phase rotation sequence. Nevertheless, these two schemes need extra spectral band to transmit the phase rotation sequence as side information. In [19], [20], a sliding window tone reservation (SW-TR) technique has been proposed. The SW-TR method utilizes the peak reduction tones of several consecutive data blocks to cancel the peak power of the FBMC/OQAM signals inside a window. In [21], the baseband amplitude clipping method is applied for reducing the PAPR of FBMC/OQAM signals. In [22], [23], an improved PTS scheme by employing multi-block joint optimization for the PAPR reduction of FBMC/OQAM was proposed. The above schemes for FBMC/OQAM PAPR reduction require additional processing and increase complexity. In [24], a hybrid PAPR reduction scheme with SLM and TR for FBMC/OQAM is proposed, the joint algorithm combines the advantages of the two conventional PAPR reduction schemes.

In this paper, a union algorithm based on conventional PTS scheme and TR scheme to reduce PAPR in FBMC/OQAM system is studied. Firstly, the combined scheme utilized PTS to process FBMC/QOAM signal to reduce the PAPR, then the result is further processed by TR scheme to reduce PAPR. As long as the two schemes

Manuscript received December 16, 2015; revised May 14, 2016.
This work is supported by the International Science and Technology Corporation Plan organized by the Ministry of Science and Technology of China, Grant No. 2015DFR10510 and the National Natural Science Foundation of China, Grant No. 61562018.
Corresponding author email: wencai@hainu.edu.cn.
doi:10.12720/jcm.11.5.478-483

are selected properly, the hybrid scheme could obtain better PAPR performance and reduce the computational complexity. To the best of our knowledge, a union algorithm based on PTS and TR has not yet been investigated for FBMC/OQAM systems.

The rest of this paper is organized as follows. Section 2 introduces the FBMC/OQAM signal and the conventional PTS and TR scheme. In Section 3, we propose a hybrid FBMC/QOAM PAPR reduction scheme which combines the two conventional schemes to obtain joint PAPR reduction gain. This is the main contribution of this paper. Simulation results are shown in Section 4. Finally, conclusions are drawn in Section 5.

II. FBMC/OQAM Signal Model

A. FBMC/OQAM Signals

The FBMC/OQAM transmitter structure is shown in Fig. 1. The transmitter consists of N subcarriers. At first, the data after QAM modulation into A_m, $A_m=[a_{m,1},a_{m,2}...a_{m,N-1},a_{m,N}]$, the QAM symbols then through serial to parallel, the real and imaginary part of each symbols are transmitted on a subcarrier, respectively. After the prototype filter and phase modulation, the transmission FBMC/OQAM data blocks can be obtained by adding all subcarrier signals. The mth FBMC/OQAM data block signal in time domain can be expressed as [18]

$$\begin{aligned} s_m(t) &= \sum_{n=1}^{N} a_{m,n} h_{m,n}(t) \\ &= \sum_{n=1}^{N}\left\{\Re\{a_{m,n}\} h(t-mT)+ j\Im\{a_{m,n}\} h\left(t-mT-\frac{T}{2}\right)\right\} e^{j\phi_{m,n}}, \\ & mT \le t < (m+\beta+\frac{1}{2})T \end{aligned} \quad (1)$$

where $a_{m,n}$ denotes the mth QAM symbol on the nth subcarrier, $\Re\{.\}$ and $\Im\{.\}$ denote the real and imaginary parts of $a_{m,n}$, respectively. T denotes the symbol period, and $h(t)$ is the response of the prototype filter with βT length, β is the overlapping factor. $\phi_{m,n}$ is an additional phase term with $\phi_{m,n}=n(\frac{2\pi t}{T}+\frac{\pi}{2})$. $s_m(t)$ is a single FBMC/OQAM signal data block formula, the M consecutive data block is written as

$$s(t)=\sum_{m=1}^{M} s_m(t),\quad 0\le t\le (M+\beta-1/2)T \quad (2)$$

In conventional OFDM system, each OFDM symbol length is T , there are no overlaps between adjacent symbol blocks, the definition of peak-to-average power ratio is proposed for each individual OFDM symbol.

Fig. 2 shows the overlapping FBM/OQAM signal structure. According to the overlapping structure, the definition of PAPR in FBMC/OQAM system should be corrected.

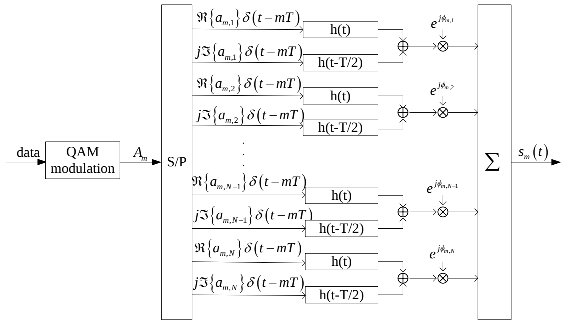

Fig. 1. The FBMC/OQAM transmitter structure

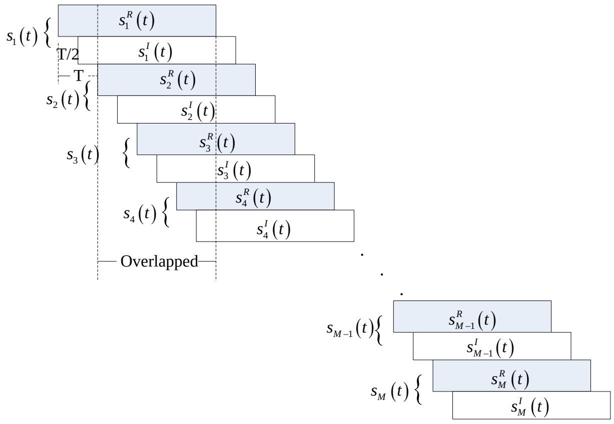

Fig. 2. The FBMC/OQAM overlapping structure

We divide $s(t)$ into $M+\beta$ intervals, interval equal to T (the last one is $T/2$). The PAPR of each interval is written as

$$PAPR(dB)=10\log_{10}\frac{\max_{iT\le t\le (i+1)T}|s(t)|^2}{E\left[|s(t)|^2\right]} \quad (3)$$

where $i=0,1,...,M+\beta-1$, $E\left[|s(t)|^2\right]$ denotes the $s(t)$ expectation.

B. Conventional Partial Transmit Sequence Scheme for FBMC/OQAM

The partial transmit sequence technique partitions an input data block into V disjoint sub-blocks. Unlike the SLM technique in which scrambling is applied to all sub-carriers, scrambling (rotating its phase independently) is applied to each sub-block in the PTS technique. Then each partitioned sub-block is multiplied by a corresponding complex phase factor $b^v=e^{j\phi v}, v=1,2,...,V$

$$s_m(t)=\sum_{v=1}^{V} b^v s_m^v(t) \quad (4)$$

where $\{s_m^v(t)\}$ is referred to as a partial transmit sequence. The phase vector is chosen so that the PAPR can be minimized, which is shown as

$$\arg\min_{b^v} \max_{0\le t\le T}\left|\sum_{v=1}^{V} b^v s_m^v(t)\right|^2 \tag{5}$$

In general, the selection of the phase factors $\{b^v\}$ is limited to a set of elements to reduce the search complexity. One particular example is a suboptimal combination algorithm, which uses the binary phase factor of $\{1,-1\}$ [18]. In the PTS scheme, the phase rotation operation is used for each transmit signal independently, the PAPR performance is affected by the overlapped FBMC/OQAM signals.

C. Conventional Tone Reservation Scheme for FBMC/OQAM

In TR scheme, iterative clipping filtering algorithm is usually adopted, the N subcarriers (tones) are partitioned into data tones and peak reduction tones (PRTs). Symbols in PRTs are chosen such that FBMC/OQAM signal in the time domain has a lower PAPR. The positions of PRTs are known by the receiver and transmitter.

The mth data block S_m^n is divided into data vector D_m^n and PAPR reduction vector C_m^n.The input symbols can be expressed as

$$S_m^n = D_m^n + C_m^n = \begin{cases} C_m^n, & n\in\mathbb{R} \\ D_m^n, & n\in\mathbb{R}^C \end{cases} \tag{6}$$
$$C_m^n \equiv 0,\ \text{for } n\in\mathbb{R}^C,\ D_m^n\equiv 0,\ \text{for } n\in\mathbb{R}$$

where $\mathbb{R}=\{n_1,n_2,...n_R\}$ denotes the set of tones reserved for peak reduction, $\mathbb{R}^C$ denotes the set of data subcarriers, $\mathbb{R}^C$ is the complement set of $\mathbb{R}$ in $\mathbb{N}=\{1,2,\cdots N\}$.

Then, the peak reduced FBMC/OQAM signal using TR scheme can be written as

$$PAPR_{TR}(dB) = 10\log_{10}\frac{\max\limits_{iT\le t\le(i+1)T}\left|s(t)+c(t)\right|^2}{E\left[\left|s(t)\right|^2\right]} \tag{7}$$

where $c(t)$ is the peak reduction signal. By selecting proper peak reduction signal, the FBMC/OQAM signal peak power can be reduced to a certain extent. However, it cannot achieve the same effect of reducing PAPR as that in OFDM system. As we mentioned previously, OFDM signals independently select the proper peak reduction signal for each data block, there is no overlap between the blocks. While in FBMC/OQAM signal, the adjacent data blocks are overlapped. Therefore, using conventional TR scheme to reduce the FBMC/OQAM signal peak-to-average ratio has limited effect.

III. Hybrid Method

In this Section, we propose a new union algorithm based on PTS and TR schemes for PAPR reduction of FBMC/OQAM signal. The obtained QAM symbols are passed through a bank of transmission filters and FBMC modulated using N tone modulators whose carrier frequencies are $1/T$ spaced apart, forming the FBMC/OQAM. Then the FBMC/OQAM symbols are applied sequentially to PTS processing, after getting the optimal signals, then go through to the TR processing. Fig. 3 shows the implementation of Hybrid scheme.

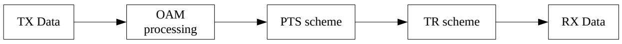

Fig. 3. The implementation of hybrid scheme

The hybrid scheme is presented below.

Step 1: Firstly, we assign the PRTs to 0 and add to the data symbol. Partition the input data block into V sub-blocks.

Step 2: Set all the phase factors $b^v=1$ for $v=1:V$, find PAPR of (4), and set it as PAPR min. Then set v=2.

Step 3: Find PAPR of Equation (4) with $b^v=-1$; If PAPR>PAPR min, switch b^v back to 1. Otherwise, update PAPR min= PAPR.

Step 4: If $v<V$, increment v by one and go back to Step 3. Otherwise, exit this process with the set of optimal phase factors, $\tilde{b}$.

Then we obtain the lower PAPR signals $s_{PTS}(t)$ by PTS method. The signal is followed by TR method.

Step 5: Determine the position of the reserve tones and set the iteration number, and set a signal threshold A

Step 6: The signal is to clip the amplitude of the signal with a predefined threshold.

$$\tilde{s}_{PTS}(t) = \begin{cases} s_{PTS}(t), & |s_{PTS}(t)|\le A \\ Ae^{j\theta_S}, & |s_{PTS}(t)|> A \end{cases} \tag{8}$$

where $s_{PTS}(t)=|s_{PTS}(t)|e^{j\theta_S}$, θ_S is the phase of $s_{PTS}(t)$.The expected clipping signal corresponding to (8) is

$$f(t) = \begin{cases} 0, & |s_{PTS}(t)|\le A \\ \tilde{s}_{PTS}(t)-s_{PTS}(t), & |s_{PTS}(t)|> A \end{cases} \tag{9}$$

In order to reduce the interference to the data tones and avoid bit error rate performance degradation, we utilize an approximate signal $f(t)$ to reduce the peak power, which only has nonzero signal on the reserved tones. It needs several iterations to produce $f(t)$.

Step 7: If the maximum number of iteration is reached, the iteration stops. The final peak canceling signal is

$$\tilde{f}(t) = \begin{cases} \sum\limits_{m=1}^{M} c_m^n(t), & 0\le t\le MT \\ 0, & else \end{cases} \tag{10}$$

where $c_m^n(t)$ is the time domain sequence corresponding to C_m^n.

Step 8: Replace $s_{PTS}(t)$ with

$$s_{PTS}(t) = s_{PTS}(t) + \tilde{f}(t) \tag{11}$$

The final $s_{PTS}(t)$ is the result of the hybrid PTS and TR scheme.

IV. Simulation Results

In this section, we present simulation results to verify our analysis. PAPR reduction performances of the proposed hybrid scheme versus the conventional PTS and TR schemes are discussed. The square root raise cosine filter is employed in this paper, the rolloff factor of the filter is 1, the length of the filter $h(t)$ is chosen to $4T$, where $\beta = 4$. The complementary cumulative distribution function (CCDF) is employed to measure the PAPR reduction performance. Table I shows the simulation parameters.

Table I: Simulation Parameters

Parameters	Values
Total number of sub-carrier	64
M data blocks	16
Peak reduction tones with null sub-carriers	8
Modulation	4OQAM
Overlapping factor	4
Threshold (A)	2.2,2.4,2.6
V	4,8
Number of iterations	4,8
PRT set	Random generation and selection

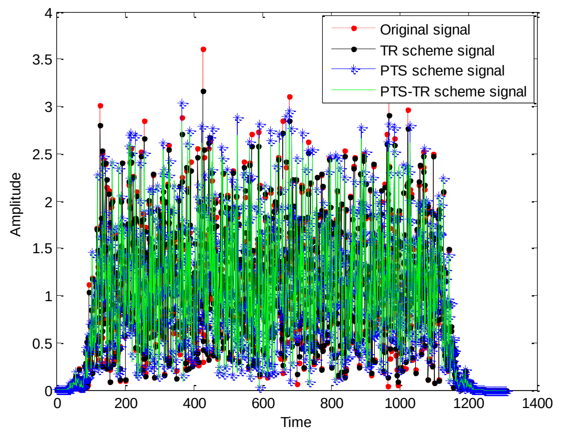

Fig. 4. Peak canceling signal of hybrid scheme, conventional schemes and original signal

Fig. 4 shows the peak canceling signals of hybrid scheme, conventional schemes and original signal. Peak powers of the signal appear in a few points, majority of points have lower powers. It can be found that, compared with the two conventional approaches, the proposed scheme can efficiently reduce the peak powers of the signal.

In Fig. 5, we show the CCDF curves for TR, PTS and proposed scheme (PTS-TR) with A=2.4, iterations=4 and V=4. The curve "original" is the performance of FBMC/OQAM signal without any PAPR reduction processing. When CCDF= 10^{-3}, it is observed that the PAPR could be reduced by about 1.3 dB with the conventional TR, by 1.3 dB with PTS, and by 2.3 dB with PTS-TR, respectively. The PTS-TR scheme outperforms 1 dB than TR scheme and PTS scheme.

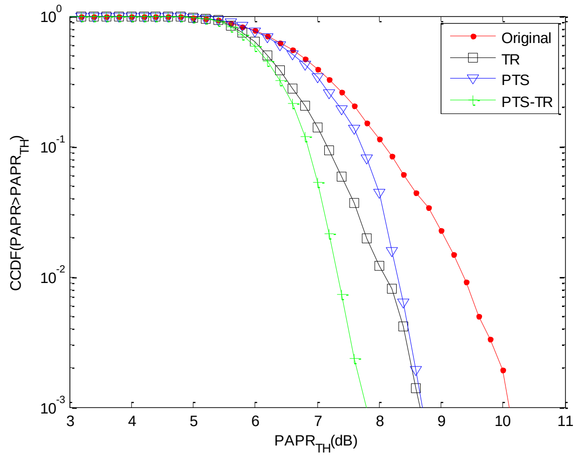

Fig. 5. PAPR reduction for conventional schemes via proposed scheme.

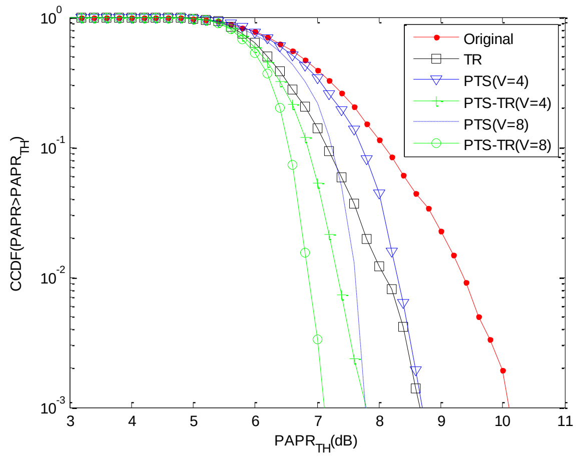

Fig. 6. PAPR reduction of hybrid PTS-TR implementation with A=2.4, iterations =4 and V=4,8, respectively.

In Fig. 6, it is shown that the PAPR reduction performance of the proposed scheme and the two conventional schemes for A=2.4, iterations=4 and V=4, 8, respectively. Compared with the conventional TR scheme, the proposed hybrid scheme can reduce the PAPR performance by about 0.9 dB and 1.6 dB when CCDF is 0.001, V=4, 8 respectively, and compared with the conventional PTS scheme, the proposed scheme can reduce the PAPR performance by about 0.9 dB and 0.7 dB with V=4, 8, respectively. It is obvious that the PAPR reduction performance could be improved with V increasing for the proposed PTS-TR scheme.

Fig. 7, we show the PAPR reductions of the PTS-TR scheme with different clipping threshold, V=4, iterations=4, A is selected as A=2.2, A=2.4, A =2.6. When CCDF= 10^{-3}, the PAPR reductions of the PTS-TR scheme with A =2.2, A =2.4, A =2.6 are 2.6 dB, 2.3 dB and 2.2 dB, respectively. Obviously, when choose A =2.2, it can achieve the highest PAPR reduction. In the following simulation, A is chosen as 2.2.

Fig. 8 depicts the PAPR reduction of the PTS-TR scheme with V=4, 8 and iterations=4,8, respectively. For V=4, different number of iterations, we can see that the PTS-TR scheme with i=8 achieves about 0.4 dB of more PAPR reduction performance than the PTS-TR with i=4. For V=8, the PTS-TR with i=8 achieves the best PAPR reduction performance. The PAPR could be reduced by 3.4 dB at CCDF=0.001.

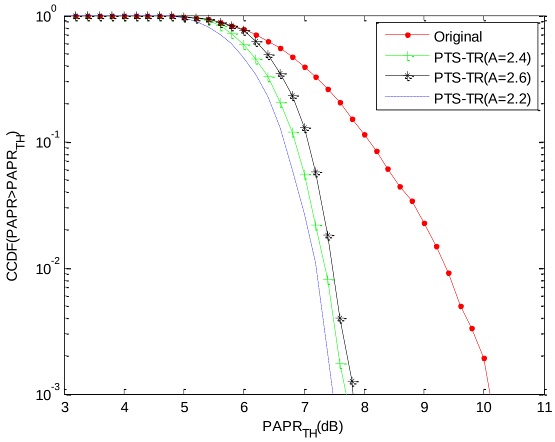

Fig. 7. PAPR reduction of hybrid PTS-TR scheme with different threshold

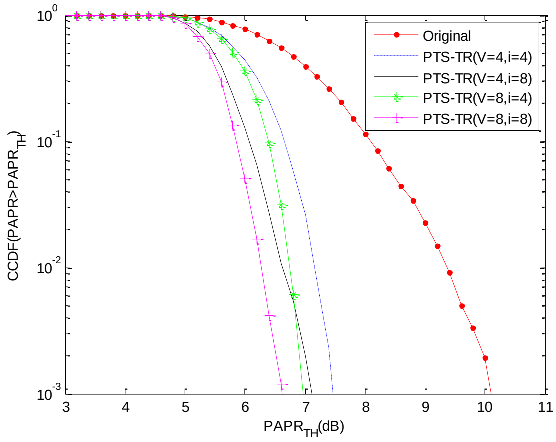

Fig. 8. PAPR reduction of hybrid scheme with different number of iterations

As show in the simulation results, it can be verified that the proposed PTS-TR scheme provides better PAPR reduction performance than the conventional PTS and TR schemes for FBMC/OQAM system.

V. Conclusion

In this paper, we propose a new hybrid PTS-TR PAPR reduction scheme for FBMC/OQAM system. The numerical results show that higher PAPR reduction is achieved with hybrid scheme. Compared with the conventional PTS and TR schemes, the simulation results prove that the signal decreased distortion level and the proposed scheme requires less iterative computation to achieve a certain PAPR reduction.

Acknowledgment

This work is supported by the International Science and Technology Corporation Plan organized by the Ministry of Science and Technology of China, Grant No. 2015DFR10510 and the National Natural Science Foundation of China, Grant No. 61562018. The authors would like to thank the editor and the anonymous reviewers for their valuable comments.

References

[1] J. F. Du and S. Signell, “Time frequency localization of pulse shaping filters in OFDM/OQAM systems,” in *Proc. 6th International Conference of Information, Communications & Signal Processing*, Singapore, 2007, pp. 1-5.

[2] B. F. Boroujeny, “OFDM versus filter bank multicarrier,” *IEEE Signal Processing Magazine*, vol. 28, no. 3, pp. 92-112, May 2011.

[3] G. Cheng, Y. Xiao, and S. Li, “Joint frequency offset and channel estimation for OFDM/OQAM system,” *IEICE Transaction on. Communications*, vol. E95-B, no. 5, pp. 1848-1851, May 2012.

[4] F. Schaich and T. Wild, “Waveform contenders for 5G-OFDM vs FBMC vs UFMC,” in *Proc. International Symposium on Communications, Control and Signal Processing*, Athens, 2014, pp. 457-460.

[5] Y. Tao, L. Liu, S. Liu, and Z. Zhang, “A survey: Several technologies of non-orthogonal transmission for 5G,” *Communications*, China, vol. 12, no. 10, pp. 1-15, October 2015.

[6] FP7-ICT PHYDYAS Project. Prototype Filter and Structure Optimization. Project Deliverable D5.1, (Section 5.2.3). [Online]. Available: http://www.ict-phydyas.org/delivrables

[7] M. Schellmann, Z. Zhao, H. Lin, P. Siohan, and N. Rajatheva, “FBMC-Based air interface for 5G Mobile: Challenges and proposed solutions,” in *Proc. 9th International Conference on Congnitive Radio Oriented Wireless Networks and Communications*, Oulu, 2014, pp. 102-107.

[8] R. Razavi, P. Xiao, and R. Tafazolli, “Information theoretic analysis of OFDM/OQAM with utilized intrinsic interference,” *IEEE Signal Processing Letters*, vol. 22, no. 5, pp. 618-622, May 2015.

[9] T. Jiang, C. X. Ni, D. M. Qu, and C. G. Wang, “Energy-efficient NC-OFDM/OQAM-based cognitive radio networks,” *IEEE Communications Magazine*, vol. 52, no. 7, pp. 54-60, July 2014.

[10] P. Siohan, C. Siclet, and N. Lacaille, “Analysis and design of OFDM/OQAM systems based on filter bank theory,” *IEEE Transaction on Signal Processing*, vol. 50, no. 5, pp. 1170-1183, May 2012.

[11] P. Achaichia, M. L. Bot, and P. Siohan, “OFDM/OQAM: A solution to efficiently increase the capacity of future PLC networks,” *IEEE Transactions on Power Delivery*, vol. 26, no. 4, pp. 2443-2454, October 2011.

[12] R. Chang, "High-speed multichannel data transmission with band limited orthogonal signals," *Bell System. Technical Journal*, vol. 45, pp. 1775-1796, 1966.

[13] B. Saltzberg, "Performance of an efficient parallel data transmission system," *IEEE Transaction on Communication Technology*, vol. 15, no. 6, pp. 805-811, June 1967.

[14] H. S. Joo, S. J. Heo, H. B. Jeon, J. S. No, and D. J. Shin, "A new blind SLM scheme with low decoding complexity for OFDM systems," *IEEE Transaction on Broadcasting*, vol. 58, no. 4, pp. 669-676, December 2012.

[15] X. Qi, Y. Li, and H. Huang, "A low complexity PTS scheme based on tree for PAPR reduction," *IEEE Communication Letters*, vol. 16, no. 9, pp. 1486-1488, September 2012.

[16] G. Saeed and A. Ruhallah, "Tone reservation for OFDM systems by maximizing signal-to-distortion ratio," *IEEE Transaction on Wireless Communications*, vol. 11, no. 2, pp. 762-770, February 2012.

[17] A. Skrzypczak, J. P. Javaudin, and P. Siohan, "Reduction of the peak-to-average power ratio for the OFDM/OQAM signals," in *Proc. 63rd IEEE Vehicular Technology Conference*, Melbourne, Vic, pp. 2018-2022, 2006.

[18] Y. Zhou, T. Jiang, C. Huag, and S. Cui, "Peak-to-average power ratio reduction for OFDM/OQAM signals via alternative signals method," *IEEE Transactions on Vehicular Technology*, vol. 63, no. 1, pp. 494-499, January 2014.

[19] S. Lu, D. Qu, and Y. He, "Sliding window tone reservation technique for the peak-to-average power ratio reduction of FBMC/OQAM signals," *IEEE Wireless Communication Letters*, vol. 1, no. 4 , pp. 268-271, April 2012.

[20] V. S. Kumar and S. Anuradha, "Sliding Window tone reservation using smart gradient projection method for PAPR reduction of FBMC signals," in *Proc. International Conference on Electrical, Electronics, Signals, Communication and Optimization*, Visakhapatnam, 2015, pp. 1-5.

[21] Z. Kollar and P. Horvath, "PAPR reduction of FBMC by clipping and its iterative compensation," *Journal of Computer Networks and Communications*, vol. 2012, February 2012.

[22] D. Qu, S. Lu, and T. Jiang, "Multi-Block joint optimization for the peak-to-average power ratio reduction of FBMC-OQAM Signals," *IEEE Transactions on Signal Provessing*, vol. 61, no. 7, pp. 1605-16114, April 2013.

[23] C. Ye, Z. Li, T. Jiang, C. Ni, and Q. Qi, "PAPR reduction of OQAM-OFDM signals using segmental PTS scheme with low complexity," *IEEE Transaction on Broadcasting*, vol. 60, no. 1, pp. 141-147, January 2014.

[24] S. Vangala and S. A nuradha, "Hybrid PAPR reduction scheme with selective mapping and tone reservation for FBMC/OQAM," in *Proc. 3rd International Signal Processing, Communication and Networking*, Chennai, India, 2015, pp. 1-5.

Han Wang received the B.S. degree in electrical engineering from Hubei University of Nationalities, China, in 2009 and the M.S. degree in information and communication system from Hainan University, Haikou, China, in 2013. He has worked in China Mobile Jiangxi branch as a network engineer for one year. Now, he is pursuing the Ph.D. degree with the Department of College of Information Science & Technology in Hainan University. His research interests include maritime communication and information theory.

Wencai Du received the Bachelor of Science degree from the Peking University, Beijing, China, in 1978. He received the two M.S. degree from the Hohai University, Nanjing, China, in 1986, and from ITC, Enschede, The Netherlands, in1996. He received the Ph.D. degree at University of South Australian, in 2000. He conducted ostdoctoral research at Technion-Israel Institute of Technology (IIT), Israel, from March, 2001-March 2002. His research interests span the areas of computer science and communication engineering. He is especially interested in the computer networking, service computing, e-service and maritime communication. Dr. Du has authored or co-authored 18 books and more than 80 scientific publications. Dr. Du has served on the technical and executive committees of several major conferences and workshops. He was the Conference Chair to IEEE/ACIS ICIS 2011, Conference Co-Chair to SNPD 2010, London, Conference Chair to IEEE/ACISto SERA 2009, and Program Chair to SNPD 2009, Daegu, Korea.

Yani Cui received the B.S. degree in Communication Engineering from Hainan University, China, in 2011. Now, she is a Master-Doctor combined program graduate student in the Department of College of Information Science & Technology in Hainan University. Her research interests include maritime communication and maritime unmanned aerial vehicle flight strategy.

Lingwei Xu was born in Shandong Province, China, in 1987. He received his M.E. degree in Electronics and Communication Engineering from Ocean University of China, China in 2013. Now he is a Ph.D. candidate in Ocean University of China. His research interests include ultra-wideband radio systems, MIMO wireless systems, and M2M wireless communications.