A novel joint technique for PAPR reduction in CO-OFDM systems*

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For the high peak-to-average power ratio (PAPR) of coherent optical orthogonal frequency division multiplexing (CO-OFDM) system, a novel joint technique which is the combination of iterative partial transmit sequence (IPTS) and clipping technique is proposed. Simulation results demonstrate that the PAPR and bit error rate (BER) performance of the proposed technique both outperform those of the single techniques. Under the same conditions, the threshold value and peak power of IPTS clipping joint technique are optimized by 3.44 dB and 0.86 dBm compared with those of IPTS techinque, respectively. At the BER of 10^{-3}, the optical signal to noise ratios (OSNRs) of the novel joint technique after 320 km and 400 km single-mode fiber (SMF) transmission are 0.68 dB and 1.18 dB smaller than those of clipping technique, respectively.

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As a novel modulation technology, optical orthogonal frequency division multiplexing (O-OFDM) has high spectral efficiency and extreme robustness to fiber dispersion[1,2]. Therefore, it has been widely studied in recent years for high-speed, large-capacity and long-haul optical communications. However, the high peak-to-average power ratio (PAPR) is one of the major drawbacks of O-OFDM technology, which demands that the dynamic range of nonlinear devices, such as digital-to-analog converters (DACs), analog-to-digital converters (ADCs) and power amplifiers, is large enough. As a result, the higher cost and power-consumption are produced. In contrast, the performance of system will be affected due to the larger bit error rate (BER) and inter-channel interference (ICI) caused by distorted signal[3]. Thus, it is significant to research the PAPR reduction techniques for O-OFDM system.

At present, the techniques for reducing the PAPR of O-OFDM signal can be mainly categorized into signal distortion techniques, coding techniques and signal scrambling techniques[4,5]. In order to solve the limitations of conventional PAPR reduction techniques, a variety of improved or joint techniques have been proposed[6-9]. In this paper, the iterative partial transmit sequence (IPTS) technique is combined with the clipping technique to reduce the PAPR of CO-OFDM system. Compared with the single clipping technique, the proposed joint technique can not only reduce the PAPR effectively, but also improve the BER performance of system.

In partial transmit sequence (PTS) technique[10], the input data block $\boldsymbol{X}=[X_0,X_1,\cdots,X_{N-1}]^{\mathrm{T}}$ is partitioned into V disjoint subblocks, which are represented by the vectors $\{\boldsymbol{X}_v\ ,v=1,2,\cdots,V\}$. Therefore, $\boldsymbol{X}=\sum_{v=1}^{V}\boldsymbol{X}_v$. Then the partial sequences are independently rotated by phase factors of $\{b^{(v)}=\exp\left(\mathrm{j}\phi_v\right),\phi_v\in[0,2\pi),v=1,2,\cdots,V\}$, and the time domain signal of $x=\sum_{v}^{V}b_v$. $IFFT(\boldsymbol{X}_v)$ is generated by inverse fast Fourier transform (IFFT). Finally, the signal with the minimum PAPR and the optimal phase factors is chosen to be transmitted.

The computational complexity of conventional PTS technique is rather large due to the exhaustive way to search the optimal sequence. Aiming at this problem, an improved PTS technique called iterative partial transmit sequence (IPTS) is proposed, which can achieve the compromise between PAPR performance and computational complexity. If $b_v=\{\pm1\}$, the IPTS technique is described as follows.

(1) Partition the data vector with N subcarriers into V disjoint subblocks, and perform N points IFFT.

(2) Set initial phase factor as b_v=1 for v=1,2,⋯,V,

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compute PAPR, get the value as PAPR0, and let *index*=1.

(3) Let $b_{index}=-1$ and calculate the PAPR of signal again.

(4) If the current PAPR is smaller than PAPR0, let PAPR0=PAPR and keep b_{index} invariant. Otherwise, let $b_{index}=1$.

(5) Let $index=index+1$. If $index<V+1$, revert to step (3), otherwise perform step (6).

(6) Obtain the optimum phase factor with the minimum PAPR.

Assuming that W phase angles are allowed, there are W^V alternative representations for an OFDM symbol. The numbers of complex multiplications and additions to perform one time PTS technique are $VW^V\left[(N/2)\cdot\log_2^N\right]$ and $VW^V(N\cdot\log_2^N)$, respectively. Nevertheless, the optimal phase factor can be obtained by only V steps for IPTS technique. W times of PAPR computation and W–1 times of comparison are needed at every step. The computational complexity is reduced obviously, compared with W^V times of PAPR computation and W^V–1 times of comparison for conventional PTS technique.

The principle of clipping technique is to set the peak of input signal as a predetermined value, otherwise the input signal is transmitted without perturbing. Generally, the clipping ratio of $CR=20\log_{10}^{(A/\sigma)}$(dB) is used to weigh the level of clipping, where σ is the root-mean-square (RMS) power of OFDM signal, and A is the threshold value.

Although the clipping technique can reduce the PAPR of signal obviously, in-band distortion and out-band interference will be produced due to the nonlinear operation. As a result, the BER performance and spectral efficiency of system are reduced[11]. The out-band interference can be eliminated by filtering after clipping. Fig.1 depicts the complementary cumulative distribution function (CCDF) curves of OFDM signal after repeated clipping and filtering with 128 subcarriers (N=128), 4 dB clipping ratio (CR=4 dB) for four quaternary amplitude modulation (4QAM), and oversampling factor of 2 (L=2).

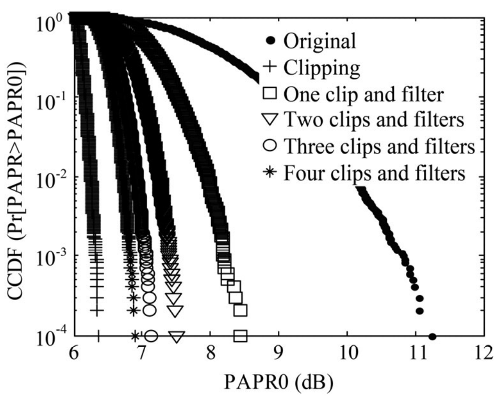


Fig.1 CCDF curves after repeated clipping and filtering

From Fig.1, the PAPR performance of repeated clipping and filtering technique is gradually close to that of conventional clipping technique with the increase of repetition time. At the CCDF of 0.000 1, the PAPR0 values of conventional clipping technique and four times clipping and filtering technique are 6.35 dB and 6.89 dB, respectively. The difference is just 0.54 dB, which indicates that filtering after clipping is feasible. The peak value of signal is reduced obviously compared with that without clipping, regardless of the peak regrowth phenomenon[11].

In this paper, IPTS technique is combined with clipping technique for better PAPR performance. Although clipping will degrade the BER performance of system, IPTS technique can decrease the number of signals whose amplitudes exceed the threshold value. As a result, the undesirable effect on the performance of system caused by clipping will be reduced. Additionally, out-band interference can be eliminated by filtering after clipping. Meanwhile, in-band noise is also reduced for the IPTS operation. Hence, the IPTS clipping joint technique will not increase the BER and computational complexity of system seriously. In contrast, better PAPR and BER performance can be obtained compared with single clipping technique.

Fig.2 depicts the CCDF curves of different techniques with N=128, CR=4 dB for 4QAM, and L=2. Four subsequences and adjacent partitioning method are used for PTS and IPTS techniques.

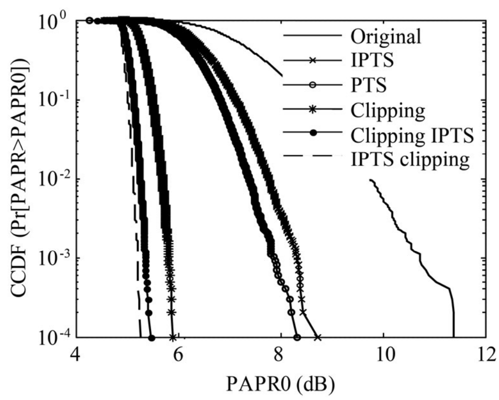


Fig.2 CCDF curves of different techniques with *V*=4

From Fig.2, the PAPR0 values of original signal, IPTS, PTS, clipping, clipping IPTS joint technique and IPTS clipping joint technique are 11.39 dB, 8.71 dB, 8.32 dB, 5.89 dB, 5.48 dB and 5.27 dB at the CCDF of 0.000 1, respectively. The PAPR0 of IPTS technique is increased by 0.39 dB compared with that of PTS technique. Obviously, the computational complexity of IPTS technique is reduced at the cost of inferior PAPR performance. The PAPR0 of IPTS clipping joint technique is optimized by 0.21 dB compared with that of clipping IPTS joint technique, which demonstrates that it is more reasonable to put IPTS technique firstly. Compared with those of single IPTS and clipping techniques, the PAPR0 of IPTS clipping joint technique is decreased by 3.44 dB and 0.62 dB, respectively.

O-OFDM systems can be commonly categorized into direct-detection optical OFDM (DDO-OFDM) system and coherent optical OFDM (CO-OFDM) system according to the method of detection in receiver. CO-OFDM system is considered as the solution to realize high data rate optical transmission for its superior performance in spectral efficiency, receiver sensitivity and polarization-dispersion resilience, but it requires higher implementation complexity compared with DDO-OFDM system[12,13]. The structure of CO-OFDM system is shown in Fig.3.

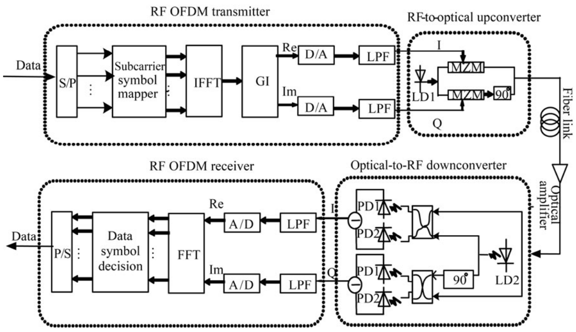


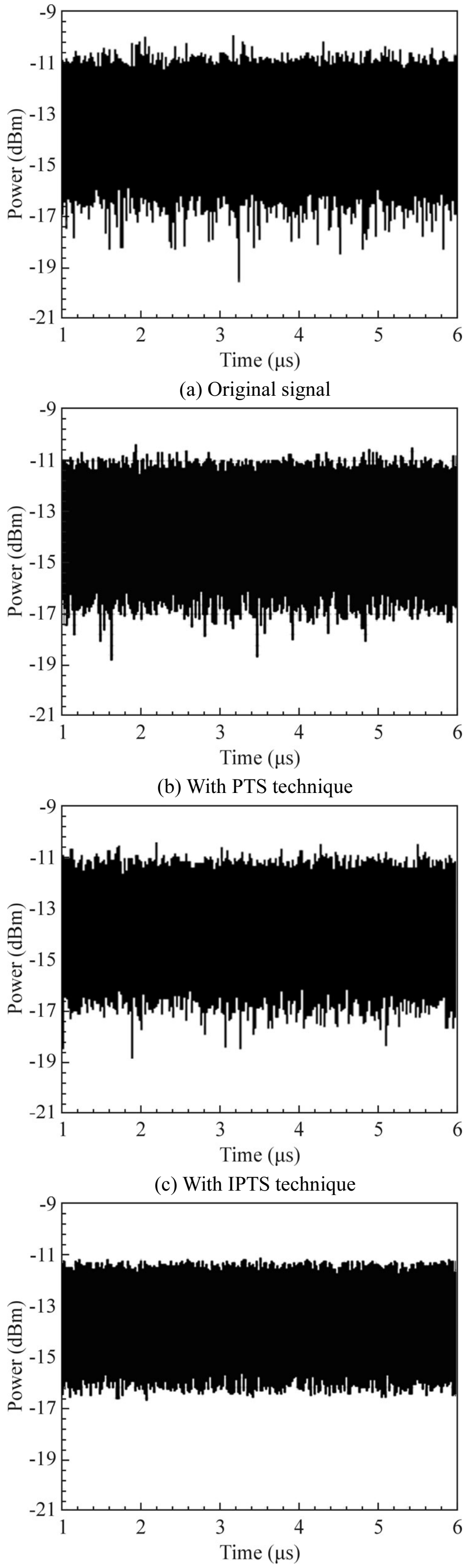
Fig.3 Structure diagram of CO-OFDM system

CO-OFDM system is built by use of Optisystem software in this paper, and the corresponding simulation parameters are set as follows. The data rate is 20 Gbit/s, the number of subcarriers is 512, 4QAM modulation is adopted, the length of cyclic prefix (CP) is 64, and the length of OFDM symbol is 576. A continuous wave (CW) laser is used as the light source with optical carrier frequency of 193.1 THz and line width of 100 kHz. The optical link consists of 8 spans of 80 km single-mode fiber (SMF) with dispersion coefficient of 16.75 ps/(nm·km), nonlinearity coefficient of 2.6×10^{-20} m^2/W, valid area of 80 μm^2 and attenuation of 0.2 dB/km. The gain and noise figure of erbium-doped fiber amplifier (EDFA) are 16 dB and 4 dB, respectively.

The CO-OFDM signal can be obtained, when the radio frequency (RF) OFDM signal generated by MATLAB is transmitted through Mach-Zehnder modulator (MZM).

The PAPR performance of different techniques can be analyzed by observing the change of power of CO-OFDM signal. Fig.4 shows the simulation results. For convenient observation, the range of horizontal coordinates is set from 1 μs to 6 μs, and the range of vertical coordinates is set from –21 dBm to –9 dBm.

From Fig.4, the peak power values of original signal, IPTS, PTS and IPTS clipping joint technique are –10.11 dBm, –10.41 dBm, –10.46 dBm and –11.27 dBm, respectively. The peak power of IPTS technique is 0.05 dBm larger than that of conventional PTS technique. The peak power of IPTS clipping joint technique is decreased by 1.16 dBm and 0.86 dBm compared with those of original signal and PTS technique, respectively. Moreover, the edge of signal power with the novel joint technique is more regular, which indicates that the PAPR of CO-OFDM system can be effectively reduced by combining IPTS technique with clipping technique.



(a) Original signal

(b) With PTS technique

(c) With IPTS technique

(d) With IPTS clipping joint technique

Fig.4 Simulation signal power values of different techniques in optical domain

In order to demonstrate the validity of the proposed novel joint technique, the BER performances of IPTS clipping joint technique and clipping technique are compared after 320 km and 400 km SMF transmission, respectively. The results are shown in Fig.5 with 4 subblocks, adjacent partition and 4 dB clipping ratio.

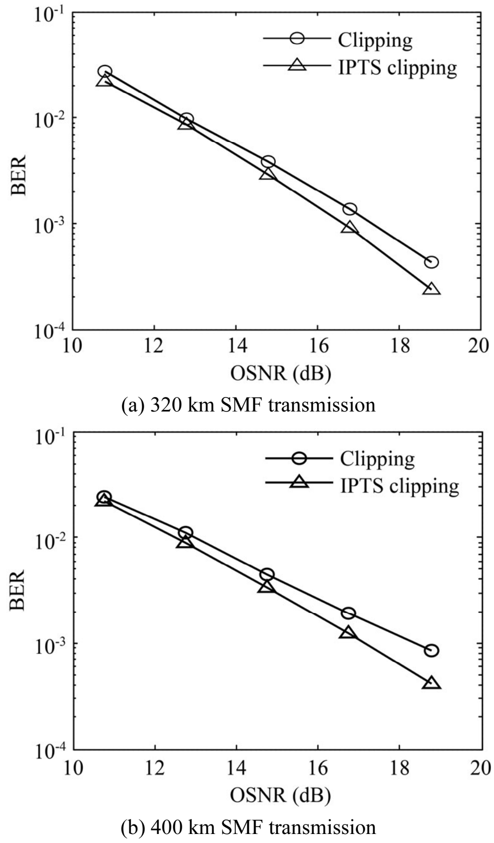


Fig.5 BER performances of IPTS clipping joint technique and clipping technique

From Fig.5(a), the OSNR of clipping technique is 17.33 dB at the BER of 10^{-3} after 320 km SMF transmission. However, the OSNR of IPTS clipping joint technique is 16.65 dB, which is optimized by 0.68 dB. From Fig.5(b), the OSNRs of the two techniques are 18.34 dB and 17.16 dB at the BER of 10^{-3} after 400 km SMF transmission, respectively. Obviously, the OSNR of IPTS clipping joint technique is improved by 1.18 dB at the BER of 10^{-3} compared with that of single clipping technique.

In order to effectively reduce the PAPR of CO-OFDM system, a novel joint technique which is the combination of IPTS and clipping technique is proposed. Simulation results demonstrate that the PAPR and BER performance of the novel joint technique proposed in this paper are superior to those of single techniques. The computational complexity is reduced compared with PTS technique. Compared with clipping technique, the BER performance is improved.

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