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PAPR Reduction for MU-OFDM Systems

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Abstract

Multiuser Orthogonal Frequency Division Multiplexing(MU-OFDM) has attracted much attention as the fourth generation mobile communication system, because it can realize high-bit-rate and high capacity transmission by multiplexing information symbols of many users with orthogonal codes. In addition it is especially useful in the downlink transmissions. However, similar to OFDM system the transmitted signal from MU-OFDM system also exhibits a very high Peak to Average Power Ratio (PAPR) when using large number of subcarriers and with increased number of users resulting in nonlinear distortion at the high power amplifier and the degradation of the bit error rate. In this paper the performance of Selected Mapping technique will be analyzed and will be compared with another technique called Partial Transmit sequence for PAPR reduction in case of MU-OFDM.

Keywords

PAPR, OFDM, MU-OFDM, CCDF

I. Introduction

Wireless communication is one of the most pulsating areas in the communication field today. The goal for the next generation of mobile communications system is to seamlessly integrate a wide variety of communication services such as high speed data, video and multimedia traffic as well as voice signals. To build such broadband multimedia mobile communication systems it is necessary to take up very high bit rate transmissions. Due to high data rates the symbol duration becomes shorter than the delay spread, giving rise to Inter Symbol Interference (ISI). So, the technology needed to tackle the challenges imposed by the practical wireless media in order to make these services available is popularly known as the Orthogonal Frequency Division Multiplexing (OFDM) System. OFDM is a popular and widely accepted modulation and multiplexing technique in the area of wireless communication. It is a spectrally efficient multicarrier modulation technique for high speed data transmission over multipath fading channels. The OFDM physical layer implements scalable spectrum efficiency to achieve high data rates with flexible radio coverage. OFDM modulation schemes offer many advantages for multicarrier transmission at high data rates over time dispersive channels, particularly in mobile applications. Due to the numerous advantages of this system, it has been successfully applied in wide variety of digital communications over the past several years and has been adapted to the wireless LAN standards as IEEE 802.11a/g. In our earlier work [1] we have presented how OFDM reduces the BER in a multipath fading environment compared to the modulation scheme without OFDM. One of the main issues of OFDM is high Peak-to- Average Power Ratio (PAPR) of the transmitted signal. This high PAPR is due to the non-constant envelope of the signal.

A number of approaches have been proposed to deal with the PAPR problem such as Amplitude clipping, coding, peak windowing, peak cancellation, Tone Injection, Tone Reservation, Selected Mapping (SLM) and Partial Transmit Sequences (PTS). These techniques achieve PAPR reduction at the expense of increased transmit signal power, bit error rate, data rate loss, computational complexity, and so on. In wireless communication systems it is often desirable to allow many users to share simultaneously a finite amount of radio spectrum, so this work focuses on simulation and analysis of Multi-User OFDM system and reduction of PAPR for the same.

II. Problem of PAPR

One of the major problems of OFDM signal is the large dynamic range of the signal. This amplitude fluctuation is expressed by a parameter called 'Peak to Average Power Ratio' (PAPR). An OFDM signal consists of a number of independently modulated subcarriers, which can give a large PAPR when added up coherently. When N signals are added with the same phase, they produce a peak power that is N times the average power [4]. A large PAPR ratio brings disadvantages like an increased complexity of the analog-to-digital (A/D) and digital-to-analog (D/A) converters and a reduced efficiency of the RF power amplifier.

An OFDM signal is the sum of complex random variables, each of it can be considered as a complex modulated signal at a different frequency. Let us denote the collection of all data symbols X_k, k=0,1,…N-1, as a vector X=[X_0, X_1,…X_{N-1}] which is a data block. N is the number of subcarriers. The complex baseband representation of a multicarrier signal consisting of N subcarriers is given as follows

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

Here an approximation will be made that only those samples of x(t) will be considered which are N times L, where L indicates an integer that is greater than or equal to 1. The vector representation of the L times oversampled time domain signal samples arex = [x_0, x_1,…x_{NL-1}] and obtained as

$$x_n=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}X_k e^{\frac{j2\pi nk}{NL}},\quad 0\le n\le NL-1 \qquad (2)$$

where the sequence x_ncan be interpreted as the inverse discrete Fourier transform (IDFT) of data block X with Ntimes (L-1) zero padding. It is well known that the PAPR of the continuous-time signal cannot be obtained precisely by the use of Nyquist rate sampling, which corresponds to the case ofL=1. It is shown in [9] that L=4can provide sufficiently accurate PAPR results. The PAPR computed from the L times oversampled time domain signal samples is given by

$$PAPR=\frac{\max[x_n^{\,H}x_n]}{E[x_n^{\,H}x_n]} \qquad (3)$$

Where x_n is a complex vector, E[.] is expectation operator with 0≤n≤NL-1.

III. System Model

Recently Multi User OFDM (MU-OFDM) has received much attention due to its capability to high speed wireless multiple access communication systems. In MU-OFDM system, data streams from multiple users are orthogonally multiplexed onto the downlink and uplink channels. The MU-OFDM system is realized by the combination of CDMA and OFDM, where each transmitter/receiver user pair has its own distinct signature code for transmitting over a common channel bandwidth. It has attracted much attention as the fourth generation mobile communication system, since it can realize high bit-rate and high capacity transmission by multiplexing information symbols of many users with orthogonal codes. In MU-OFDM all the users transmit on different subcarriers at the same time.

The MU-OFDM system model is shown in fig. 1.

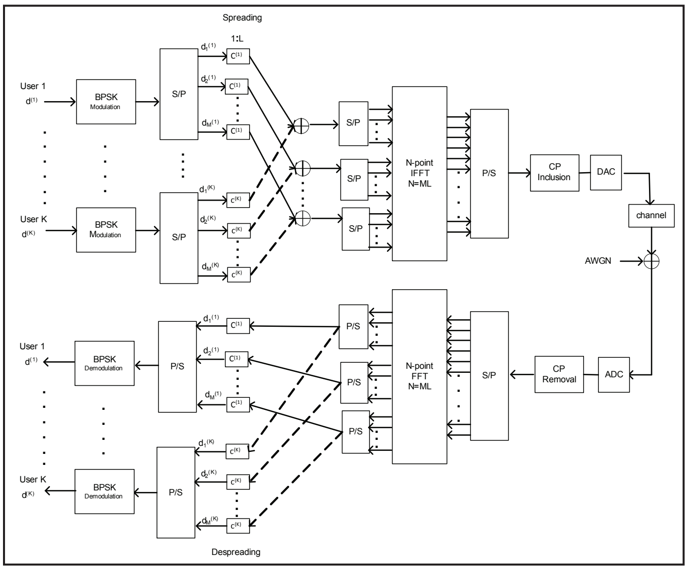

Fig. 1: System Model for MU-OFDM

Here the information signal from different users after BPSK modulation is denoted by $d^k = [d_1^k, d_2^k, \dots d_M^k]$ where M denotes the data symbols of the kth user, k=1,2,…K. After serial to parallel conversion, the data is multiplied with another faster rate, wider bandwidth signal, which is referred to as a pseudo-noise sequence (PN sequence). This operation is called as spreading. Here each symbol is spread by the user specific code $c^k=[c_1^k, c_2^k, \dots c_L^k]$ where L is the spreading gain or the spreading factor. The spreading codes are preferred to be orthogonal set of sequences for the low multiuser interference. The spreaded data from each user is then added. Assuming K active users in the system, the added data is passed through a serial to parallel converter and then input to the IFFT of size N=ML.

The resultant baseband transmission signal for one MU-OFDM symbol [3] is

$$s(t)=\sum_{m=1}^{M}\sum_{l=1}^{L}\sum_{k=1}^{K} d_m^{(k)} c_l^{(k)} e^{j2\pi\{M(l-1)+(m-1)\}t/T_s} \quad (4)$$

To eliminate ISI caused by the multipath channel, guard period is inserted which is done by using Cyclic Prefix. The signal is then up converted and transmitted over the channel where it is encountered with the multipath fading environment and addition of noise.

IV. Implementation of SLM for MU-OFDM

The block diagram to implement SLM is shown in fig. 2. The multiplexed MU-OFDM signal is multiplied by U-1 different phase sequences,

$$\Phi_p=[\Phi_{p,1},\Phi_{p,2},...,\Phi_{p,N}],\ p=1,2,.....U \quad (5)$$

The first phase vector will introduce no rotation to the signal such that there will be U-1 phase rotated symbol sequences and one original. Phase sequences have length equal to the number of subcarriers before the IFFT process. After the IFFT process the PAPR is calculated for the U-1 phase rotated and one original sequence, and then the sequence with the minimum PAPR is selected and transmitted.

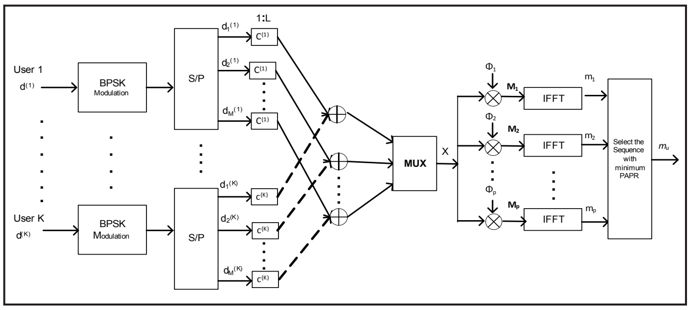

Fig. 2: Block diagram for SLM in MU-OFDM

V. Partial Transmit Sequence (PTS) Technique

The PTS scheme is an efficient and distortionless approach for reducing PAPR. One of the most important advantages of the PTS scheme compared with other PAPR reduction schemes is that we can apply it to a multicarrier system with an arbitrary number of subcarriers, and any order of modulation scheme. In PTS technique the data block is partitioned into V disjoint sub-blocks as shown in figure 3. These are then combined after proper phase rotation of individual sub-blocks to minimize PAPR. All subcarrier positions which are already represented in another sub-block, are set to zero.

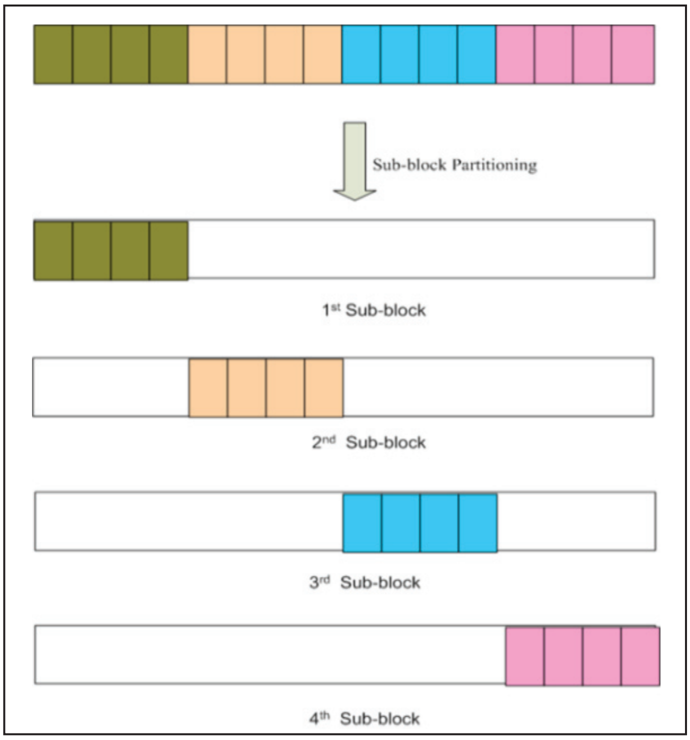

Fig. 3: Sub-block Partitioning

The block diagram for PTS is shown in fig. 4.

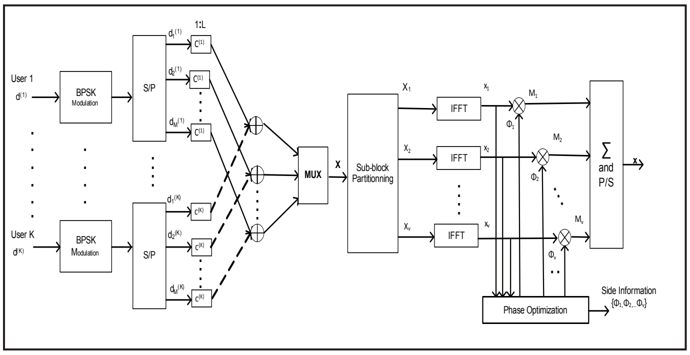

Fig. 4: Block Diagram for PTS in MU-OFDM

The spreaded signals from different users that are added and multiplexed represent one MU-OFDM signal. This data block X is partitioned into V sub-blocks $X_v, v = 1, 2, ...V$. The partition scheme used is as shown in fig. 5 such that

$$X = \sum_{v=1}^{V} X_v \tag{6}$$

The sub-blocks X_v are then transformed into V time domain partial transmit sequences, $x_v = \Im^{-1}\{X_v\}, v = 1, 2, ...V$.

The rotation factors $\Phi_v,\ v = 1, 2, ...V$ which are pure rotations such that $|\Phi_v| = 1$ are generated and optimized for each sub-block X_v to find an appropriate value that minimizes the PAPR of the system.

The weighted combination of the V sub-blocks gives the optimum transmit sequence [3].

$$x = \sum_{v=1}^{V} \Phi_v x_v \tag{7}$$

VI. Simulation and Discussion

Here the performance evaluation of MU-OFDM system using SLM according to figure1 is carried out. The simulation parameters and the algorithmic steps to implement SLM for multiuser case is same as discussed in the implementation for single user case. The fig. 5 shows the CCDF plot for SLM with different values of U=64,128 and 256, the number of phase sequences. The phase sequences have been generated using Riemann Matrix. It can be observed that as U increases the PAPR value decreases. But this minimization is achieved at the cost of increase in the computational complexity as the number of IFFT computations required to find the minimum value of PAPR is directly proportional to U. In addition to that, amount the side information (if needed) to be sent at the receiver will also increase thereby increasing the redundancy. The amount of side information for SLM is given as $\log_2 U$. PTS algorithm is implemented using V=4 and W=4 where V denotes the number of sub-blocks and W denotes the number of admitted angles. For W=4, the phase rotation factors have been chosen from the set $\{-1, 1, +j, -j\}$.

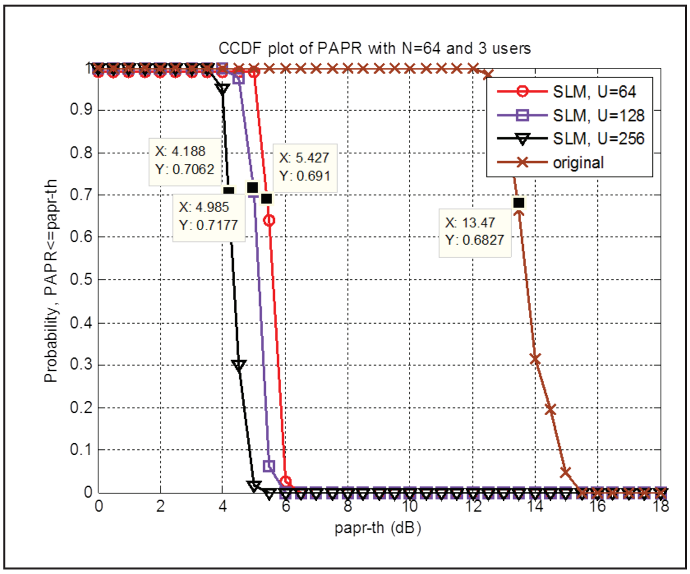

Fig. 5: CCDF Plot for SLM in MU-OFDM System

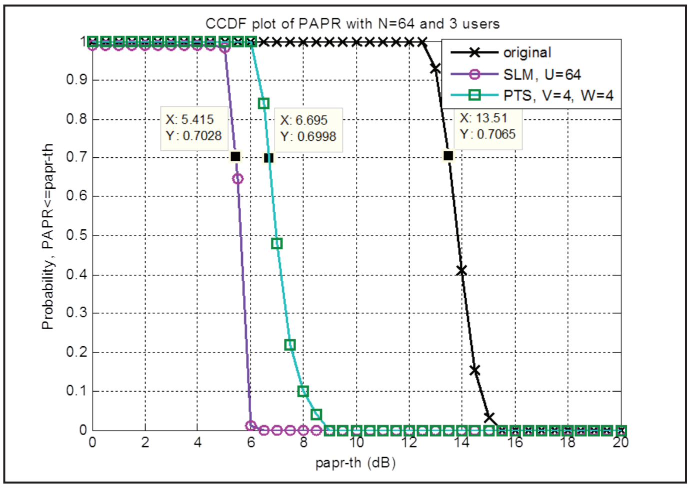

Fig. 6: Comparison of SLM and PTS Technique

Here Φ_1 can be set to 1 without any loss of performance. So there should be an exhaustive search for (V-1) phase factors. The amount of PAPR reduction depends on the number of sub-blocks V and the number of allowed phase factors. Fig. 6 shows the comparison of SLM and PTS where the amount of side information are same. The side information for PTS is given as $\log_2 W^{(V-1)}$. So in this case the amount of side information for each will be 6-bits. It can be observed that SLM can reduce the PAPR value of MU-OFDM by 8.095dB which is better than PTS which achieves a reduction by 6.815dB for the same amount of side information compared to the unmodified signal. This is because in PTS the phase is rotated by sub-blocks, where as in SLM the phase is rotated by one sub-carrier. Thus the probability of low PAPR using the SLM is higher than the PTS. Table 1 summarizes the comparison of the two techniques.

VII. Conclusion

In wireless communication systems it is often desirable to allow many users to share simultaneouslya finite amount of radio spectrum, so the work focused on simulation and analysis of Multi-User OFDM system and PAPR reduction was aimed at this system model. For this system, the methods like SLM and PTS were implemented and compared. It was found thatSLM again performed better than PTS in reducing the PAPR for the same amount of side information.

Table 1: Comparison between SLM and PTS

Parameters	Techniques	
	SLM (U=64)	PTS (V=4, W=4)
IFFT operations per Data block	64	4
Side Information	6 bits	6 bits
PAPR	5.41dB	6.69 dB

Using SLM the PAPR value was 5.41dB and with PTS it was 6.69dB for MU-OFDM system.Another important evolving technology is the Ultra Wide Band (UWB) which is expected to support a myriad of users with a spectrum spreading over several GHz. Modern UWB systems use modulation techniques, such as OFDM, to occupy these extremely wide bandwidths. In addition, the use of multiple bands in combination with OFDM modulation can provide significant advantages to traditional UWB systems. One major difficulty of MU-OFDM-UWB signal is its large PAPR. To reduce this ratio, the techniques discussed here can also be extended to this system. The future of wireless communication is expected to be centralized around the UWB-OFDM systems, so looking into its problem areas and coming up with possible and effective solutions will be very useful.

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