Modified PTS with FECs for PAPR Reduction in MIMO-OFDM System with Different Subblocks and Subcarriers

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Abstract

Multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) systems have been proposed in the recent past for providing high data-rate services over wireless channels. When combined with space time coding it provides the advantages of space-time coding and OFDM, resulting in a spectrally efficient wideband communication system. However, MIMO OFDM systems suffer with the problem of inherent high peak-to-average power ratio (PAPR) due to the intersymbol interference between the subcarriers. In order to obtain optimal PAPR reduction using the partial transmitted sequence (PTS), the total search for the number of subblocks and the rotation factors must be accomplished. As the number of subblocks and rotation factors increases, PAPR reduction improves. The number of calculation increases as the number of subblocks increases, such that complexity increases exponentially and the process delay occurs simultaneously. In this paper, a generalised framework for PAPR reduction for MIMO OFDM systems based on modified PTS using forward error-correcting codes (FECs) such as Turbo codes and Golay codes are employed. PAPR reduction is jointly optimised in both the real and imaginary part by use of fast Fourier transform (FFT) algorithm in the modified PTS which can be utilized for finding the optimum phase weighting factors, and can achieve the lower PAPR and computational complexity of MIMO OFDM systems. The simulation results show that the combined FEC with modified PTS technique significantly provides better PAPR reduction with reduced computational complexity compared to original PTS technique in the MIMO-OFDM systems.

Keywords: *MIMO, OFDM, PTS, STBC, Turbo code, Golay Codes, Reed-Muller Codes and PAPR.*

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation technique for high data rate wireless communications due to its robustness to frequency selective fading, high spectral efficiency and low computational complexity [1, 2]. OFDM can be used in conjunction with multiple-input multiple-output (MIMO) technique to increase the diversity gain and/or the system capacity by exploiting spatial domain [3, 4]. Because the OFDM system effectively provides numerous parallel narrowband channels. MIMO-OFDM is considered a key technology in emerging high data-rate communication systems, including digital subscriber lines (DSL), IEEE 802.11, IEEE 802.16, and IEEE 802.15.3a and it is increasingly held that OFDM results in an improved downlink performance for fourth generation (4G).

Recently space-time coded OFDM systems have been receiving wide spread attention. A space-time-frequency coded OFDM system which achieves maximum diversity is proposed in [5]. In [6] space-time codes have been designed for use with OFDM over frequency selective channels, which can achieve a spatial diversity technique by using multiple antennas at the transmitter and receiver and it is promising, since it does not increase the transmit power and the signal bandwidth. This can be efficiently utilised through multiple input multiple output (MIMO) systems. To enhance the capacity of the system diversity techniques are normally employed. Despite its many advantages, MIMO-OFDM suffers with the problem of high PAPR and carrier frequency offset sensitivity [7]. Hence, it is important to reduce the PAPR, otherwise, high power amplifiers (HPA) in the transmitter need to have a linear region that is much larger than the average power, which makes them expensive and inefficient. This is because if an HPA with a linear region slightly greater than the average power is used, the saturation caused by the large peaks will result in intermodulation distortion, which increases the bit error rate (BER) and causes spectral widening, resulting in adjacent channel interference.

A number of techniques were proposed to control the PAPR of the transmitted signals in MIMO-OFDM systems, such as clipping [8], selective mapping (SLM) [9] and partial transmit sequence (PTS) [10]. Deterministic schemes, such as clipping could be an effective technique for PAPR reduction. However, clipping is a nonlinear process and may cause significant in-band distortion, which degrades the BER performance and out-of-band noise, which reduces the spectral efficiency. PTS and SLM are probabilistic methods which achieve significant PAPR reduction with only a small data rate loss; however PTS or SLM has no inherent error control compared to the use of block coding with Golay complementary sequences [11]. These techniques achieve PAPR reduction at the expense of transmit signal power increase, BER increase, data rate loss, computational complexity increase and so on.

The conventional PTS scheme is simple and distortionless, sometimes its computational complexity is burden-some. Generally, in PTS, the input data block is divided into disjoint subblocks. The subblocks are multiplied by phase weighting factors (±1, ±j) and then added together to produce OFDM symbols or number of candidate signals which ensures the low PAPR. However, Conventional PTS requires an exhaustive search over all the phase factor combinations, which results in the search complexity increasing exponentially with the number of subblocks. Hence the modified PTS scheme [12] is proposed to lower the computational complexity which maintains the similar PAPR reduction performance compared with the conventional PTS scheme. A theoretical framework of PAPR reduction by channel coding is given in [13-15] which requires a co mplex optimization process, particularly when large number of subcarriers is employed. To alleviate the problem of high complexity further an approach [16-18] has been proposed, in which real and imaginary parts are separately multiplied with phase factors, moreover PAPR is conjointly optimized in real and imaginary parts.

In this paper, modified PTS is combined with forward error-correcting codes (FECs) such as turbo codes and Golay complementary sequences with Reed-Muller codes and used for the PAPR reduction of the transmitted signal in multiple transmit antenna systems. In the previous work, PAPR reduction is jointly optimized in both the real and imaginary parts separately multiplied with phase factors when dividing the different subcarriers into 4 subgroups [19]. Although it takes extra power to transmit the side information and PAPR will be increased, this investigation determines the optimal phase weighting factor such that the overall system complexity is reduced. In this work, the new approach to tackle the PAPR problem to reduce the complexity based on modified PTS which can be utilized for finding the optimum phase weighting factors and the subblock partition schemes can achieve the lower PAPR and computational complexity of MIMO OFDM systems.

The rest of the paper is organized as follows: Section 2, briefly introduces PAPR in MIMO OFDM system. Section 3, outlines of complementary Golay sequences, Reed-Muller code and their properties. Turbo coded PTS scheme is presented in Section 4. Section 5 presents the simulation results. The conclusions are drawn in Section 6.

2. PAPR in MIMO-OFDM System

In OFDM modulation technique, a block of N data symbols, $X_k = \left(X_{0,} X_{1,} \ldots . X_{N-1}\right)$, is formed with each symbol modulating the corresponding subcarrier from a s et of subcarriers. The N subcarriers are chosen to be orthogonal, that is, T is the original data symbol period, and f_0 =1/T is the frequency spacing between adjacent subcarriers.

The complex baseband OFDM signal for N subcarriers can be written as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k f_0 t}, 0 \le t \le T \qquad (1)$$

Replacing t=n $T_b\sqrt{}$where T_b =T/N, gives the discrete time version denoted by

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/LN}, \text{ n=0,1,…,NL-1} \qquad (2)$$

where, L is the oversampling factor. The symbol-spaced sampling sometimes misses some of the signal peaks and results in optimistic results for the PAPR. The sampling can be implemented by an inverse fast Fourier transform (IFFT).

The PAPR of the transmitted OFDM signal, $x(t)$, is then given as the ratio of the maximum to the average power, written as

$$PAPR = \frac{\max_{0\le t \le T} |x(t)|^2}{E\left[\left|x(t)^2\right|\right]} \qquad (3)$$

where E[·] is the expectation operator.

From the central limit theorem, for large values of N, the real and imaginary values of $x(t)$ becomes Gaussian distributed. The amplitude of the OFDM signal, therefore, has a Rayleigh distribution with zero mean and a variance of N times the variance of one complex sinusoid. The complementary cumulative distribution function (CCDF) is the probability that the PAPR of an OFDM symbol exceeds certain threshold $PAPR_0$, which can be expressed as

$$CCDF(PAPR(x(n))) = \mathrm{P}_r(PAPR(x(n))) > PAPR_0 \qquad (4)$$

Due to the independence of the N samples, the CCDF of the PAPR of single input single output (SISO) OFDM as a data block with Nyquist rate sampling is given by

$$P = P_r(PAPR(x(n)) > PAPR_0) = 1-(1-e^{-PAPR_0})^N \quad (5)$$

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated and it is not accurate for a s mall number of subcarriers. Therefore, there have been many attempts to derive more accurate distribution of PAPR.

For a MI MO-OFDM system, analysis of the PAPR performance is the same as the SISO case on each single antenna. For the entire system, the PAPR is defined as the maximum of PAPRs among all transmit antennas [20], i.e.,

$$PAPR_{MIMO-OFDM} = \max_{1 \le i \le M_t} PAPR_i \quad (6)$$

where, $PAPR_i$ denotes the PAPR at the ith transmit antenna. Specifically, since in MIMO-OFDM, M_t N time domain samples are considered compared to N in SISO-OFDM, the CCDF of the PAPR in MIMO-OFDM can be written as

$$P_r(PAPR_{MIMO-OFDM} > PAPR_0) = 1-(1-e^{-PAPR_0})^{M_t N} \quad (7)$$

Comparing (7) with (5), it is evident that MIMO-OFDM results in even worse PAPR performance than SISO-OFDM.

3. Golay Sequences and Reed- Muller Code

3.1 Coding Theory

The binary complementary sequences were proposed by M.J.E. Golay in 1961 [21]. The complementary sequences are sequence pairs for which the sum of aperiodic autocorrelation functions is zero for all delay shifts. It was mentioned in [22] that the autocorrelation properties of complementary sequences can be used to construct the OFDM signal with low PAPR.

3.2 Complementary Sequence Theory equations

The pair of sequence x and y of length N, ie., $x = [x_0, x_1, x_2, ...x_{N-1}]$ and $y = [y_0, y_1, y_2, ...y_{N-1}]$, are said to be complementary if the following condition hold on the sum of both autocorrelation functions:

$$\sum_{k=0}^{N-1}(x_k x_{k+i} + y_k y_{k+i}) = 2N; \qquad i = 0$$

$$= 0 \; ; \qquad i \neq 0 \quad (8)$$

After taking the Fourier transform on both sides of Eq. (8) the above condition is translated into the following equation.

$$|X(f)|^2 + |Y(f)|^2 = 2N$$

(9)

where $X(f)$ and $Y(f)$ are the power spectrum of x and y respectively. From the spectral condition of (9), it is observed that the maximum value of the power spectrum is bounded by 2N.

$$|X(f)|^2 \le 2N \quad (10)$$

Because the average power of X(f) is equal to N, assuming that the power of the sequence x is equal to 1, the PAPR of X(f) is bounded as

$$PAPR \le \frac{2N}{N} = 2 \text{ (=3dB)} \quad (11)$$

Hence, using complementary sequences as input to generate an OFDM symbol, it is guaranteed that the maximum PAPR of 3dB can be achieved.

3.3 Error Correction using Complementary Code

In this work, complementary sequence to suppress the PAPR in the MIMO-OFDM systems is considered. Complementary sequences are encoded by the generator matrix G_N and b_N [23]. Let A_N denote the corresponding codeword sequences of length N and u is the integer sequences between [0, M-1] of length k. Then A_N can be written as

$$A_N = u \,.\, G_N + b_N \text{ (mod M)}, \quad (12)$$

where G_N is a $k \times N$ matrix and b_N is a phase shift sequence of length N while k is related to $N=2^{k-1}$ for k=3,4,5,…

If the M-ary PSK (Phase shift keying) modulation is used in ith transmit antenna then the phase sequence of A_N is given by,

$$\phi_i = \frac{2\pi}{M} a_i + \Delta\phi \quad (13)$$

where $\Delta\phi$ is the arbitrary phase shift and a_i is the ith sequence of A_N.

A large set of binary complementary pairs of length 2^m can be obtained from the 2nd order co sets of the well-known 1st order Reed-Muller code R(1, m). This Reed-Muller code results in low PAPR in addition to its error-correcting capability.

The rth order Reed-Muller code is designated as R(r, m), where m is the parameter related to the length of the code, $n=2^m$ and $0 \le r \le m$. Half of the codes of R(r, m) are complements of the other half. R(1, m) is also known as a bi-orthogonal code since it can be obtained from the generator matrix of an orthogonal code by adding all-ones codeword to it [24].

In this work, modified PTS is combined with Golay complementary sequence, PTS is based on combining signal subblocks which are phased-shifted by different phase factors to generate multiple candidate signals, so as to select the low PAPR signal. Fig.1 shows the model of space-time block coding (STBC) MIMO-OFDM system.

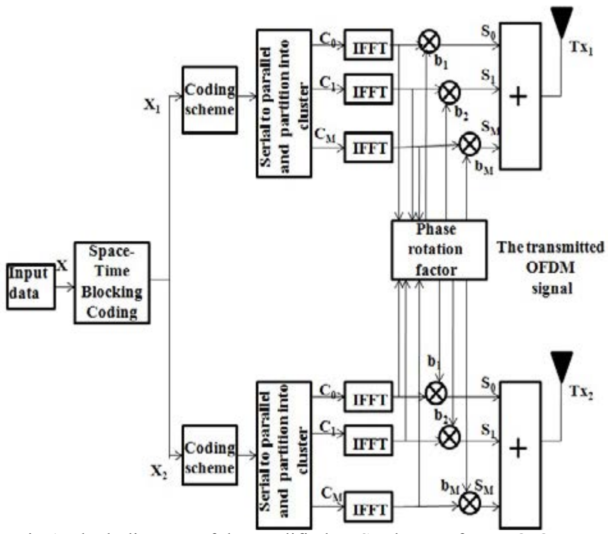

Fig.1 Block diagram of the modified PTS scheme of MIMO-OFDM system

Consider the data symbol vector $X=[X_0,X_1,.....,X_{N-1}]$ is encoded with space-time encoder into two vectors X_1 and X_2,

$$X_1=[X_0,-X^*{}_1,.....X_{N-2},-X^*{}_{N-1}],$$
$$X_2=[X_1,X^*{}_0,.....X_{N-1},X^*{}_{N-2}].$$

Encode the data blocks by using Reed Muller code. Define the codeword as a vector,

$$S_1=[C_0,-C^*{}_1,.....C_{N-2},-C^*{}_{N-1}]^T,$$
$$S_2=[C_1,C^*{}_0,.....C_{N-1},C^*{}_{N-2}]^T.$$

where, C is an encoded set of code words for any number of carriers.

S to be transmitted is divided into several sub-blocks, *V*, by using subblock partition scheme. In general, subblock partition scheme can be classified into 3 categories. The three partition methods are adjacent, interleaved and random.

S is partitioned into *M* disjoint sets, which is represented by the vector,

$$S_m\text{ , } m=1, 2, ..., M \tag{14}$$

In this work, the codeword vector S is partitioned by using adjacent method. Assume that the subblocks or clusters consist of a contiguous set of subcarriers and are of equal size. The objective is to optimally combine the M clusters, which in frequency domain is given by

$$S^{'}=\sum_{m=1}^{M}b_m S_m \tag{15}$$

where, $\{b_m$, m=1, 2,…, $M\}$ are weighting factors and are assumed to be perfect rotations. In other words, the time domain is given by

$$s=\sum_{m=1}^{M}b_m s_m \tag{16}$$

where, s_m consist of a set of subblocks with equal size and b_m is the phase factor, which are required to inform the receiver as the side information. The set of weighting factor for *V* clusters or subblocks are optimised in the time domain so as to achieve the better PAPR performance. PTS generates a signal with a low PAPR through the addition of appropriately phase rotated signal parts. The codeword to be transmitted are divided into several subblocks, *V*, of length N/*V*. Mathematically, expressed by

$$A_k=\sum_{v=1}^{V}A_k{}^{(v)}\text{ ,}\quad v=1, 2, \ldots, V \tag{17}$$

All subcarriers positions in $A_k{}^{(v)}$ which are occupied in another subblock are set to zero. Each of the blocks, *v*, has an IFFT performed on it,

$$a_n{}^{(v)}=IFFT\left\{A_k{}^{(v)}\right\} \tag{18}$$

The output of each block except for first block which is kept constant, is phase rotated by the rotation factor as given by

$$e^{j\theta(v)}\in[0,2\pi] \tag{19}$$

The blocks are then added together to produce alternate transmit signals containing the same information as given by

$$\tilde{a}_n=\sum_{v=1}^{V}a_n{}^{(v)}.e^{j\theta(v)} \tag{20}$$

Each alternate transmit signal is stored in memory and the process is repeated again with a different phase rotation value. After a set number of phase rotation values, *W*, the OFDM symbol with the lowest PAPR is transmitted as given by

$$\tilde{\phi}^2,\tilde{\phi}^3,....\tilde{\phi}^v=\arg\min(\max|\tilde{a}_n|) \tag{21}$$

The weighting rotation parameter set is chosen to minimise the PAPR. The computational complexity of PTS method depends on the number of phase rotation factors allowed. The phase rotation factors can be selected from an infinite number of phases $\phi^{(v)}\in(0,2\pi)$. But finding the best weighting factors is indeed a complex problem. To increase the potential capability of PAPR reduction performance for the PTS method, these phase factors combination correctly maintain the orthogonality between the different modulated carriers. The coding method adds pattern of redundancy to the input data in order to reduce the PAPR. In MIMO communication, data rate or diversity order can be improved by exploiting the spatial dimension. In the same spirit, treating the parallel transmit signals jointly, PAPR reduction may be improved. A modified PTS technique with forward error correcting codes such as Golay complementary sequences with Reed-Muller code is proposed to provide better PAPR reduction in the MIMO-OFDM systems with lower computational complexity as shown in Fig.1.

4. Turbo Coding

In this work, a turbo encoder is employed which offer two advantages, significant PAPR reduction and good bit error rate performance. Fig.2 shows the block diagram of turbo encoder. Turbo codes [25, 26] are parallel concatenated convolutional codes in which the information bits are first encoded by a r ecursive systematic convolutional (RSC) code, simultaneously after passing the information bits through an interleaver, it is encoded by a second RSC code. The purpose of interleaving the coded data transforms burst error into independent errors. The result of interleaving makes error burst to spread out in time, so that errors within a co deword appear to be independent. The role of puncture is to periodically delete the selected bits to reduce the coding overhead. Turbo decoder is used to recover the transmitted signal at the receiver side.

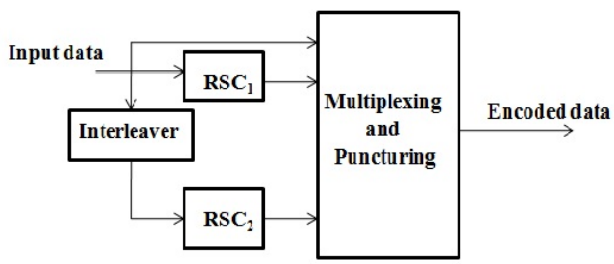

Fig.2 Turbo encoder

The turbo encoder is used to generate different independent sequences; these sequences are punctured to get the encoded data with lowest PAPR for transmission. Fig.1 shows the transmitter side of MIMO-OFDM systems, where the turbo coding and modified PTS can also be used for PAPR reduction**.**

The procedure for turbo PTS is same as Golay PTS except Reed-Muller complement sequence is replaced with turbo encoder sequence. By combining these two methods, significant performance improvement can be achieved.

5. Results and Discussion

The analysis of the modified PTS with forward error correcting codes such as Golay complementary sequences with Reed-Muller code and turbo code techniques have been carried out using MATLAB 7.0. The simulation parameters considered for this analysis is summarised in Table 1. In the MIMO-OFDM systems, modified PTS technique is applied to the subblocks of uncoded information, which is modulated by QPSK and the phase rotation factors are transmitted directly to receiver through subblock. The performance evaluation is done interms of complementary cumulative distribution function.

Table 1.Simulation parameters

Simulation parameters	***Type/Value***
Number of subcarriers	64, 128, 256, 512, 1024
Number of subblocks	2, 4,8,16
Oversampling factor	4
Number of antennas	2×2
Modulation Scheme	QPSK
Phase factor	1, -1, j, -j

Fig.3 shows the performance of modified PTS technique in MIMO-OFDM system for different number of subcarriers N= 64,128, 256, 512 and 1024. From this figure it is observed that the values of PAPR for N= 64,128, 256, 512, and 1024 become 4.8, 5.6, 6.3, 6.9 and 7.5dB respectively when CCDF = 0.6 and M_t=2.The PAPR value increases significantly as number of carriers used in the MIMO OFDM transmission increase as shown in Fig.3. Though the multi-carrier OFDM transmission provides high data rate, it results in high PAPR for higher subcarriers.

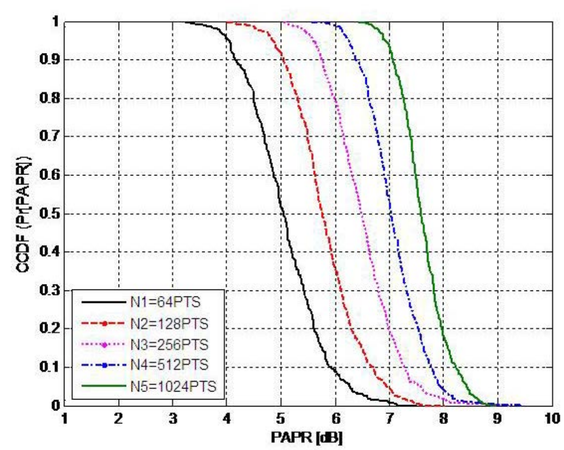

Fig.3 Modified PTS performance for different number of subcarriers and M_t=2 with V=4.

Fig.4 shows the CCDFs of PAPR performance of the PTS based MIMO-OFDM signal for different number of subblocks for a random data of block size 1000 with N=256. It can be seen from the figure that as the subblock size is increased from 2 to 4, 8 and 16; the PAPR reduces from 6.6 dB to 5.9 dB, 5.4 dB and 5.3 dB respectively, resulting in significant improvement. Obviously, as the number of independent sequences increase, the PAPR performance becomes better.

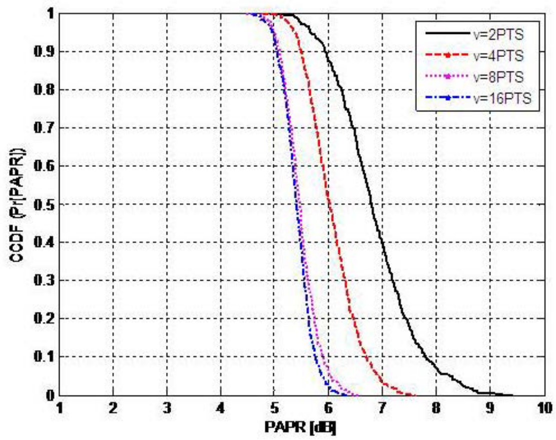

Fig.4 Modified PTS performance for different number of subblocks and M_t=2 with N=256

Fig.5 shows the performance of modified PTS with turbo coding for a subblock size V=4 for the same subcarriers N= 64,128, 256, 512 and 1024. It gives the better PAPR reduction at N=64 compared to all other subcarriers. From this figure it is noted that the values of PAPR are obtained as 4, 4.8, 5.6, 6.4 and 7 dB for 64, 128, 256, 512 and 1024 when CCDF=0.6 respectively. However, the value of PAPR is significantly reduced for modified PTS with turbo coding system when compared to modified PTS without coding scheme (Fig.3 and Fig.5). The PAPR reduction is almost 7 to 20%

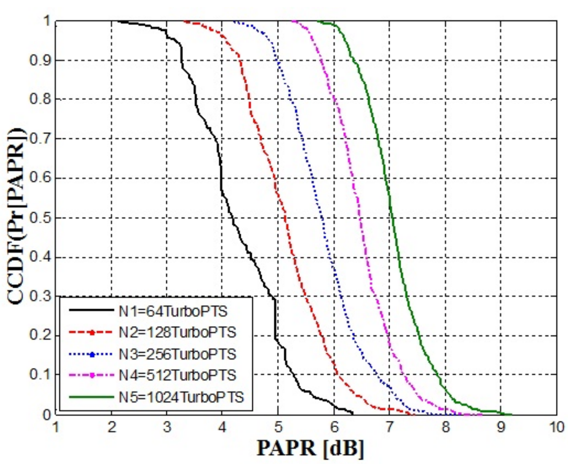

Fig.5 Modified PTS combined with turbo codes performance for different number of subcarriers and M_t=2 with V=4

In Fig.6 the combined scheme is investigated for various subblocks size V=2, 4, 8 and 16. The PAPR of the OFDM symbol is about 6.6 dB at CCDF of 0.6 when V=2 and an improvement of 5.6, 4.2 and 3.3 dB is achieved with the increase of the subblock size V=4, 8 and 16 respectively. It can be concluded that increasing V can obtain better PAPR reduction performance with the modified PTS scheme. The combined turbo with PTS scheme involves the largest number of complex additions for V≥8, but yields the best PAPR reduction performance. To estimate the PAPR, the OFDM signal was oversampled by a factor of L=4. Therefore it can be concluded that for turbo PTS technique, it is optimal to choose V=16 with N=256 to achieve considerable performance gain.

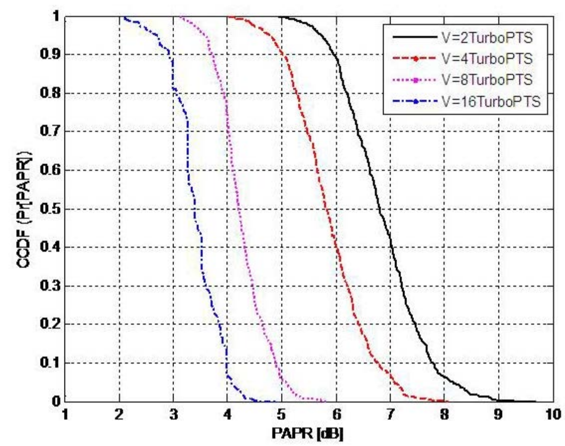

Fig.6 Modified PTS combined with turbo codes performance for different number of subblocks and M_t=2 with N=256

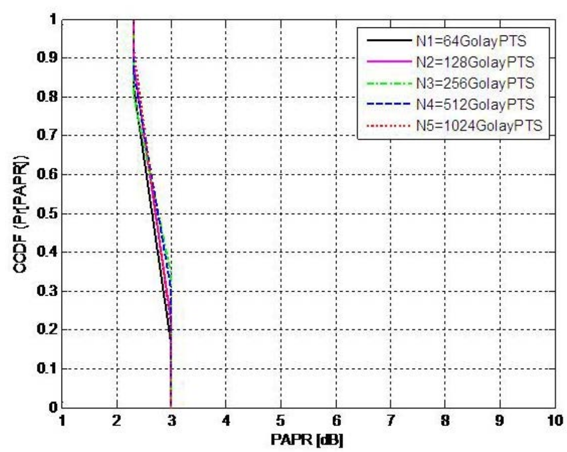

Fig.7 Modified PTS combined with Golay sequence performance for different number of subcarriers and M_t=2 with V=4

Fig.7 demonstrates the performance of combined Golay with PTS for subblock size V=4 for different subcarriers N=64, 128, 256, 512 and 1024. It is observed from this figure that even with increase in the number of subcarriers PAPR remains constant as Golay sequences is employed. The value of PAPR become 2.6dB when CCDF=0.6 for all the subcarriers. Referring to Fig.3, Fig.5 and Fig.7 it is inferred that, combined Golay with PTS results in significant PAPR reduction compared to the modified PTS schemes with turbo code and without coding. It is almost 50% in PAPR reduction.

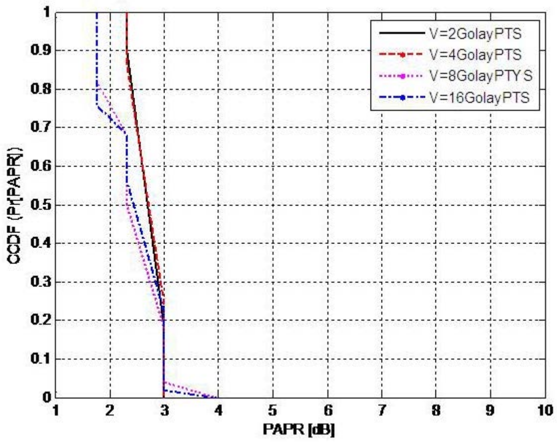

Fig.8 Modified PTS combined with Golay sequence performance for different number of subblocks and M_t=2 with N=256

In Fig.8, the combined scheme is evaluated for various subblocks V=2, 4, 8 and 16. It is observed from the figure for any subblock length the PAPR always lies around 3 dB values. Furthermore for CCDF of 0.6 with V=16, PAPR of Golay complementary sequence reduces by 3 dB as compared to uncoded scheme.

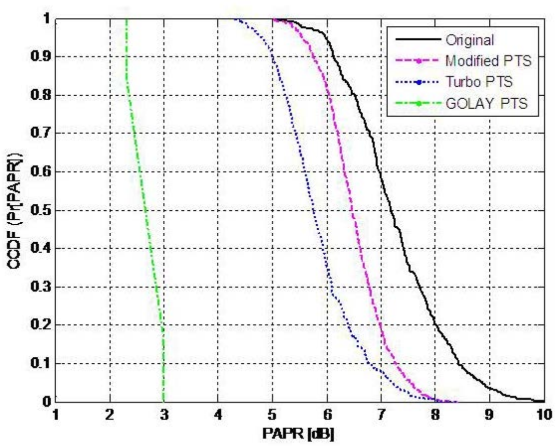

Fig.9 Comparison of original, modified PTS, Turbo PTS and Golay PTS for Mt=2, V=4 and 256 subcarriers.

In Fig.8 the combined scheme is investigated for various subblocks size. The PAPR of the OFDM symbol is about 6.6 dB at CCDF of 0.6 when V=2 and an improvement of 0.8, 2 and 2.8 dB is achieved with the increase of the subblock size V=4, 8 and 16 respectively. It can be concluded that increasing V can obtain better PAPR reduction performance with the modified PTS scheme. The combined turbo with PTS scheme involves the largest number of complex additions for V≥8, but yields the best PAPR reduction performance. To estimate the PAPR, the OFDM signal was oversampled by a factor of L=4. Therefore it can be concluded that for turbo PTS technique, it is optimal to choose V=16 with N=256 to achieve considerable performance gain.

Fig.9 shows the CCDF performance for the original, modified PTS, turbo PTS and Golay with PTS for M_t=2, V=4 and N=256 subcarriers for the purpose of comparison. It can be seen that the PAPR of modified PTS is 6.3 dB, Turbo-PTS is 5.6 dB and Golay-PTS is 2.6dB at CCDF of 0.6, respectively. From this figure it is concluded that combined Golay with PTS results in significant PAPR reduction compared to all other schemes.

6. Conclusions

In this paper, PAPR reduction technique based on modified PTS with FEC in MIMO-OFDM systems using STBC has been considered. This approach, which combines the PTS technique with Golay complementary sequences and Reed-Muller code, divides the subcarriers of OFDM into several disjoint subblocks resulting in significant performance gain in terms of PAPR reduction with low complexity. As a result, the CCDF of PAPR exhibits a steeper decay, increased by a factor equal to the number of transmit antennas. The employment of MIMO configuration improved the capacity and the performance of the OFDM system. The simulation results indicated that the proposed technique has a P APR reduction capability more than that of the modified PTS technique. The PAPR reduction of around 0.2 dB at CCDF value of 0.6 is constantly observed for all values of subcarries in MIMO OFDM than OFDM system. Turbo PTS provides good PAPR performance but as the number of subcarrier increases PAPR increases. Golay PTS results in a performance improvement of 3.4 dB in terms of PAPR reduction compared to Turbo PTS for N=256 when dividing the subcarriers into 4 subgroups and a CCDF value of 0.6 and also provides low complexity.

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