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Overlapped Scaling Tone Reservation method for PAPR Reduction in OFDM/OQAM Systems

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Abstract

Peak-to-Average Power Ratio (PAPR) reduction using Tone Reservation (TR) method is studied for the application in Offset Quadrature Amplitude Modulation based Orthogonal Frequency Division Multiplexing (OFDM/OQAM) transmission using bank of filtered subcarriers. The novel TR method for the filtered subcarriers is presented, which takes into consideration the overlapping nature of the OQAM signals. To eliminate the peaks of the OFDM/OQAM signals effectively, the proposed Overlapped Scaling Tone Reservation (OS-TR) method generate the peak cancelling signal by considering the least square approximation algorithm with possible adjacent symbol overlap. Simulation results show that the proposed method used in OFDM/OQAM system can provide better performance than Controlled Clipping Tone Reservation (CC-TR) method directly used in the OFDM/OQAM system and even outperform Multi Block-Tone Reservation (MB-TR) method.

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Keywords: OS-TR; PAPR; OFDM/OQAM; CC-TR; MB-TR.

1. Introduction

Recently OFDM/OQAM are attaining increasing attention, because of its tight spectral characteristics, minimized side lobes and immunity towards interference[?,?]. Similar to OFDM system, FBMC also suffers from peak to average power ratio (PAPR), which is inherent in multicarrier systems, which degrades high power amplifiers efficiency. Moreover, various PAPR reduction techniques are present in literature for OFDM, among them tone reservation (TR)[?,?,?,?] had grabbed increased attention. As OFDM/OQAM and OFDM are having similar properties, the TR method of OFDM can be extended to OFDM/OQAM signals. However, as OFDM/OQAM adjacent data blocks overlap with each other, while they are independent for OFDM systems, therefore, directly applying TR methods of OFDM systems to OFDM/OQAM systems is not effective.

A sliding window tone reservation (SW-TR)[?] technique obtains moderate PAPR reduction, which uses the peak reduction tones of several consecutive data blocks to cancel the peak power of the OFDM-OQAM signal inside

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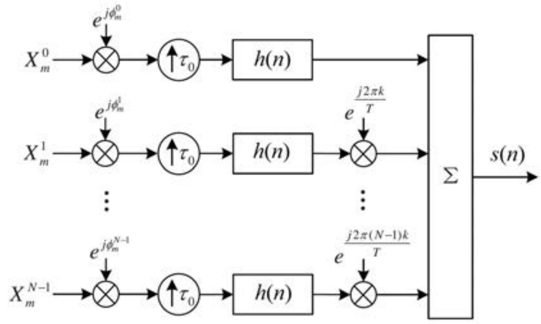

Fig. 1. OFDM/OQAM System Model

a window. The Multi Block Tone Reservation (MB-TR) was discussed in[?], for this modified algorithm, the current data block and its adjacent data blocks are jointly considered to obtain the clipping noise, and then, the peak cancelling signal was achieved by the weighted least square algorithm. Similarly, limited methods are proposed to reduce PAPR for OFDM/OQAM signals in the literature, such as Selective mapping (SLM)[? ?], Partial Transmit Sequence (PTS)[?] by considering possible symbol overlapping structure. Aim at the overlapped structure of the OFDM/OQAM signals, all of the above schemes provide effective solution for the high PAPR problem, and the main idea can be summarized as: deal with the multiple adjacent data blocks simultaneously instead of optimizing each data block independently.

In this article, Overlapped Scaling (OS-TR) methods is considered to reduce the PAPR in OFDM/OQAM system, which exploits OFDM/OQAM signals overlapping nature thereby giving better performance than the CC-TR and MB-TR methods[?]. Since adjacent data blocks in the OFDM/OQAM signals overlap with each other, the OS-TR method scales the filtered clipping noise to produce the peak-cancelling signal, and all the influences of the associated data blocks overlap are taken into account when computing the scaling factors. The OS-TR method could achieve a good trade-off between the PAPR reduction and the computational complexity.

2. OFDM/OQAM SYSTEM AND ACE TECHNIQUE

2.1. Characterization of OFDM/OQAM System

As shown in Fig.1, the baseband modulated OFDM/OQAM system is considered with N subcarrier, real valued symbols modulated by Offset QAM are transmitted, and then the transmitted signal can be written as

$$s(n) = \underbrace{\sum_{m=0}^{M-1} \sum_{k=0}^{N-1} X_m^k \underbrace{h(n - m\tau_0) e^{j\frac{2\pi k}{T}n} e^{j\phi_m^k}}_{h_m^k(n)}}_{s_m(n)} \tag{1}$$

where $1/T$ denotes the subcarrier spacing, M represents the number of input data block, X_m^k is a real valued symbol at the time frequency index (m, k) with $\tau_0 = T/2$ as symbol interval. $X_{2\delta}^k$ and $X_{2\delta+1}^k$ $(\delta \in \mathbb{Z})$ are the real and imaginary parts of the staggered complex QAM symbol. $h(n)$ is the prototype filter impulse response with length $LT(L \in \mathbb{Z})$. Thus, the length of OFDM/OQAM transmitted signal length is $(L + M - 1)T$.

Since the OFDM/OQAM signals are overlapped with adjacent data blocks due to the bank of filters and the time offset between the real and imaginary parts as shown in Fig.2, the conventional definition of PAPR for OFDM systems no longer match perfectly to the OFDM/OQAM systems. Thus we divide the time domain OFDM/OQAM signals into intervals $(M + L)$ equally with the time duration T. then, the PAPR of each interval is

$$PAPR_q = \frac{\max\limits_{qT \le n \le (q+1)T-1} |s(n)|^2}{E[|s(n)|^2]}, q = 0, 1, .., M + L - 1 \tag{2}$$

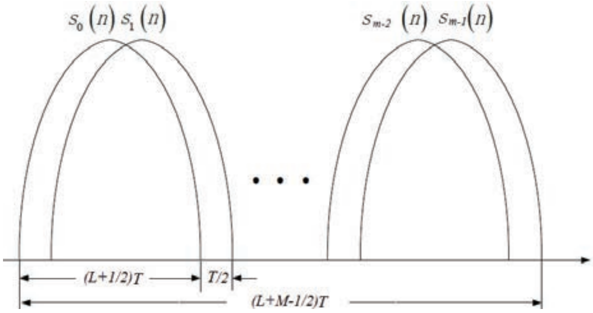

Fig. 2. OFDM/OQAM Symbols Overlapping Structure

where $E[.]$ denotes the expected value operation.

2.2. OFDM/OQAM System Based on the Tone Reservation

For the TR technique, a small percent of subcarriers N_r are reserved as a Peak Reduction Tones(PRTs) and remaining subcarriers $(N - N_r)$ are used for data transmission. The ordered set of PRT indices are denoted by $\mathcal{R} = \{k_0, k_1, ..., k_{N_r-1}\}$, where N_r denotes the size of the PRT set. Thus, the peak-reduced symbol on the k^{th} sub-carrier of the m^{th} data block can be expressed as

$$S_m^k = D_m^k + C_m^k = \begin{cases} D_m^k, & k \in \mathcal{R}^c \\ C_m^k, & k \in \mathcal{R} \end{cases}, \tag{3}$$

where $\mathcal{R}^c$ is the complement set of $\mathcal{R}$ in $\mathcal{N} = [0, 1, . .., N - 1]$, D_m^k and C_m^k represents the data and peak reduction signals on the k^{th} tone of the m^{th} data block, respectively and

$$D_k^m = 0,\ for\ \ k \in \mathcal{R},\ \ C_k^m = 0,\ for\ \ k \in \mathcal{R}^c \tag{4}$$

Then, the peak-canceling signal $c(n)$ can be obtained, and the peak reduced OFDM/OQAM signal $s(n)$ is

$$\hat{s}(n) = \sum_{m=0}^{M-1}\sum_{k=0}^{N-1}(D_m^k + C_m^k)h_m^k(n) = \sum_{m=0}^{M-1}\sum_{k=0}^{N-1}D_m^k h_m^k(n) + \sum_{m=0}^{M-1}\sum_{k=0}^{N-1}C_m^k h_m^k(n) = s(n) + c(n) \tag{5}$$

where $c(n)$ is time domain peak cancelling signal i.e.,

$$c(n) = \sum_{m=0}^{M-1}\sum_{k=0}^{N-1}C_m^k h_m^k(n) \tag{6}$$

In this case, the Peak to Average Power Ratio is defined as

$$PAPR_q^{'} = \frac{\max\limits_{qT \le n \le (q+1)T} \left|s(n) + c(n)\right|^2}{E[|s(n)|^2]}, q = 0, 1, ..., M + L - 1 \tag{7}$$

Thus, from (6) C must be chosen to minimize the maximum of the time domain signal to effectively obtain the peak cancelling symbol C^{opt} , i.e.,

$$\mathbf{C}^{opt} = arg\ \min_{\mathbf{C}}\ \max_{qT \le n \le (q+1)T} \left|s(n) + c(n)\right|^2, q = 0, 1, ..., M + L - 1 \tag{8}$$

Since the OFDM/OQAM signals are overlapped with adjacent data blocks due to the bank of filters and the real and imaginary parts are time staggered by half a symbol period, the conventional definition of PAPR for OFDM systems no longer match perfectly to the OFDM/OQAM systems.

3. Proposed PAPR Reduction Method for OFDM/OQAM System

The proposed OS-TR method is executed on a multi block level, thereby maintaining the continuous nature of OFDM/OQAM system, to generate the optimal peak cancelling signal.

Time domain signal $s(n)$ at the output of the transmitter can be written using (1). $s(n)$ clipping is considered using soft limiter as like in[?] and filtering the clipped to reserved tones. The clipped OFDM/OQAM signal $\bar{s}(n)$ is

$$\bar{s}(n) = \begin{cases} s(n), & if \;\; |s(n)| \leq A \\ Ae^{j\theta_n}, & if \;\; |s(n)| > A \end{cases}, 0 \leq n \leq (M + L - 1/2)T \tag{9}$$

where A is the predefined threshold and θ_n is the phase of $s(n)$. The clipping noise is defined as

$$f(n) = \bar{s}(n) - s(n), 0 \leq n \leq (M + L - 1/2)T \tag{10}$$

Demodulate clipping noise $f(n)$, and convert the clipped signal to the corresponding frequency domain signal, as

$$F_m^k = \Re\left\{ \sum_{n=0}^{(M+L-1/2)T-1} f(n)h(n - m\tau_0)e^{-j\frac{2\pi k}{T}n}e^{-j\phi_m^k} \right\} \tag{11}$$

As the input symbols in OFDM/OQAM system are real valued, the symbols on the peak reduction tones F_m^k also needs to be real valued to satisfy the OFDM/OQAM symbol structure. Then, leaving peak reduction tones of F_m^k, so that a value of zero on the other subcarriers, i.e.,

$$F_m^k = \begin{cases} F_m^k, & k \in \mathcal{R} \\ 0, & k \in \mathcal{R}^c \end{cases}, 0 \leq n \leq (M + L - 1/2)T \tag{12}$$

Thus, the frequency domain peak cancelling signal $F = [F_0, F_1, ..., F_{M-1}]^T$, where $F_m = [F_m^0, F_m^1, ..., F_m^{N-1}]^T$, $m = 0, 1, ..., M - 1$. Modulate F_m^k to obtain the time domain portion of the clipped signal $\hat{f}_m(n)$. In order to approximate $c(n)$ as close to $\hat{f}_m(n)$, $\hat{f}_m(n)$ is scaled by a constant p_m, and is given by

$$c(n) = \sum_{m=0}^{M-1} p_m \hat{f}_m(n) \tag{13}$$

where as

$$\hat{f}_m(n) = \sum_{k=0}^{N-1} F_m^k(n)h(n - m\frac{N}{2})e^{j\frac{2\pi k}{T}n}e^{j\phi_m^k} \tag{14}$$

Obviously, the objective function of OS-TR method, which decreases the Euclidean distance between the clipping noise $f(n)$ and peak cancelling $c(n)$ signal using least square approximation by considering the possible symbol overlap in OQAM symbol structure is given by

$$\min_{p_0, p_1, ..., p_{M-1}} \left\{ \sum_{n=0}^{(M+L-1/2)T} \left[\sum_{m=0}^{M-1} p_m \hat{f}_m(n) - f(n) \right]^2 \right\} \tag{15}$$

As mentioned previously, $\hat{f}_m(n)$ is the time domain signal ranging $\frac{mT}{2}$ to $(L + \frac{m}{2})T$ and L signals of $\hat{f}_m(n)$ overlap with the previous section i.e., $\hat{f}_{m-1}(n), \hat{f}_{m-2}(n), ..., \hat{f}_{m-(L+1)}(n)$. Therefore, while calculating the p_m, the possible overlapping of the signal is considered over the full interval $\frac{mT}{2} \leq n \leq (L + \frac{m}{2})T$ for $m = 0, 1, ..., M - 1$ as discussed in[?] . The least square method is used to calculate the scaling factor by considering the possible overlaps as follows

$$p_m = \begin{cases} \frac{\sum_{n \in \mathbb{S}_0} |\hat{f}_0(n)||f(n)|}{\sum_{n \in \mathbb{S}_0} |\hat{f}_0(n)|^2}, & m = 0 \\ \frac{\sum_{n \in \mathbb{S}_m} |\hat{f}_m(n)||f(n) - \sum_{k=0}^{m-1} p_k \hat{f}_k(n)|}{\sum_{n \in \mathbb{S}_m} |\hat{f}_m(n)|^2}, & 1 \leq m \leq M - 1 \end{cases} \tag{16}$$

Among them $\mathcal{S}_m = \{n/|f(n)| > 0, \frac{mT}{2} \leq n \leq (L + \frac{m}{2})T\}, m = 0, 1, ..., M - 1$. Hence, the optimized scaling factor p_m, which indicates that $\sum_{m=0}^{M-1} p_m \hat{f}_m(n)$ is the least square approximation of $|f(n)|$. Moreover, from (15), as the distance between $\sum_{m=0}^{M-1} p_m f_m(n)$ and $|f(n)|$ is very small, the new peak cancelling signal amplitude is approximated to original clipping noise within 3 iterations.

Algorithm(Overlapped Scaling Algorithm)

Step-1: Set the threshold value A and the max number of iterations I , randomly generate a set of reserved subcarriers $\mathcal{R}$.

Step-2: The original time domain signal of all the data blocks at the output of the OFDM/OQAM transmitter can be written using (1)

Step-3:If $\max|s(n)| > A$,let the number of iterations $i = 1$ and go to step 4; otherwise, output the signal $s(n)$ and terminate the algorithm.

Step-4:Generate a peak cancelling signal $c(n)$:

1. According to (9) and (10) the time domain signal $s(n)$ is processed and the clipping noise is generated and denoted by $f(n)$
2. Transform $f(n)$ to the frequency domain to produce F_m^k, and set $F_m^k = 0$ for all $k \notin R$.
3. In according with (14) transform F_m^k to time domain $\hat{f}_m(n)$.
4. Accordingly calculate the scaling factor p_m which is given by(16)
5. Calculate the peak cancelling signal $c(n)$ using (13)

Step-5:The peak cancelling signal $c(n)$ is superimposed on the original time domain signal $s(n)$, to obtain the new peak reduced signal.

$$\hat{s}(n) = s(n) + c(n) \tag{17}$$

Step-6:Calculate a current time domain signal peaks $\max|\hat{s}(n)|$,if $i < I$ and $\max|\hat{s}(n)| > A$ then $\hat{s}(n) = s(n), i = i + 1$ and jump back to step4, otherwise, the time domain signal $s(n)$ is the final signal to be transmitted.

4. Simulation Results

In this section, the PAPR reduction performance and BER performance of the proposed OS-TR methods are conducted for comparison. The OFDM/OQAM system employs 64 subcarriers with 10^4 data blocks are randomly generated and are QPSK modulated. The number of randomly generated PRTs is $N_r = 8$ and square-root raise cosine (SRRC) filter with length $4N$.

Fig. 3(a) shows the comparison of the PAPR reduction of the OS-TR scheme with a Clipping Ratio of CR=6.01dB and a Tone reservation ratio of $\mathcal{R} = 7.82\%$. The set of reserved tones $\mathcal{R}$ is randomly generated. To verify the PAPR reduction performance of the OS-TR scheme is compared with the CC-TR scheme. Besides, the number of iterations for the CC-TR method is considered as 10. From Fig.3(a), it is observed that the proposed OS-TR method has effective reduction in PAPR than the CC-TR method. For instance, at 10^{-4} clip probability, the OS-TR method achieves 3.8dB reduction in PAPR within 3 iterations, while CC-TR method takes almost 20 iterations to achieve 1.4dB reduction in PAPR. Since in the CC-TR method the adjacent data blocks are independently considered, thus introducing the serious peak regrowth. However, the neighbouring data blocks are effectively evaluated in OS-TR method. Besides, the proposed OS-TR method needs only three iterative operations. Therefore, the OS-TR scheme could achieve better PAPR reduction than the CC-TR scheme with much lower computational complexity.

The algorithms are expanded to tone reservation ratio and the distance between clipping pulses is increased to show the error effects of main lobes and side lobes. Due to the increment in tone reservation ratio, the main lobe outside the pulse duration and the side lobes of clipped pulses are small, and the error approximation is small with tone reservation Ratio of 12.5% for a clipping depth(CD) of 5.1dB. Fig. 3(b) compares the algorithm for 5.1dB CD, 12.5% TR. As shown in Fig.3(b), after 20 iterations a reduction of 2.2dB PAPR is observed in case of CC-TR at 10^{-4} clip probability. At each iteration, small reduction in PAPR is achieved by CC-TR method, and to obtain maximum reduction in PAPR, more number of iterations is required. To achieve effective performance in PAPR reduction, at

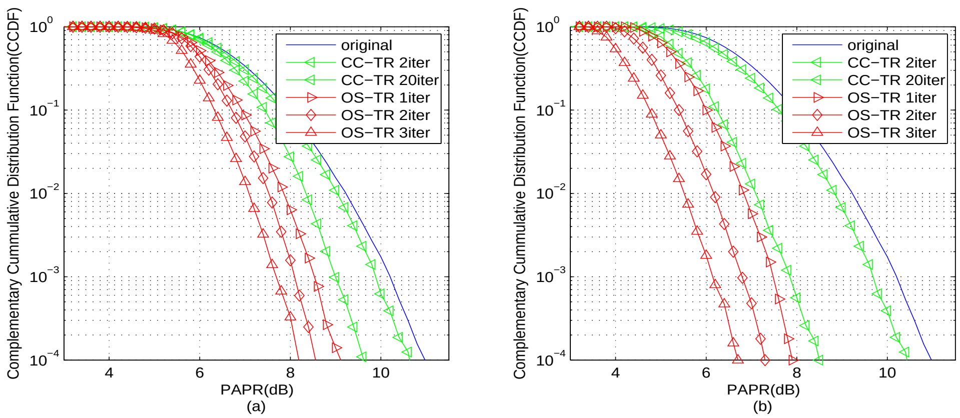

Fig. 3. PAPR reduction comparison of Clipping Control Tone Reservation (CC-TR) and Overlapped Scaling Tone Reservation (OS-TR) algorithms with radomly selected $\mathcal{R}$, (a)where $\mathcal{R}$ = 7.82%, CR=6.0dB; (b) where $\mathcal{R}$ = 12.5%, CR=5.1dB

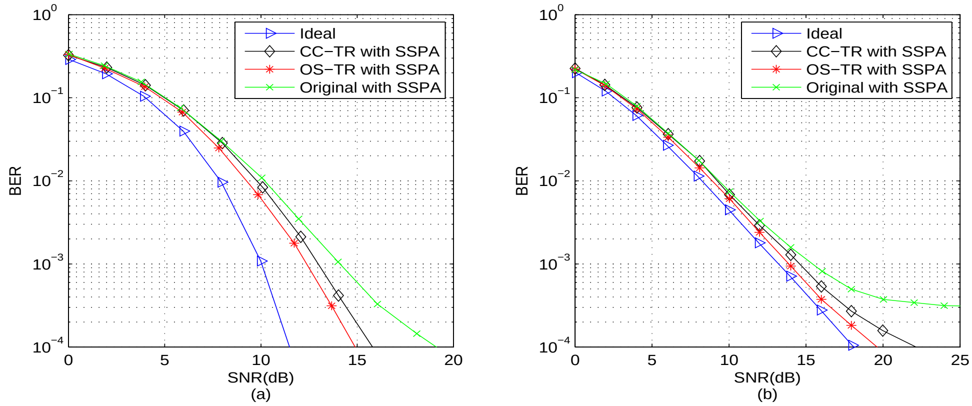

Fig. 4. BER performances of Overlapping OS-TR and CC-TR schemes with QPSK modulation over (a) AWGN Channel; (b) Rayleigh Channel.

least 20 iterations has to be carried out for CC-TR method, which means that the CC-TR method convergence rate is slow. However, as depicted in Fig.3(b), OS-TR method requires only one iteration to achieve almost 3.0dB reduction in PAPR at 10^{-4} clip probability. However, after first two iterations, a small reduction in PAPR is observed, i.e., around 0.6dB, which indicates the OS-TR convergence rate is faster when compared with CC-TR method.

By considering solid-state power amplifier (SSPA), the BER performance of OS-TR method is evaluated over Rayleigh fading and Additive White Gaussian Noise (AWGN) channels respectively. In practice, to obtain sufficient transmit average power, High Power Amplifiers (HPA) are most often employed at the side of the transmitter. For simulation, in order to overcome phase distortion the smoothing parameter is set to 2 in SSPA design and Input Back Off (IBO) as 0dB. The channel between receive and transmit antenna is patterned as the frequency selective Rayleigh fading channel with impulse response . The multipath maximum delay length considered is where N denotes the length of OFDM/OQAM symbol. The multipath fading factor is 0.8. By employing QPSK constellation, the BER performances over AWGN and Rayleigh fading channel for OFDM/OQAM system with 64 sub-carriers with 8 reserved tones, for OS-TR and CC-TR method are depicted in Fig. 4(a) & Fig. 4(b). Here also 2 and 20 are taken as the number of iterations for the OS-TR and CC-TR methods, respectively. The best BER performance is obtained by ignoring the effect of SSPA and nonlinear transform, but it has more PAPR when compared with OS-TR method. And the proposed OS-TR method when compared with original OFDM/OQAM system with HPA, offer effective BER performance. Moreover, OS-TR method can offer better performance than that of the CC-TR method.

Table 1. PAPR reduction comparison of 64 subcarrier OFDM/OQAM modulated system employing different PAPR reduction techniques.

	Proposed Method			Current Literature				
	Original	CC-TR	OS-TR	SW-TR	MB-TR	OSLM	MBJO	S-PTS
PAPR at $10^{-3}(dB)$	10.4	7.8	6.1	6.2	8.6	8.4	7.4	5.9

The proposed method efficiency is also compared to that the literature found in[? ? ? ? ?]. Since the methods presented in literature are simulated with a critical sampled OFDM/OQAM only up to 10^{-3} clip probability for 64 subcarriers, so this was considered as the basic measure for PAPR comparison. Therefore at 10^{-3} clipping probability, it is feasible to consider baseline for PAPR performance comparison. This performance comparison can be observed from Table 1 with OS-TR method.

5. Conclusion

In this paper, the proposed OS-TR is a simple and effective method, which is generated by jointly considering the adjacent data blocks, then, the peak cancelling signal was achieved by the least square algorithm with possible symbol overlap, which fitted the waveform of the peak-cancelling signal to the waveform of clipping noise. In addition, the proposed OS-TR method converges fast enough making use of optimal scaling factor, newly generated peak cancelling signal amplitude is approximated to original clipping noise by scaling the peak cancelling signal. Considerable gains in PAPR reduction capabilities are attained by the proposed technique and compared very favourably with current OFDM/OQAM signals PAPR reductions in literature. Finally, from the simulation results we conclude that OS-TR method provide effective reduction in PAPR and improved BER performance with much lesser computational complexity.

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