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A Hybrid Composition of PAPR Degradation with Near-Optimal Performance in OFDM Systems

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ABSTRACT:

To reduce the PAPR in OFDM systems selected mapping schemes (SLM) are widely used due its distortion less nature. However a major drawback of traditional SLM technique is high computational complexity to select a low PAPR signal it requires a bank of inverse fast Fourier (IFFT) operations. This paper proposes a novel architecture for PAPR reduction in OFDMs with low computational complexity. In this proposed method, frequency domain cyclic shifting, complex conjugate, sub-carrier reversal operations are performed to increase the PAPR reduction performance in OFDM systems whereas in traditional SLM scheme only frequency domain phase rotation can be performed to generate the candidate signals. Furthermore, to reduce the multiple IFFT problems, all of the frequency domain equivalent operations are converted into time-domain equivalents. It is shown that the sub carrier partitioning and re-assembling processes are important in realizing low complexity time domain equivalent operations. Moreover, it is shown theoretically and numerically that the computational complexity of the proposed scheme is significantly lower than the traditional SLM method and the PAPR reduction performance is within 0.001 dB of that SLM.

Keywords: ***OFDM (Orthogonal frequency division multiplexing), peak to average power ratio (PAPR), selected mapping (SLM), bit-error-rate (BER).***

INTRODUCTION

After more than thirty years of research and development, OFDM [1-4] has been extensively adapted in wireless communications due to its low vulnerability to multipath propagation and high spectral efficiency [3]. In many applications, high data rate transmissions are required over wireless channels with OFDM systems. However a major drawback of OFDM based transmission system is its high PAPR, which leads to in-band distortion and out of band radiation when the signals are passed through a non-linear power amplifier. There are various proposals for PAPR reduction in OFDM systems in literature, including tone reservation, tone injection, clipping, partial transmit sequence, activeconstellation extension, nonlinear companding, selected mapping(SLM) [5]. Among all these techniques SLM is most commonly used due to its distortion less natur. However a major drawback of traditional SLM technique is highcomputational complexity to select a low PAPR signal it requires a bank of inverse fast Fourier (IFFT) operations [7]. To reduce the computational complexity, several lowcomplexity SLM architectures have been proposed in which the frequency domain phase rotations are converted into equivalent frequency domain phase rotations. This paper proposes a novel architecture for PAPR reduction in OFDMs with low computational complexity. In this proposed method, frequency domain cyclic shifting, complex conjugate, sub-carrier reversal operations are performed to increase the PAPR diversity in OFDM systems whereas in traditional SLM scheme only frequency domain phase rotation is used to generate the candidate signals [9].

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RELATED WORK

Orthogonal Frequency Division Multiplexing is a digital transmission method developed to meet the increasing demand for higher data rates in communications. Major drawback is high PAPR. Analysis and simulation of PAPR that the occurrence of large peaks in OFDM. The effect on system performance in terms of the Bit Error Rate (BER) and Power Spectral Density (PSD) is simulated for an OFDM transceiver with a saturated High Power Amplifier. This is followed by a study of published PAPR reduction methods [3]. The first contribution is a low complexity variation of Partial Transmit Sequences (PTS). In PTS several alternate transmit signals are seeded from the same source, each alternate transmit signal has a reversible and different phase rotation performed on the data. The transmit signal with the lowest PAPR is chosen for transmission. In novel variations, called Cyclic Shifted Sequences (CSS) and Time Inversion (TI), different shifts of the data are performed which avoid the need for complex multiplications. In certain cases a whole IFFT operation can be removed with a negligible effect on performance when CSS is combined with PTS. Furthermore it is shown that the peak re-growth ofTI and CSS after pulse shaping filtering is considerably less than for PTS [2]. Next clipping techniques are presented which reduce substantially the complexity of clipping algorithms by using novel methods to calculate the magnitude, avoiding the use of multiplications but existing more complex and also losing signal.

SYSTEM MODEL

We consider a MIMO-OFDM communication system with M transmit and receive antennas and N sub-carriers as in Fig. 1. The modulated symbols form an N x 1 frequency domain data vector

$$X = [X[0], X[1], \dots X[N-1]]^T \quad (1)$$

Where X[k] indicates the modulated symbol of kth sub-carrier and (.)T indicates the transpose operation. To generate time domain signal vector x, an N-point IFFT is performed where the nth element of x is given by,

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k].\exp\left\{\frac{j2\pi nk}{N}\right\}, \qquad n = 0, 1, \dots, N\text{-}1 \quad (2)$$

The PAPR of the discrete time OFDM signal is represented as

$$PAPR(x) = \frac{\max_{0 \le n \le N-1} |x[n]|^2}{E[|x[n]|^2]}, \quad (3)$$

WhereE [.] symbolizes the expectation operation. In general, the PAPR reduction is evaluated by means of complimentary cumulative distributive function (CCDF) which is expressed as

$$CCDF_{PAPR(x)} = \Pr(PAPR(x) > \gamma) \quad (4)$$

Where the probability of PAPR of x exceeds a given clip level. It has been seen that the pilot tones normally applied in wireless OFDM transmission [4] for synchronization and channel estimation purposes can be used in PAPR reduction too. A write up on examinations of their utilization is introduced in. The authors propose to control with the pilot symbols by choosing those of their qualities that limit PAPR of the entire OFDM symbol. A set of orthogonal pilot successions is proposed in so blind identification can be performed at the receiver in view of the orthogonally of the symbols on the pilot tones andno SI must be transmitted to the receiver. Applying pilots to the PAPR minimization, which is proposed in this paper, varies from that depicted above and is theoretically very simple.

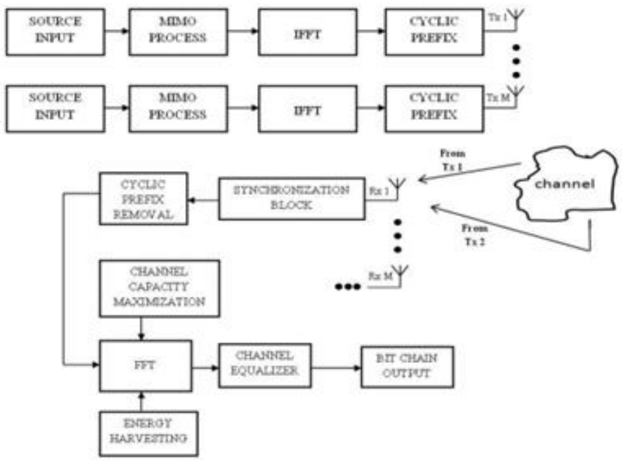

Fig. 1. MIMO-OFDM system model for performance improvement

Based on the MIMO-OFDM technique [6], to reliably reproduce the transmitted signal, the receiver has to be synchronized with the transmitter in frequency, phase and time in communication system. The mismatch between the transmitter and receiver sampling clocks

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and their reference frequency in an OFDM system leads to frequency offset. The sampling clock errors occur in two ways:

1. Gradual variation in the sampling time leads to rotation of sub-carriers and resulting loss of signal to noise ratio (SNR) due to inter carrier interference (ICI) and
2. Loss of orthogonally due to the energy spread and adjacent sub-carriers among the sub-carriers. Defining a normalized sampling error as

$$t_{\Delta} = \frac{T' - T}{T} \quad (5)$$

where T is the transmit sampling period and T′ is the receive sampling period. Power is approximated as

$$P_{t_{\Delta}} \approx \frac{\pi^3}{3}(Kt_{\Delta})^2 \quad (6)$$

Where k is the sub-carrier index. Therefore the degradation increases with the square of the sub-carrier index K and the offset. An OFDM system with large number of sub-carriers is very sensitive to sampling offset. In the next section let us see in detail about the above mentioned techniques and view the simulation and results obtained on its basis.

PEAK TO AVERAGE POWER RATIO IN MIMO-OFDM

Let us now consider two signals x(t) and y(t) as the real and imaginary parts of a complex baseband output signal $\check{S}$ with an interval of t ϵ [0,Ts] as

$$\check{S} = x(t) + jy(t) \quad (7)$$

$$= \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} A_k e^{\frac{j2\pi kt}{T_s}} \quad (8)$$

Where T is the time period of the OFDM system and is the complex data of the Kth sub-carrier. According to Nyquist rate OFDM has maximum spectral efficiency and it constrains the overlapping of bands in channels. The use of IFFT makes its implementation simple and less complex. Perfect synchronization of transmitters and receivers is also obtained using zero forcing beam forming (ZFBF) [8]. High PAPR is the main drawback of this multicarrier modulation that leads to two major problems; it increases the complexity of analog to digital and digital to analog convertors and reduces the efficiency of the RF power amplifiers. A discrete time baseband OFDM has PAPR defined as the ratio of the maximum power of peak to the average power of the OFDM signal.

$$PAPR_{db} = 10log_{10}\left\{\frac{P_{peak}}{P_{avg}}\right\} \quad (9)$$

Here P_{peak} is the maximum power for one OFDM frame and P_{avg} is the average power consumed by each frame.

TRADITIONAL SLM TECHNIQUE

The OFDM data symbol (similar to that of equation (1)) in a traditional SLM method is multiplied symbolwise by one of the U pseudorandom phase mask where

$$X_n = [X_{1,n}, \dots, X_{N,n}]^T$$

$$M_u = [M_1^u, \dots, M_N^u]^T, \quad (u = 1, \dots, U)$$

where, $M_i^u = \exp(j\varphi_{i,u})$

Taking these as vector products $X_n \otimes M_u$ the OFDM symbol time domain representation is

$$x_n^u = F^{-1}(X_n \otimes M_u), \quad u = 1, \dots, U \quad (10)$$

Where is the IFFT matrix operation and on computing U such vectors, is transmitted which presents the lowest PAPR value. This corresponds to the index u* for which ( ) for (i = 1,…,N) and (u = 1,…,U) evaluates the lowest value. Hence this index u* should be transmitted as an extra message keeping in mind to detect the OFDM data symbol effectively, in the simplest form. Examining a simple case where the pilot tones are placed on a set of sub-carriers whose indices belongs to a set * + where M is the number of pilot tones applied. Therefore at nth time period the OFDM data blocks are divided into blocks of data and pilot symbols (Xn and Pn).

$$X_n = [X_{1,n}, \dots, X_{N,n}]^T$$

$$P_n = [P_{1,n}, \dots, P_{N,n}]^T \quad (11)$$

where X_n and P_n are estimated by

$$X_{i,n} = \begin{cases} D_{i,n} & \text{for, } i \in \{1,..,N\}\backslash\Upsilon \\ 0 & \text{for } i \in \Upsilon \end{cases} \quad (12)$$

$$P_{i,n} = \begin{cases} 0 & \text{for, } i \in \{1,..,N\}\backslash\Upsilon \\ B_{i,n} & \text{for } i \in \Upsilon \end{cases} \quad (13)$$

Where (from QAM or QPSK) and (from BPSK or QPSK) are the data and pilot symbols of the ith subcarrier of the nth OFDM symbol (i = 1 ,…, N). The pilot symbols in general need not be the same at each time period n, hence it can be represented as the index n.

MODIFIED SLM WITH GROUP PILOT CONCEPT

Modifications to the original SLM method of OFDM where the pilot tones are applied is stated where U pilot sequence is transmitted for every time period instead of a

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single sequence [10]. The candidates U are evaluated by the transmitter for nth time sequence as

$$x_n^u = F^{-1}(X_n \otimes M_u + P_n^u)\,, \qquad u = 1,\dots,N \tag{14}$$

And the mask M_u is obtained by

$$M_i^u = \begin{cases} exp(j\varphi_{i,u}) & \text{for, } i \in \{1,..,N\}\backslash Y \\ 0 & \text{for } i \in Y \end{cases} \tag{15}$$

Henceforth the pilot symbols are involved in the evaluation of the OFDM time samples sequence as OFDM is modified only at the positions of the user data. The quantity of various pilot tones is equivalent to the quantity of various masks, if the pilots are transmitted in an adequately powerful way; it conveys the side information in the meantime. At the receiver FFT is carried out after the cyclic prefix is removed giving rise to a frequency domain vector sequence

$$R_n = [R_{1,n}, \dots, R_{N,n}]$$

where

$$R_{i,n} = \begin{cases} D_{i,n} M_{i,n}^{u*} H_{i,n} + N_{i,n} & \text{for, } i \in \{1,..,N\}\backslash Y \\ B_{i,n} H_{i,n} + N_{i,n} & \text{for } i \in Y \end{cases} \tag{16}$$

and is the Gaussian noise sample on the ith FFT output sequence for the nth OFDM symbol. These complex samples belong to that consists of the pilot symbols. It is also corrupted by additive white Gaussian noise (AWGN) [8-10]so the transfer function of the channel is estimated, derived and tracked. An OFDM frame structure consists of a preamble and OFDM user symbols. If suppose the preamble occupies the full OFDM symbol's length, then this frame came be used to find the initial channel transfer function coefficients and it can be suitably preselected to include a low PAPR value since such an OFDM symbol is fixed. Using the pilot symbols the channel transfer function is subsequently tracked and if required, interpolation in both frequency and time axis is carried out on them. Hence using the group pilot concept of SLM PAPR reduction is applied effectively.

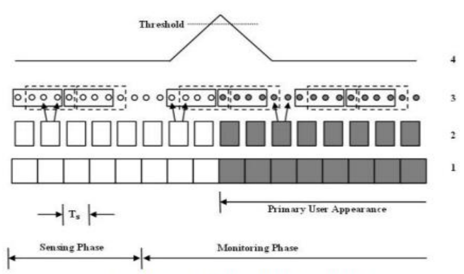

Fig. 2 Process of the Energy ratio algorithm
1) OFDM blocks in time domain, 2) Samples in frequency domain, 3) Reserved tones with sliding windows $N_{RT} = 2$ and $N = 4$, 4) Decision making variable X_k

CFO ESTIMATION AND COMPENSATION

The maximum admissible carrier frequency offset CFO_{max} between the transmitter and receiver is of a maximum CFO integer range, $\mathcal{E}_{imax} = {}^{CFO_{max}}/_{\Delta f}$ and the integer CFO range is $\mathcal{L} = [-\mathcal{E}_{imax}, -\mathcal{E}_{imax} + 1, \dots, -1, 0, 1, \dots, \mathcal{E}_{imax} - 1, \mathcal{E}_{imax}]$ and the training symbols are transmitted in front of the OFDM frame. A fractional CFO is estimated by maximum likelihood estimator

$$\hat{\mathcal{E}}_f = \frac{1}{2\pi D}\{\textstyle\sum_{n=0}^{N_s-1} y(n) y^*(n+D)\} \tag{17}$$

where y(n) is the received signal in time domain and $D = N_s + N_g$. Autocorrelation is done such that two or more training symbols are inserted in time domain at the beginning of the frame. Compensation of CFO is carried out with a cross correlation of the transmitted training symbol after employing a progressive phase shift

$$\hat{\mathcal{E}}_i = \max_{m \in \mathcal{L}} \left|\textstyle\sum_{n=0}^{N_s-1} y_{comp}(n) y_t^*(n) e^{-2jmn/D}\right| \tag{18}$$

Cross correlation is repeated for every integer CFO in $\mathcal{L}$ and the maximum is looked for. The integer CFO that relates to maximum correlation is considered as the estimated CFO integer and after estimation the OFDM is compensated by phase rotation of the time domain signal by $-2\pi(\hat{\mathcal{E}}_f + \hat{\mathcal{E}}_i)n$ where the time index is denoted by n.

SFO ESTIMATION AND COMPENSATION

The average phase difference in pilots in frequency domain between two consecutive OFDM symbols determining [ ] where J is the number of pilots which are inserted in one preamble is first determined. Then matrix X is constructed by which the pilot sub-carrier indicies x_j are properly arranged, where $x_j = 0, 1, \dots, J-1$ as

$$X = \begin{bmatrix} x_0 & x_1 & x_2 & \cdots & x_{J-1} \\ 1 & 1 & 1 & \cdots & 1 \end{bmatrix}^T \tag{19}$$

And finally the carrier frequency offset $\hat{\mathcal{E}}$ and sampling (timing) frequency offset $\hat{\delta}$ is given as

$$[\hat{\delta} \quad \hat{\mathcal{E}}]^T = \frac{N_s}{2\pi(N_s+N_g)}(X^*X)^{-1}X^*y \tag{20}$$

In view of the traditional OFDM systems, CFO and SFO estimation and compensation is definitely needed and with energy ratio algorithm this evaluation becomes easy. It can provide OFDM synchronization even with existing algorithms in an efficient manner.

SIMULATION AND RESULTS

From Fig.3 the result of PAPR reduction is seen. It is represented as two wave forms one without any PAPR minimization and the other using modified group pilot SLM concept. The figure shows the variations when compared between the CCDF and PAPR in dB.

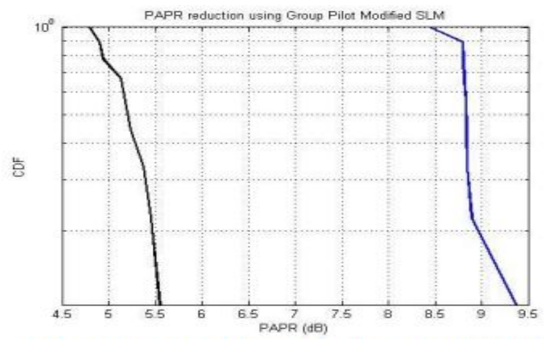

Fig. 3.PAPR reduction using group pilot modified SLM concept

The detection probabilities of various false alarms are noted in Fig. 4. Here the x-axis represents the receiver power ratio (RPR) also called as secondary to primary power ratio (SPR) which is associated to primary to secondary noise ratio (PNR) as $PNR|_{db} = SNR|_{db} - SPR|_{db}$, t is the ratio on which the energy ratio algorithm is decided while for deciding the monitoring algorithm SPR is the major factor. Fig. 5 examines the combined effects of the OFDM impairments such as power leakage, CFO and SFO with respect to the detection probability. The sub-carriers are sampled four by four in the spectrum and as the shape of the sub-carrier narrows down, ICI, CFO and SFO have slight degradations in their performance. By applying the window concept for CFO and SFO estimation and compensation, the power leakage to the neighboring sub-carriers does not degrade much of the PU detection. From tl due to all impairments is only 0.2dB for $P_D = 0.9$.

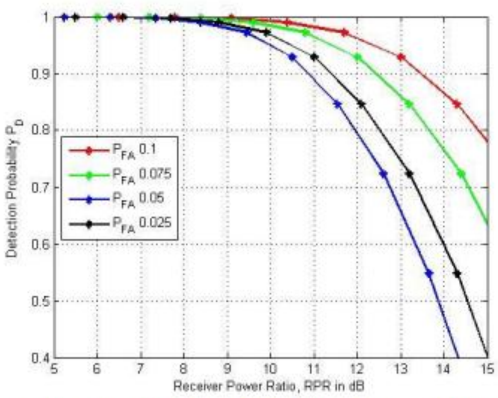

Fig. 4. Probability of false alarm detection versus receiver power ratio

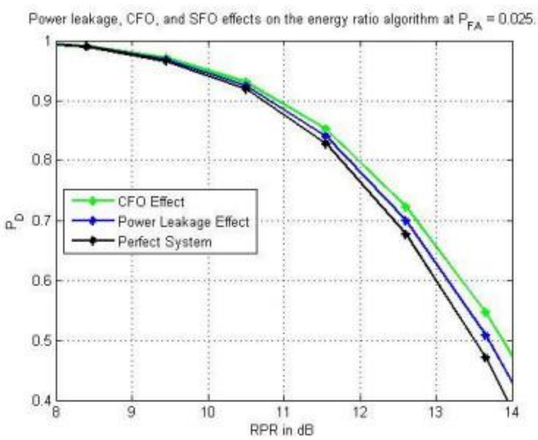

Fig. 5. Power leakage, CFO and SFO effects on the energy ratio algorithm

CONCLUSION

Compared to the traditional SLM scheme, in which the candidate signals are generated using frequencydomain phase rotation only, a novel architecture is proposed in this study which additionally uses three operations namely, frequency domain cyclic shifting, complex conjugate and sub-carrier reversal operations can be performed to maximize the PAPR reduction performance of the candidate signals. In order to avoid the multiple-IFFT problem inherent in the traditional SLM method, the proposed scheme converts all four frequency-domain operations into time-domain equivalent operations. It has been shown that the computational complexity of the proposed approach can be minimized through an appropriate partitioning and reassembling of the sub-carriers in the OFDM system. In addition, the theoretical analysis results have shown that the number of complex multiplications and complex additions required in the proposed scheme for (U, V) = (4, 4) are 8.59% and 68.75%, respectively, of those required in the traditional SLM scheme. Furthermore, the simulation results have shown that the performance loss of the proposed scheme relative to that of the traditional SLM scheme is less than 0.001 dB for 16-QAM, M = 32, N = 256, U = 4, V = 4, and$PrPAPRX>\gamma$ = 10−4 . In other words, the proposed scheme closely approximates the PAPR reduction performance of the traditional SLM method, but with a significantly reduced computational complexity. A PAPR reduction scheme based on hadamard SLM is proposed. Simulation results state that the PAPR reduction performance is improved compared with SLM and Hadamard SLM. The hadamard SLM has lower computational complexity, the proposed scheme achieves comparable PAPR reduction performance to the simplified SLM and Hadamard-SLM scheme.

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