A COMBINED SLM AND CLOSED-LOOP QO-STBC FOR PAPR MITIGATION IN MIMO-OFDM TRANSMISSION

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ABSTRACT

A closed-loop quasi-orthogonal space time block coding scheme developed by Toker, Lambothoran and Chambers has much attraction due to its full diversity and full rate. This scheme exploits feedback from the receiver to the transmitter and rotation of certain antenna transmitted symbols by a particular phase value to achieve an effectively orthogonal code matrix. This technique however ignores the effect of increased peak-to-average power ratio (PAPR) introduced by the phase rotations, and the associated demands on the range of linearity of transmission power amplifiers. This work focuses on jointly achieving full diversity and full rate whilst minimizing PAPR. Two symbols within an orthogonal frequency division multiplexing (OFDM) frame are therefore either used for transmitting selected mapping side information or for PAPR mitigation thereby retaining the diversity gain of the multiple antennas whilst being able to perform the PAPR mitigation. For an OFDM system with 128 subcarriers and QPSK data symbols, the new scheme shows that the multiple antenna PAPR can be effectively reduced.

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has become a popular technique for high speed data transmission in frequency-selective radio channels [1]. It has been adopted in different wireline and wireless communication standards such as high-bit-rate digital subscriber lines (HDSL), asymmetric digital subscriber lines (ADSL), very high-speed digital subscriber lines (VHDSL), digital audio broadcasting (DAB), and high-definition television (HDTV) [2]. For high data rate wireless applications multiple-input multiple-output (MIMO) transmission combined with OFDM is being considered in most current technology applications such as WiFi/WiMax [3]. In OFDM intersymbol interference is prevented by adding a guard interval, which allows multipath effects to be mitigated using a simple equalizer on a frequency-by-frequency basis. This simplifies the design of the receiver and leads to inexpensive hardware implementations.

One disadvantage of using OFDM is that its time-domain signals suffer from large envelope variations. Such variations, quantified by the peak-to-average power ratio (PAPR), can be a problem for certain devices such as digital-to-analog converters (D/A) and power amplifiers (PA) in the transmitter. In particular, realization of an amplifier with a large linear range of operation can be expensive. If a high PAPR signal passes through an amplifier with a nonlinear response, it may suffer significant spectral regrowth, in-band distortion and performance degradation [3]. This drawback motivates the search for PAPR reduction techniques and many solutions have been proposed for single-input single-output (SISO) systems; and these can be classified into three categories: (i) distortionless PAPR reduction such as tone reservation [4], coding [5], tone injection [4], partial transmit sequence [6] and selected mapping (SLM) [7]; (ii) PAPR reduction with distortion such as transmit filtering [8], clipping [9]; and (iii) various combinations of the above.

The application of the SLM technique of [7] to MIMO was studied in [10]. Using MIMO-SLM can improve the overall bit-error rate (BER) performance and increase the reliability of side-information (SI) at the expense of the PAPR reduction gain. However, this work is generally limited to two transmit and one receive antennas.

In this paper, we extend the proposed technique in [10] and study the PAPR performance of closed loop quasi-orthogonal space-time block codes (QO-STBCs). This new technique is based upon rotating two symbols in the OFDM frame in place of sending useful information in combination with the SLM method, so that the maximum peak power over all four transmit antennae can be decreased whilst maintaining the diversity gain.

The structure of this paper is as follows. In the next section background material is presented. In Section 3, the combination of the PAPR mitigation approach in closed loop QO-STBC for MIMO-OFDM transmission with the SLM method is presented. Simulation results are provided in Section 4. Practical issues in feedback are introduced in Section 5. Finally, Section 6 contains the conclusion.

2. BACKGROUND

2.1 SLM IN SISO-OFDM

Selected mapping (SLM) was introduced in [7] as a PAPR reduction in SISO transmissions. In SISO-SLM, the PAPR reduction is achieved by multiplying independent phase sequences with the original data such that the PAPR of each data combination is reduced. Then, the sequence with the lowest PAPR is chosen for transmission. In other words, the original source signal, in Fig. 1, is converted into a vector $\mathbf{C}$ of length $M \times N$ through a Kronecker product denoted by $\otimes$, i.e. $\mathbf{C} = \mathbf{C_{orig}} \otimes \mathbf{1}$, where $\mathbf{1}$ is an $M \times 1$ vector with unity elements and $\mathbf{C_{orig}}$ is an $N \times 1$ vector containing the original signal information.

The M subvectors within C are weighted elementwise by the components of the complex vectors b_i, i = 1,..., M to form $\mathbf{C}_i$, i = 1,..., M. Note that all of the elements of the b_i se-

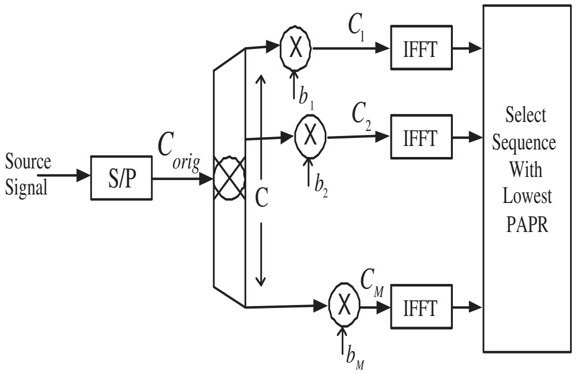

Figure 1: Selective mapping approach in SISO systems.

quences are chosen randomly among the set of $b_i \in (\pm 1, \pm j)$ to reduce complexity.

2.2 PAPR IN MIMO-OFDM

Let us now consider a MIMO-OFDM system using L_t Tx antennas and N subcarriers. For such a system the length N transmit OFDM frame corresponding to the i^{th} time-domain symbol is given by [10]

$$x_i[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} c_i[k] e^{j2\pi kn/N} \ ,0 \leq n \leq N-1 \qquad (1)$$

where $j = \sqrt{-1}$, $c_i[k]$ is the complex symbol of transmitter i at the k^{th}subcarrier in the frequency domain and n is the discrete time index. In practice, the baseband modulation is performed in the digital domain using an oversampled version of $x_i[n]$ given by

$$x_i[n/L] = \frac{1}{\sqrt{NL}} \sum_{k=0}^{NL-1} \tilde{c}_i[k] e^{j2\pi kn/NL} \ ,0 \leq n \leq NL-1 \qquad (2)$$

where L is the oversampling factor and $\tilde{c}_i[k]$ is the original data symbols with zero values assigned in between, so that they form a better estimate for the peak of the signal in the time-domain. It should be noted that when $L = 1$ $x_i[n]$ is the Nyquist-sampled version of the continuous version of $x_i(t)$.

The PAPR calculated on the basis of the discrete-time representation of the transmitted OFDM signal is defined as

$$PAPR(x_i[n]) = \frac{max_{i,n}|x_i[n]|^2}{E_{i,n}\{|x_i[n]|^2\}} \qquad (3)$$

where max[$\cdot$] and E$\{\cdot\}$ produce respectively the maximum element and the expected value of the input symbols. One more important measurement, which can be helpful in analyzing the PAPR performance of an OFDM system, is the Complementary Cumulative Distribution Function (CCDF) i.e.

$$Pr(PAPR > \gamma) = [1 - (1 - e^{-\gamma})^{N \cdot L_t}]^M \qquad (4)$$

where L_t denotes the number of transmit antennas. This equation can be interpreted as the probability that the PAPR of a block symbol is greater than a particular γ [7].

2.3 Quasi-Orthogonal Space Time Block Codes (QO-STBCs)

The quasi-orthogonal space time block codes in [11] were for the case of four transmit antennas ($L_t = 4$) and were designed to simultaneously transmit four complex symbols S_1, S_2, S_3, S_4 over frequency flat channels during four time intervals. We extend this to a block form suitable for space-time MIMO-OFDM as in the following matrix.

$$\mathbf{G}(\mathbf{S}) = \begin{pmatrix} \mathbf{S_1} & \mathbf{S_2} & \mathbf{S_3} & \mathbf{S_4} \\ -\mathbf{S_2^*} & \mathbf{S_1^*} & -\mathbf{S_4^*} & \mathbf{S_3^*} \\ -\mathbf{S_3^*} & -\mathbf{S_4^*} & \mathbf{S_1^*} & \mathbf{S_2^*} \\ \mathbf{S_4} & -\mathbf{S_3} & -\mathbf{S_2} & \mathbf{S_1} \end{pmatrix} \qquad (5)$$

where the operation $(.)^*$ denotes complex conjugation. The transmit matrix $\mathbf{G}(\mathbf{S})$ corresponds to four transmit antennas as shown in Figure 2, transmitting a symbol block of four OFDM symbol intervals. The n^{th} column of this matrix corresponds to the blocks transmitted from the i^{th} antenna at consecutive OFDM symbol intervals.

In this scheme the channel is assumed to be frequency selective and remains constant over four symbol intervals, i.e. a quasi-static channel. The original QO-STBC scheme provides full code rate at the expense of loss in diversity, which results in degradation in performance. An alternative solution proposed in [12] is to provide full diversity while achieving full code rate. The principle of the later scheme or what is called closed loop QO-STBC is to rotate the signal which is radiated from two of the antennas by phases defined by the feedback from the receiver. The performance advantage of the scheme is confirmed when the feedback information is quantized and even when feedback is completely lost, the performance is no worse than that of the original Alamouti scheme [14]. Despite the pleasing properties that the closed loop QO-STBC scheme provides, it, however, does not take PAPR mitigation into account. The aim of this study is to reduce the occurrence of PAPR over all transmitted antennas in the closed loop QO-STBC when applied to MIMO-OFDM as explained in the following section.

3. PAPR REDUCTION IN CLOSED LOOP QO-STBC

Consider that the block code matrix in (5) is transmitted in the form of quaternary phase-shift keying (QPSK) symbols through a frequency selective channel, and the signal is received with only one receive antenna. Between each transmitter and one receive antenna, the channel is multipath and the coefficients of the channel are modelled by independent complex valued random variables with zero mean and unity variance. Also, consider that each multipath channel is quasi-static over a quasi-orthogonal transmission interval.

In a PAPR reduction problem, the peak value of the time-domain signal should be bounded by a specific value $\max[|x_i(t)|] \leq \gamma \ \forall \, t$ as in (3). This bound on the time-domain signal after sampling translates easily to the frequency-domain because the IFFT is linear. Stated concisely without loss of generality, the goal of our new scheme is to use two symbols in the OFDM frame, which had previously been used for SI in the two antenna MIMO-SLM scheme, to rotate the third and fourth antennas by one of a set of pre-defined rotation angles to reduce the PAPR after applying the rotation angles to the other symbols in the OFDM frame necessary in the QO-STBC scheme. These rotation angles, ϕ, θ, are the

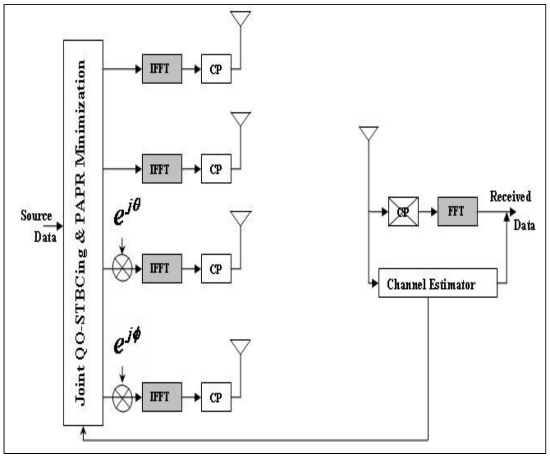

Figure 2: Block diagram of the proposed joint QO-STBCing and PAPR concept.

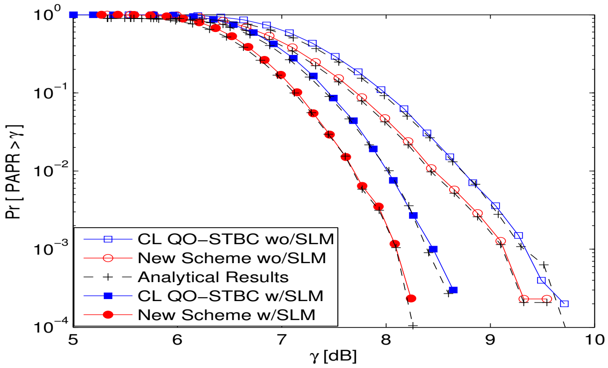

Figure 3: CCDF of the PAPR, the frame with lowest average PAPR for the conventional closed loop QO-STBC technique and the new scheme both combined with the SLM method, $N = 128$, $M = 4$ and with QPSK modulation, oversampling factor of unity.

elements of the set $\{\phi, \theta \in \psi = \pi k/8, k = 1, ..., 8\}$ and chosen to satisfy

$$\{\phi, \theta\} = arg \min_{\{\phi,\theta\}\in\psi} PAPR(\phi, \theta) \tag{6}$$

and therefore keep the complexity of the optimization search within bounds, i.e. 64 rotations must be examined when exhaustive search is employed as in this paper. Future work will consider move general values in the two symbols, i.e. non constant modulus values. A selective mapping (SLM) method, explained in Section 2, is applied in conjunction with our scheme to further reduce the PAPR in the OFDM signals. Note that in the SLM approach all of the M subvectors are assumed to be known to both the transmitter and the receiver. In order to recover the data at the receiver SI bits, of length $[\log_2(M)]$, have to be transmitted to indicate which out of the Mb_i sequences was used in the transmitter. In this proposed combined scheme, we transmit the SI bits over two symbols in the OFDM frame. The position of these two symbols is chosen so that we maximize the frequency diversity across the frame as in [10] and that same SI is transmitted on two antennas which maximizes the spatial diversity. The position of the SI information within the other two antennas is exploited to mitigate PAPR increase due to the feedback coefficients as explained in the next section.

4. SIMULATION RESULTS

In this section, we present a simulation for a complex baseband OFDM system with N = 128 subchannels, employing QPSK for four transmit and one receive antennas over frequency selective fading channel by using 10^5 randomly generated OFDM block symbols.

Figure 3 shows evaluation results in terms of the CCDF of implementing the new scheme when applied to closed loop QO-STBC with an oversampling factor of unity, L = 1. As seen from Figure 3 the new scheme without SLM achieves approximately 0.3dB reduction of the threshold, γ, as compared with the closed loop QO-STBC at the probability of $PAPR > \gamma = 0.01$. By combining the SLM approach with the both schemes, the PAPR improves by 0.8dB. We also see from Figure 3 that the theoretical expressions are in excellent agreement with the simulation results.

As already anticipated in Section 2.2, the continuous PAPR has a behavior that cannot be accurately described by the Nyquist frequency sampled digital signal, L = 1. According to [4]-[6], the presence of peaks in the continuous time-domain signal can be detected with proper confidence when L = 4, see Figure 4. The identical pattern as in Figure 3 is shown in the curves presented in Figure 4 which confirms our proposal. However, the absolute value of γ is increased to the right supporting that this is a more accurate representation of the performance. In Figure 5 we investigate the effect of only transmitting the SI information in two of the four antennas. We show the overall average bit-error rate (BER) performance of the conventional closed loop QO-STBC system with infinite precision feedback and assuming exact SI information is available at the receiver or that it is detected at the receiver.

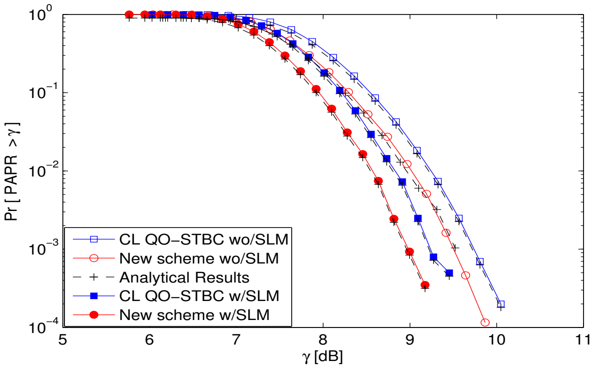

Figure 4: As Figure 3 except for an oversampling factor of 4.

Next, for a more practical solution the feedback is quantized to four levels and the same two cases for SI information are compared. The curves for exact and detected SI information are considered in both cases, thereby confirming that transmission of SI information over only two antennas is

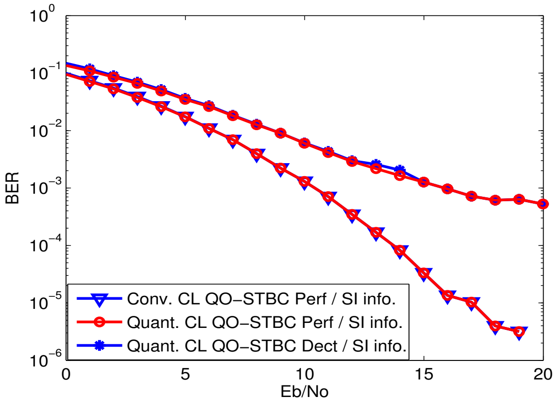

Figure 5: BER comparison with respect to side information for both conventional closed loop QO-STBC and Quantized closed loop QO-STBC, $N = 128$ and $M = 4$.

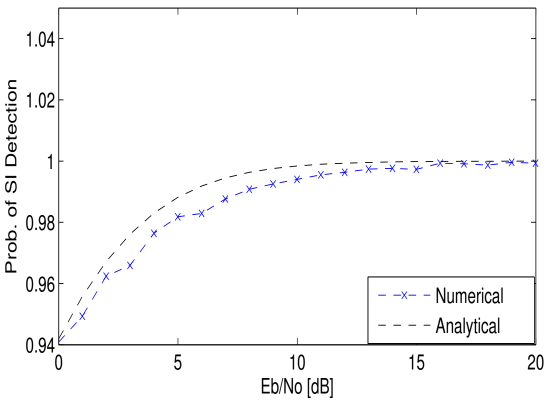

Figure 6: Probability of side-information detection from two OFDM frame symbols when N = 128 and M = 4.

sufficient in closed loop QO-STBC. Finally, Figure 6 illustrates the probability in detection of SI transmitted from two antennas. It shows that the numerical and analytical results [10] give a probability of SI detection approaching unity as Eb/No increases.

5. PRACTICAL ISSUES IN FEEDBACK

One of the major challenges in closed loop QO-STBC is the use of feedback. For time division duplex systems (TDD), the channels in the uplink and the downlink can be assumed to be identical and therefore the feedback issues become straight forward, whereas feedback would be more important in frequency division duplex (FDD) where the information has to be transmitted from the receiver to the transmitter and therefore channel stationarity is a key issue. In practice by exploiting the strong correlation in the feedback sequence among the subcarriers, the feedback overhead could be decreased [13].

6. CONCLUSION

We have proposed a new technique that achieves a marked reduction in the PAPR in closed loop QO-STBC with a low complexity, by using two phase rotations in certain frequency bins. Also, we combined this technique with the SLM method and achieved further reduction in PAPR. Future work will examine the optimal way of finding the values of $\{\phi, \theta\}$, rather than constraining their values to one of 64 values, so that whatever data samples and whatever feedback values we have, the PAPR always remains minimum.

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