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An Improved SLM Technique Using Discrete Cosine Transform in OFDM System

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ABSTRACT

Background: Orthogonal Frequency Division Multiplexing (OFDM) is widely used as a standard modulation for various high data rate wireless communication systems. It is worked by converting high data rate streams into a number of parallel low data rate streams. OFDM has many advantages over single carrier modulation systems. Some of these advantages are robustness to frequency fading channels, high transmission bit rate and high spectral efficiency. However, OFDM has its drawbacks. One of the main problems is high Peak-to-Average Power Ratio (PAPR), which brings disadvantage likes an increased complexity of system. Several techniques have been proposed in order to reduce PAPR. Hence, this paper presents Discrete Cosine Transform (DCT) precoded Selected Mapping (SLM) technique that is implemented to reduce PAPR of OFDM system. Simulation results show that implementation of DCT precoded SLM technique can reduce PAPR to about 1.55dB for 512 subcarriers and four selective data blocks at clipping probability of 10^{-3}. From the simulation results, as number of subcarriers increases, PAPR value also increases. The PAPR reduction effect is improved with the increasing number of selective data blocks. Besides, the number of selective data blocks should also be chosen carefully as it affects the computational complexity of OFDM system.

INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a modulation and multiplexing that has been adopted as a standard for various high data rate wireless communication systems. It is worked by converting a high data rate into a number of low-rate streams that are transmitted over parallel, narrowband channels that can be easily equalized (Molisch 2011). OFDM has a high data rates, high spectral efficiency, high quality of service and robustness to frequency selective fading channels and narrowband interference (Raj and Malleswaran 2012). With those characteristics, it is used in various wireless communication especially in high data rate wireless communication system as it was previously mentioned. Applications of OFDM are wireless local area network (WLAN), digital audio broadcasting, asymmetric digital subscriber loop (ADSL), digital video broadcasting, etc.

Most broadband systems are subject to multipath transmission. The conventional solution to multipath is an equalizer in the receiver side. In traditional modulation scheme large numbers of equalizers are used at receiver when dealing with high data rate. This is not only make the system complex, it also increase the cost of the system. With OFDM there is a simple way of dealing with multipath by implementation of digital signal

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processing (DSP) algorithms. It uses Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) to replace modulation and demodulation (Nimje and Rathakanthiwar 2013).

However, OFDM also has its shortcoming. One of the major drawbacks of OFDM signal is its large peak-to-average power ratio (PAPR). A large PAPR ratio brings disadvantages like an increased complexity of the analog-to-digital and digital-to-analog converters and poor power efficiency of the RF power amplifier. It also causes signal distortion such as in-band distortion and out-of-band radiation due to the nonlinearity of the high power amplifier (HPA) and a worse bit error rate (BER) (Lim, Heo *et al*. 2009). Therefore, PAPR reduction is one of the most essential research areas in OFDM.

Different techniques have been proposed in order to reduce PAPR. These techniques normally categorized in two group. First, there are signal distortion techniques, which reduce the peak amplitudes simply by nonlinearly distorting the OFDM signal. Example is clipping. Then, another technique which scrambles each symbol with different scrambling sequences and selecting the sequence that gives the smallest PAPR. Example is partial transmit sequence (PTS) (Chackochan and Soni 2011).

In order to reduce PAPR of OFDM system, several techniques have been proposed. Selected Mapping (SLM) is the most proposed algorithm for solving PAPR problem among the proposed techniques. However, the SLM technique has high computational complexity (Wang 2010). The study in (Gu, Baek *et al*. 2010) presented Discrete Cosine Transform (DCT) based precoder has low complexity compared to other precoder and reduce autocorrelation from data input. In this project, DCT precoded SLM technique will be implemented to reduce PAPR of OFDM system (Müller, Bäuml *et al*. 1997, Bhardwaj, Gangwar *et al*. 2012).

DCT precoded SLM technique will be simulated by using MATLAB. Then, simulation results will be analysed. Hence, this project examines several questions. Firstly, effect of DCT precoded SLM technique towards PAPR reduction will be judged. Advantages of DCT precoded SLM technique compared to other PAPR reduction scheme will also be investigated.

Dct-Ofdm:

A serial random binary data is generated and modulated under QAM modulation technique, which generates complex vector of size N modulated symbols. Assume that data stream after serial to parallel conversion is:

$$X = [X_0, X_1, \dots, X_{N-1}]^T \qquad (1.1)$$

Where N is the number of subcarriers.

A set of selective data blocks are formed representing the same information as shown in Eq. (1.2).

$$X(v) = [X_0, X_1, \dots, X_{N-1}]^T, v = 1,2, \dots, V \qquad (1.2)$$

Where v and N are the number of selective data blocks and number of subcarriers.

(a) DCT Precoder:

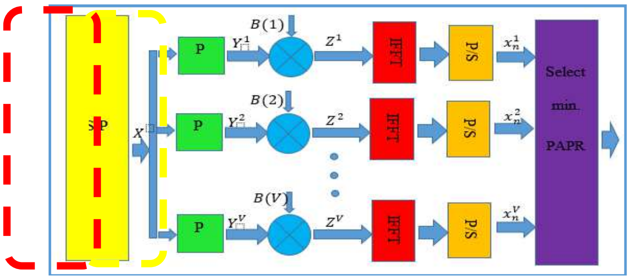

Fig. 1.1: Block diagram of DCT precoded SLM technique at transmitter

From Figure 1.1, the signal in Eq. (1.2) is passed through DCT Precoder, which is highlighted in red dotted area and the resultant signal can be written as:

$$Y_l^v = \sum_{r=0}^{N-1} p_{l,r}\, X(v) \qquad , l = 0,1, \dots, N-1 \qquad (1.3)$$

Where $p_{l,r}$ is r^{th} row and l^{th} column of DCT precoder matrix.

In general, DCT can be defined as:

$$D_k = \alpha(k) \sum_{n=0}^{N-1} Y.\cos\left[\frac{\pi}{N}\left(n + \frac{1}{2}\right)k\right] ,$$
$$k = 0,1, \dots, N-1 \qquad (1.4)$$

Where $\alpha(k)$ is defined in Eq. (1.5)

$$\alpha(k) = \begin{cases} \frac{1}{\sqrt{N}} & for\ k = 0 \\ \sqrt{\frac{2}{N}} & for\ k \neq 0 \end{cases} \tag{1.5}$$

Based on the Eq. (1.4) and Eq. (1.5), DCT precoder matrix, $p_{l,n}$ can be generated as shown in Eq. (1.6).

$$p_{l,r} = \begin{cases} \frac{1}{\sqrt{N}} & r = 0, \quad 0 \leq l \leq N-1 \\ \sqrt{\frac{2}{N}} cos\frac{\pi(2l+1)r}{2N} & 1 \leq r \leq N-1, \quad 0 \leq l \leq N-1 \end{cases} \tag{1.6}$$

Where r and l are row and column of DCT precoder matrix respectively.

(b) Selected Mapping (SLM):

From Figure 1.1, the signal in Eq. (1.2) is multiplied by V dissimilar phase sequence, which is highlighted in yellow dotted area and shown in Eq. (1.5), which results in the signal shown in Eq. (1.8)

$$B(v) = [B_0, B_1, \dots, B_{N-1}]^T \quad , \; v = 1,2,\dots,V \tag{1.7}$$

Where v is the number of selective data blocks.

$$Z^v = [Y_0^v B_0^v, Y_1^v B_1^v, \dots, Y_{N-1}^v B_{N-1}^v]^T, \quad v = 1,2,\dots,V \tag{18}$$

After performing the IFFT, the signal in Eq. (1.8) can be written as

$$x_n^v = \frac{1}{\sqrt{N}}\sum_{h=0}^{N-1} Z^v . e^{j2\pi\frac{n}{N}h} \qquad ,v = 1,2,\dots,V \tag{1.9}$$

Where $n = 0,1,2,\dots,N-1$.

Figure 1.2 shows the overall block diagram of an OFDM system using DCT precoded SLM technique

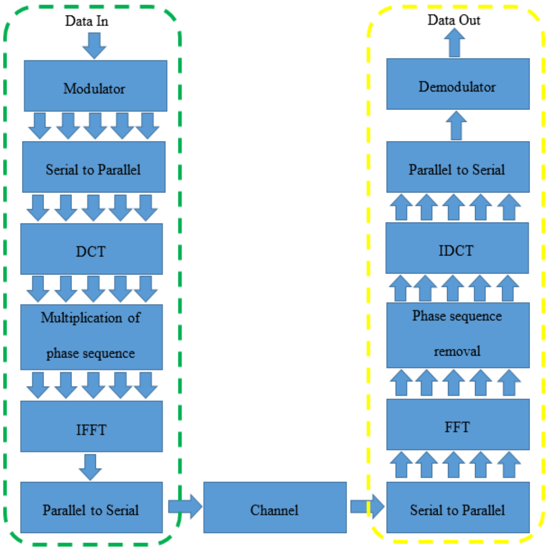

Fig. 1.2: Overall block diagram of an OFDM system using DCT precoded SLM technique

Calculation Of Peak-To-Average Power Ratio:

PAPR is the ratio between the peak power and the average power of the complex OFDM signal x_n^v. PAPR is expressed as:

$$PAPR = \frac{max|x_n^v|^2}{E|x_n^v|^2} \tag{1.10}$$

Where E is expectation.

In terms of decibel, PAPR is written as:

$$PAPR = 10log_{10}\frac{max|x_n^v|^2}{E|x_n^v|^2} \tag{1.11}$$

Where $n = 0,1,2,\ldots,N-1$ and $v = 1,2,\ldots,V$.

The time domain complex OFDM signal x_n^vcan also be defined as:

$$x_n^v = Re\{x_n^v\} + Im\{x_n^v\} \tag{1.12}$$

Where $Re\{x_n^v\}$ and $Im\{x_n^v\}$ are real and imaginary parts of OFDM symbol respectively.

Hence, the peak power and average power is shown as:

$$Peak\ power = max|x_n^v|^2$$

$$= max\left| \sqrt{(Re\{x_n^v\})^2 + (Im\{x_n^v\})^2}\right|^2 \tag{1.13}$$

$$Average\ power = E|x_n^v|^2 = \frac{1}{N}\sum_{n=0}^{N-1} \left| \sqrt{(Re\{x_n^v\})^2 + (Im\{x_n^v\})^2}\right|^2$$

Where $n = 0,1,2,\ldots,N-1$ and $v = 1,2,\ldots,V$.

(1.14)

If each IFFT input is independent and identically distributed, the real and imaginary parts of x_n^v have mutually independent Gaussian probability distribution function by central limit problem. The instantaneous power of x_n^v.

$$\beta = (Re\{x_n^v\})^2 + (Im\{x_n^v\})^2 \tag{1.15}$$

Where $Re\{x_n^v\}$ and $Im\{x_n^v\}$ are real and imaginary parts of OFDM symbol respectively.

The instantaneous power is characterized as Rayleigh distribution. Based on Eq. (2.3), the probability density function is computed as:

$$f_{M_n}(m) = \frac{m}{\sigma^2} exp\left(-\frac{m^2}{2\sigma^2}\right),\ n = 0,1,2,\ldots,N-1 \tag{1.16}$$

Where M_n is the magnitude of x_n^v.

Then, the maximum of M_n is equivalent to crest factor and the cumulative distribution function (CDF) of the maximum amplitude or crest factor of a signal is given by (Bhardwaj, Gangwar *et al*. 2012):

$$F_{M_{max}}(m) = P(M_{max} < m) \tag{1.17}$$

A CCDF curve illustrates how much time the signal uses at or above a given power level. Mathematically CCDF can be defined as:

$$CCDF = 1 - CDF \tag{1.18}$$

Bit Error Rate:

A BER test provides a useful indication of the performance of the OFDM system. If BER increase too high then the system performance will degrade. BER is the ratio between the number of bits received in error and the number of bits transmitted and is expressed as:

$$BER = \frac{number\ of\ bits\ in\ error}{total\ number\ of\ bits\ transmitted} \tag{1.19}$$

Performance of BER is simulated by adding amount of noise to the transmitted signal. During transmission, if signal-to-noise ratio (SNR) is high, then BER will be very small. However, if noise is high, then chance that BER is getting high will be very high. SNR is usually expressed in decibels as shown

$$SNR = 10log_{10}\frac{P_{signal}}{P_{noise}} \tag{1.20}$$

Where P is the average power.

Simulation And Results:

Table 1.1 shows the PAPR value of SLM and DCT precoded SLM technique using 16-QAM and 64-QAM. In this case, number of subcarriers used is 256 and number of selective data blocks is 4. Then, Figure 1.3 illustrates the graph of CCDF against PAPR using 16-QAM

Table 1.1: PAPR value of SLM and DCT precoded SLM technique using 16-QAM and 64-QAM (Clip Rate of 10^{-3})

Modulation Scheme	PAPR in dB		
	SLM Method	DCT-SLM Method	Improvement
16-QAM	10.58	9.56	1.02
64-QAM	11.00	9.63	1.37

From Table 1.1, at clip rate of 10^{-3}, the PAPR gain of 1.02dB is achieved when DCT precoded SLM technique is compared with original SLM technique under 16-QAM as shown in Figure 1.3. Then, PAPR gain of 1.37dB is achieved when DCT precoded SLM technique is compared with original SLM technique under 64-QAM. These indicate that PAPR is reduced using DCT precoded SLM technique for different modulation scheme. Based on the Table 1.1, PAPR under 64-QAM is higher than PAPR under 16-QAM. Performance of PAPR reduction under 64-QAM is also better than performance of PAPR reduction under 16-QAM.

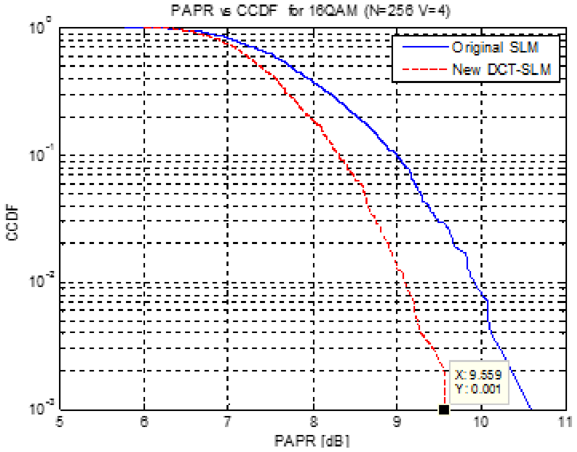

Fig. 1.3: Graph of CCDF against PAPR using 16-QAM

Table 1.2: PAPR value of SLM and DCT precoded SLM technique for N = 32, 64, 256, 512 and 1024 (Clip Rate of 10^{-3})

Number of subcarriers	PAPR in dB		
	SLM Method	DCT-SLM Method	Improvement
32	9.56	8.55	1.00
64	10.26	8.82	1.44
256	10.94	9.63	1.31
512	11.30	9.75	1.55
1024	11.33	10.04	1.29

Form Table 1.2, at clip rate of 10^{-3}, the PAPR gain of 1.00dB is achieved when DCT precoded SLM technique is compared with original SLM technique for N = 32.

Performance of Ber:

Performance of BER is simulated by adding noise to the transmitted signal. The noise is added during transmission in channel, which is AWGN channel.

Simulation result under AWGN channel:

Table 1.3 shows the BER value of SLM and DCT precoded SLM technique for two parameters which are modulation scheme and number of subcarriers. In this case, number of selective data blocks is fixed which is 4. Figure 1.4 illustrates the graph of BER against E_bN_o under AWGN channel for N = 256 and 16-QAM.

Table 1.3: BER value of SLM and DCT precoded SLM technique under AWGN channel (E_bN_o = 0dB)

Modulation Scheme	Number of subcarriers	BER	
		SLM Method	DCT-SLM Method
16-QAM	32	0.1528	0.1499
	64	0.1535	0.1510
	256	0.1583	0.1533
	512	0.1573	0.1561
	1024	0.1601	0.1535
64-QAM	32	0.1988	0.2028
	64	0.2048	0.2018
	256	0.2083	0.2061
	512	0.2103	0.2107
	1024	0.2116	0.2112

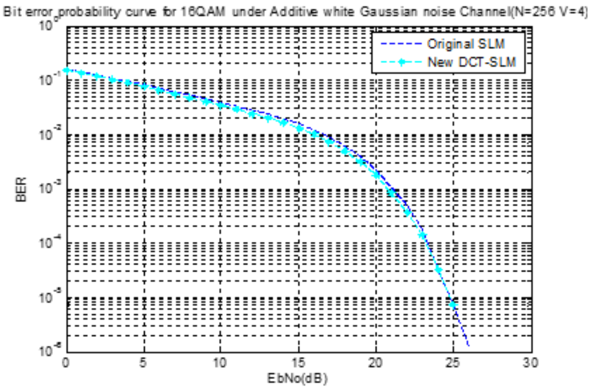

Fig. 1.4: Graph of BER against E_bN_o under AWGN channel for 16-QAM

Based on Table 1.3, almost all values of BER is slightly reduced when DCT precoded SLM technique is compared with original SLM technique. It is also reveal that performance of BER for 16-QAM is better than the performance of BER for 64-QAM for different number of subcarriers. This is because more bits are transmitted under 64-QAM compared with 16-QAM and the points of constellation for 64-QAM are more close together. Hence, the transmission becomes more susceptible to noise. Hence, the performance of BER is slightly improved when DCT precoded SLM technique is compared with original SLM technique.

Conclusion:

DCT precoded SLM technique has been implemented to reduce PAPR of OFDM system. Based on the simulation results, it shows that PAPR is reduced using this technique. Then, almost all values of BER are reduced by implementing this technique as what have been shown. The effect of DCT precoded SLM technique based on several parameters is also investigated. These parameters are modulation scheme, number of subcarriers, number of selective data blocks and channel. Modulation scheme affects the performance of PAPR reduction of OFDM system. The higher the order of modulation, the better the performance of PAPR reduction. In this paper, performance of PAPR reduction under 64-QAM is better than performance of PAPR reduction under 16-QAM as it has higher order of modulation.

Then, the number of subcarriers also brings effects to the performance of PAPR of OFDM system. Based on the simulation results, PAPR is increased when large number of subcarriers is used. Hence, for N = 1024, it has the highest PAPR of the OFDM system as it is largest number of subcarriers used in this paper.

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