

Reduced Complexity Precoding Based Peak-to-Average Power Ratio Reduction Applied to Optical Direct-Detection OFDM

Ömer Bulakci (1), Matthias Schuster (2), Christian-A. Bunge (2), Bernhard Spinnler (3)

1 : Student at Technische Universität München, Dept. of EI, Munich, Germany, omer.bulakci@mytum.de

2 : Fachgebiet Hochfrequenztechnik, Technische Universität Berlin, matthias.schuster@tu-berlin.de

3 : Nokia Siemens Networks GmbH & Co. KG, COO, IP Transport, bernhard.spinnler@nsn.com

Abstract

DCT based precoding is proposed for PAPR reduction to improve the performance of optical OFDM at limited precoding complexity. Effective PAPR reduction and the resultant OSNR performance are shown.

Introduction

Orthogonal frequency-division multiplexing (OFDM) is a promising modulation technique well known from wireless and wired communications which recently also has been discussed for optical communications. A major reason is that it can be designed to be extremely tolerant to chromatic dispersion (CD) [1]-[3]. However, a major drawback of OFDM is its high peak-to-average power ratio (PAPR) which increases with the number of subcarriers. An important problem caused by high PAPR is the high dynamic range of power amplifiers and DA/AD-converters required for distortionless transmission. Moreover, recently a correlation between PAPR and the degrading influence of four-wave mixing (FWM) was shown [4]. Consequently, PAPR reduction schemes become an essential part of optical OFDM systems.

Among a number of proposed schemes, frequency domain precoding is a promising one-shot process which is efficient, signal independent and distortion-free. Precoding is found to be more advantageous compared to the other schemes. In [5] Zadoff-Chu sequence based precoding was shown to reduce the PAPR by 3.7 dB for 1023 subcarriers (SCs). Applied to a system using compatible single-sideband (CompSSB) this PAPR improvement resulted in about 3 dB improvement in required OSNR. However, the complexity of this scheme increases quadratically with the number of SCs. Therefore, low complexity precoding designs are of particular interest especially for higher number of SCs.

In this paper a discrete cosine transform (DCT) based precoding scheme is suggested as a less complex alternative to Zadoff-Chu (ZC) based precoding scheme. DCT was shown to have PAPR reduction capability in [6] and can be efficiently implemented via fast cosine transform algorithms [7] which remarkably decrease the number of real multiplications from $4 \cdot N^2$ to $N \cdot \log_2 N$, where N represents the number of SCs.

The paper is organized as follows. First, the performance of DCT precoding in PAPR reduction is investigated generally. In a second step, it is applied to an OFDM system with direct detection using CompSSB [8]-[9], which is a PAPR sensitive format.

DCT Based Precoding Scheme

To reduce PAPR, DCT is applied to the constellation symbols in advance of inverse fast Fourier transform (IFFT) at the transmitter and inverse DCT is applied to the received symbols after Fast Fourier Transform (FFT) at the receiver. DCT reduces the side lobes of the aperiodic autocorrelation function of the input sequence in the frequency domain, and hence bounds PAPR by an upper limit [6].

Results for 5×10^5 random double-sideband OFDM symbols are presented in complementary cumulative distribution functions (CCDFs) which denote the probability that the PAPR of an OFDM symbol exceeds a given threshold $PAPR_0$. Fig.1 shows PAPR reductions of 3.1 dB and 3.4 dB at CCDF level of 10^{-3} for 127 SCs and 1023 SCs, respectively. This result is comparable with the ZC precoding, since the complexity is reduced by factors of 18 for 127 SCs and 102 for 1023 SCs at the cost of a few 0.1 dB.

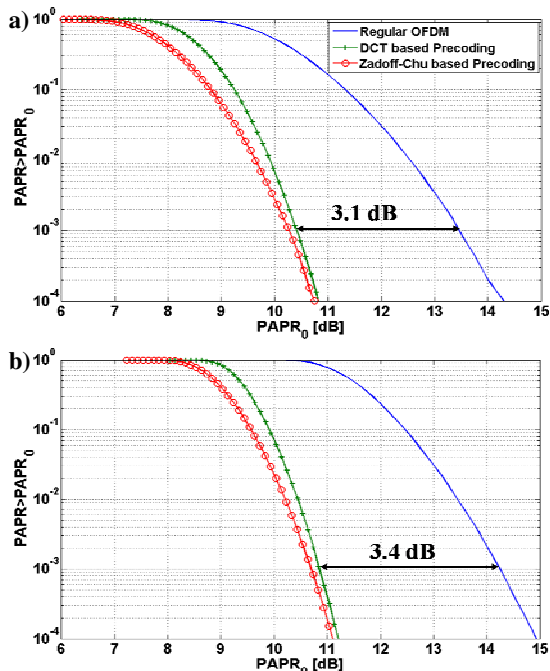


Figure 1: CCDFs for a) 127 SCs and b) 1023 SCs show comparable PAPR reduction capabilities of ZC precoding and much less complex DCT precoding.

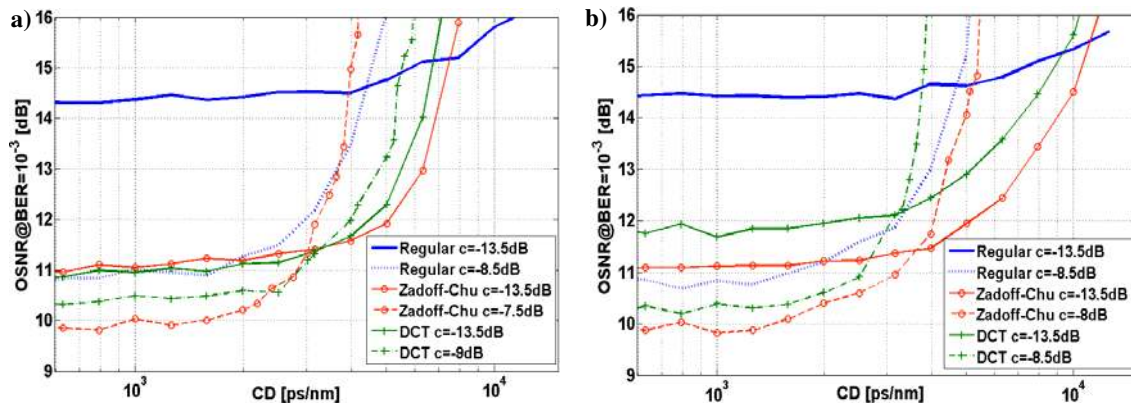


Figure 2: OSNR performance of CompSSB system with a) 127 SCs and b) 1023 SCs for different combinations of precoding schemes and clipping. DCT precoding offers a remarkably decreased complexity at limited penalty.

Demonstration on CompSSB System

To show the benefit of PAPR reduction by DCT for CompSSB, simulations were carried out considering a bandwidth of 5 GHz filled with 127 and 1023 QPSK-modulated SCs, respectively. As one SC is not used the resulting data rate is a bit smaller than 10 Gbit/s, depending on the number of SCs. After generation [8], the signals are modulated onto an optical carrier $f_0=193.1$ THz using an ideal optical IQ-modulator. The signal is transmitted over a linear optical fiber adding CD to the signal. At the receiver, the required OSNR for $BER=10^{-3}$ is determined by noise loading. The receiver employs an optical 10^{th} -order Gaussian filter of 6 GHz (FWHM) bandwidth. After detection of the signal using a single photodiode, the square-law detection is compensated by taking the square root of the signal. Then, the signal is demodulated at the OFDM receiver including equalization [8]. Influence of DA- and AD-converters is not considered.

The results for CompSSB with various combinations of precoding schemes and clipping as well as the results for regular CompSSB are shown in Fig. 2. For a clipping factor $c=-13.5$ dB the signal remains unclipped. For combined simulations of precoding and clipping c was optimized for best OSNR performance. CD tolerance comparison is done with respect to the 1 dB-OSNR-penalty of the graph with worse noise tolerance.

Unclipped regular CompSSB requires at least 14.3 dB OSNR for 127 SCs. When clipping-aided DCT precoding is applied, the minimum required OSNR decreases by 4 dB. CD tolerance of clipping-aided DCT precoding outperforms pure clipping by 1000 ps/nm and clipping-aided ZC precoding by 700 ps/nm. Up to 500 ps/nm more increase in CD tolerance can be achieved by reducing the amount of clipping from $c=-9$ dB to $c=-13.5$ dB at expense of about 0.5 dB. Clipping-aided ZC precoding outperforms clipping-aided DCT precoding by 0.5 dB in minimum required OSNR; however, via fast DCT

algorithms DCT precoding requires 94.4% less real multiplications for 127 SCs.

For 1023 SCs, unclipped regular CompSSB requires at least 14.4 dB OSNR. When clipping-aided DCT precoding is applied to regular CompSSB the minimum OSNR requirement decreases by 4.2 dB. Clipping-aided DCT precoding outperforms pure clipping in minimum required OSNR by 0.5 dB with 200 ps/nm better CD tolerance; however, it is outperformed by clipping-aided ZC precoding in minimum CD tolerance with slightly better minimum required OSNR. Nevertheless, CD tolerance can be increased by up to 1100 ps/nm by reducing the amount of clipping at the cost of a 1.5 dB reduced OSNR tolerance. Although the performance of DCT precoding is not as good as for ZC precoding, it can be preferable, since the complexity of fast DCT algorithms is 99% lower for 1023 SCs.

To reduce the complexity further, even faster DCT algorithms can be obtained by means of multiplierless approximations [10].

Conclusions

A reduced complexity DCT precoding scheme for PAPR reduction has been proposed to increase performance of optical OFDM. The PAPR reduction efficiency is presented. Up to 4.2 dB OSNR tolerance increase is demonstrated on a CompSSB system. Compared to Zadoff-Chu precoding, the complexity is reduced by up to 99% in the considered set-up.

References

1. A. J Lowery et al., JLT, 2007, pp. 131-138
2. W.Shieh et al.,OE, 2007,pp. 9936-9947
3. S. Jansen et al., OFC 2008, PDP2
4. B. Goebel et al., OFC 2008, JWA58
5. Ö. Bulakçı et al. , OFC 2008, JThA56
6. E. Sun et al., AINA 2006, Vol. 2, Page: 4 pp
7. B. G. Lee, ASSP, 1984, pp. 1243-1245
8. M.Schuster et al., PTL, 2008, pp. 670 – 672
9. M. Schuster et al., OFC 2008, OMU7
10. R.K.W. Chan et al., ICPR 2006, Vol.3, pp.921-925