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Two stage Precoding in OFDM based Cognitive Radio

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Abstract — *Cognitive radio can imerging as the technology which alleviates the problem of spectrum scarcity.Orthogonal Frequency Division Multiplexing (OFDM) is a ideal transmission technique for Cognitive Radio (CR) networks because of its flexible nature to support Dynamic Spectrum Access(DSA).While this technique has two major drawbacks, Out Of Band (OOB) leakage due to high spectral sidelobe which cause interference with Primary Users (PU) operated in the adjacent band and high Peak to Average Power Ratio (PAPR). There are many solutions were proposed for solving either of these problems individually or together.This paper presents different precoding techniques for OOBR suppression and PAPR reduction.*

Keywords- *Cognitive radio(CR); orthogonal frequency division multiplexing(OFDM);out-of-band radiation(OOBR); Peak to Average Power Ratio(PAPR)component;*

I. INTRODUCTION

Cognitive radio (CR) is an emerging communication design paradigm [1],[2] in which the radios devices equipped with transceivers can sense the underlying radio environment and adapt their transmission/reception parameters like operating frequency, power, modulation rate, etc. The specific instance in which the operating frequency is adjusted is known as Dynamic Spectrum Access(DSA). DSA has the potential to alleviate the problem of spectrum shortage [3][4]. The problem of spectrum shortage can create problems in allocating spectrum for the numerous wireless applications that are being conceived. On the other hand a recent survey by Federal Communications Commission(FCC), USA, suggests that vast portions of allocated spectrum is vastly underutilized. A radio enabled with DSA can indeed access the spectrum opportunistically whenever the licensed users are inactive, thereby leading to efficient spectrum utilization. Henceforth, we refer to networks that use DSA as CR networks. Since CR networks allow unlicensed users to access opportunistically therefore it contains two types of users namely primary (licensed) users(PU) and secondary (unlicensed) users(SU).

Orthogonal frequency division multiplexing (OFDM) is considered to be the most widely used technology in wireless communication systems. The OFDM has the potential of fulfilling the aforementioned requirements of CR inherently or with minor modifications. The underlying sensing and ability to shape the spectrum accounts OFDM to be the ideal transmission technique for CR Systems [5]. This ability of spectrum shaping of OFDM helps in avoiding the interference of CR with PU. In this paper, OFDM technique is investigated as a candidate for CR systems. In this paper, it is explained in detail regarding the precoding techniques that can reduce high PAPR and suppress OOBR that can affect the performance by causing interference to PU.

II. Major Drawbacks of OFDM Based CR

As there are advantages of using OFDM based CR there are also few disadvantages. The two major drawbacks that can degrade the performance is Out-Of-Band-Radiation (OOBR) and very high Peak to Average Power Ratio (PAPR).

A. Out of Band Radiation (OOBR)

The out-of-band radiation in OFDM transmission interferes with wireless communications in adjacent channels and endangers the co-existence of the incumbent radio systems of the spectrum. The reason for high power of OOBR is the use of the IFFT block in the OFDM transmitter [7]. OFDM uses sinc pulses for representing symbols transmitted over all the subcarriers per time constant. Large sidelobes resulting from this sinc-type pulses are a source of interference to the PU or other rental systems that might be present in the vicinity of the spectrum used by the unlicensed system. There are several methods for reducing the OOBR of the OFDM systems given as follows, In [7], OOBR of SUs can be reduced by inserting the guard band. But, it will consequently reduce the spectrum efficiency. Various schemes have been proposed in both time domain and frequency domain to improve performance of the primary users by reducing OOBR. In[7], the time domain signal is multiplied with a raised cosine windowing function to lower the sidelobes, but at a cost of expanding the symbol duration which results in lower throughput.

To improve the spectral efficiency various advanced techniques have been proposed but the technique which have achieve more suppression of OOBR with better spectral efficiency are Active interference cancellation (AIC) [8] and the introduction of cancellation carrier [9]. Both of these techniques results in enough suppression of OOBR but suffer from Signal to Noise Ratio (SNR) degradation and also extra power is wasted in cancellation subcarrier.

In [10], adaptive symbol transition technique is used in which the OFDM symbols extended adaptively at the cost of decrease in the useful symbol energy.Methods in frequency domain rely on spectrum shaping techniques and can be classified as cancellation and precoding techniques.

In [11], we discuss spectral precoding scheme. In these approaches, the information symbols are mapped to a new set of precoded symbols under some constraints. In this method large suppression of OOBR is achieved without losing BER performance but the notched frequencies selection algorithm is computationally more complex and expensive.

In [12], a scheme based on optimization process is proposed. However, the method in [12] does not have any closed form solution and hence computationally expensive. Also, the OOBR rejection is achieved at a cost of significant BER performance loss.

B. Peak to Average Power Ratio(PAPR)

One of the main drawbacks in Multi-Carrier (MC) systems is the high variation of the amplitude of the time-domain samples that can occur in the signal after the IFFT, resulting in a high value of the Peak-to-Average Power Ratio (PAPR).
Mathematically it can be defined as the,

$$\text{PAPR} = \frac{\max\ |x(t)|^2}{\text{E}\{|x(t)|^2\}}$$

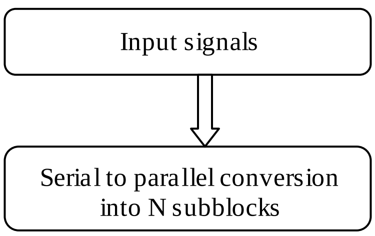
PAPR can be defined as the ratio of the peak power to the average power. where E(.) can be denoted as the expected value.

The signal that contains samples with high amplitude, equivalent to high PAPR value, and the presence of nonlinear elements in the transmission chain, e.q. high power amplifiers(HPA), result in in-band distortions, increased out-of-band emissions, and as a consequence result in Bit-Error Rate (BER) degradation at the receiver.There are several methods to reduce the PAPR which can includes the following methods,

In[13],there can be proposed the ZCT(Zadoff-Chu matrix Tansform) precoded and postcoded method. It can be said that the proposed pre/postcoded OFDM systems introduce no PAPR or BER degradation. In addition, the ZCT precoding and postcoding based OFDM systems for PAPR reduction do not require any power increment, complex optimization and side information to be sent for the receiver.

Among them, schemes like clipping and filtering [14], Partial Transmit Sequence (PTS) [15], precoding based techniques [16] and Precoding based Selected Mapping (SLM) [17] are popular. Clipping method provides a PAPR suppression but causes distortion to the signal and also degraded the BER performance. The another PTS techniques and SLM need provides a better PAPR suppression but increase additional complexity.

III. Flowchart for the Two stage Precoded OFDM (Transmitter part)



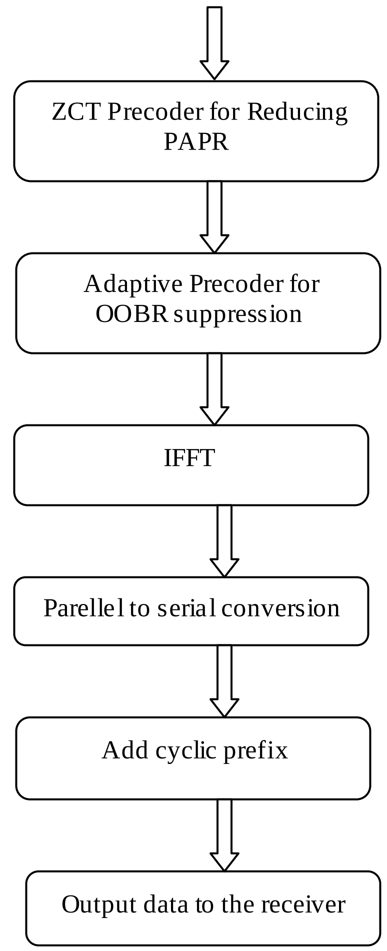


Figure 1 . Flowchart for the Two stage Precoded OFDM

The proposed scheme is made up of the two individual precoder in which at stage-1 ZCT precoder reduce the effect of PAPR so that it reduce the in band and out of band distortion and then at the stage-2 adaptive precoder is use for further reducing the out of band radiation to ensure that the signal does not interfere with the primary users which are allocating in the adjacent frequency band.
The algorithm select such away that it reduces the effect of OOBR and PAPR with the less computational complexity and low cost.Further more it can also improve its BER performance.

C. ZCT (Zad-off chu matrix transform) precoder[13]

Zadoff-Chu sequences are class of poly phase sequences having optimum correlation properties. Zadoff-Chu sequences have an ideal periodic autocorrelation and constant magnitude. The Zadoff-Chu sequences of length L can be defined as,

$$z(k) = \begin{cases} e^{\frac{j2\pi r}{L}\left(\frac{K^2}{2}+qk\right)} & for\ L\ even \\ e^{\frac{j2\pi r}{L}\left(\frac{k(k+1)}{2}+qk\right)} & for\ L\ odd \end{cases}$$

where k=0,1,2,.....,L-1,q is any integer , r is any integer relatively prime to L and j=$\sqrt{-1}$

In ZCT precoding based OFDM system in which baseband modulated data is passed through S/P convertor which generates a complex vector of size N that can be written as X = $[X_0, X_1, \dots, X_{N-1}]^T$.

Then ZCT precoding is applied to this complex vector which transforms this complex vector into new vector of length N that can be written as Y=PX= $[Y_0, Y_1, \dots, Y_{N-1}]^T$ Where R is a ZCT based row-wise precoding matrix of size L = N×N With the use of reordering as given in the below equation

$$k=mN+l$$

matrix R with row wise reshaping can be written as the

$$R = \begin{bmatrix} r_{00} & \cdots & r_{0(N-1)} \\ \vdots & \ddots & \vdots \\ r_{(N-1)0} & \cdots & r_{(N-1)(N-1)} \end{bmatrix}$$

R is N x N, ZCT complex orthogonal matrix with length L^2 = N×N.

Let q = 1 and r = 1, the ZCT for Even L can be written as the,

$$r_k = exp\ [\frac{(j * \pi * k^2)}{L^2}]$$

Accordingly, precoding X gives rise to Y as follows:

$$Y=RX$$

.

The performance parameter for the PAPR performance is CCDF and it can be written as the,

$$P\ (PAPR > PAPR_0) = 1\text{- CDF}$$
$$=1 - (1 - e^{-PAPR_0})^N$$

where $PAPR_0$ is the clipping level.

CCDF (complementry cummulative distribution function) can be denoted as the probability that the PAPR at the instantaneous point can be greater than the $PAPR_0$.

D. Adaptive precoder[17]

Adaptive precoder can sense the surrounding environment and adapt its different transmission parameters(e.g. operating frequency,power) to maintain the quality requirement and improves the performance of the system.

It can reduce the OOB by using the adaptive orthogonal projection matrix. As by its name this method can adaptively adjust the precoding matrix according to the radio environment so that ensure the less complexity.The orthogonal projection method is force the PSD of the several frequency point in the out of band to zero and for that the number of frequency suppression point can be chosen.

Precoding matrix can be shown as the , S = Pd

where S is the precoded symbol vector, d is the baseband modulated data vector and P is the precoding matrix
The out of band points are chosen such a way to achieve

$$CPd = 0$$

Where C is a frequency response coefficient matrix which is invariant , $C_{k,l} = c_k(w_l)$ where k indicating the information carrier frequency point and l indicating OOB frequency point. The orthogonal projection can be achieve by using the linear mapping method in which map the source data vector to the null space of coefficient matrix.This method select the precoded data vector such that its euclidean distance is closest to the source data vector.

IV. SIMULATION RESULTS

For the ZCT precoding based OFDM we performed extensive simulations in MATLAB in order to evaluate the performance of the ZCT precoding based OFDM systems.To show the PAPR analysis of ZCT precoding based OFDM, data is generated randomly then modulated by M-QAM (where M=4, 16, 64, 256). To show overall performance of the ZCT precoding we considered the 64 point IFFT for M-QAM.We also compared our simulation results with the conventional OFDM.

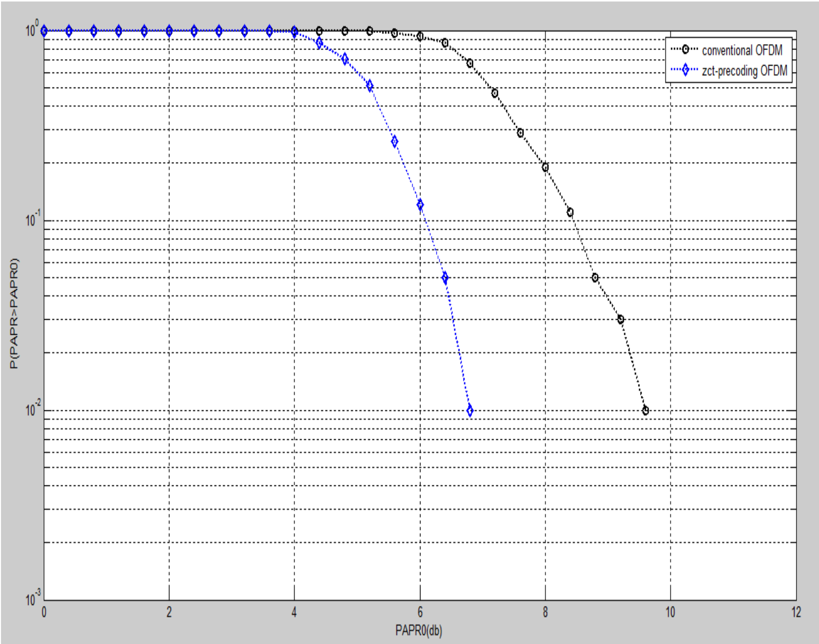


Figure 2 . Comparison of PAPR reduction for the ZCT precoder with conventional OFDM for M=4QAM

From the Fig.2 the CCDF comparison can be shown for the ZCT precoded OFDM and conventional OFDM for 4QAM. At the clip rate of 10^-1 the PAPR gain for the ZCT precoded OFDM and conventional OFDM is 6.2 and 8.6 respectively.

From the Fig.3 the CCDF comparison can be shown for the ZCT precoded OFDM and conventional OFDM for 16 QAM. At the clip rate of 10^-1 the PAPR gain for the ZCT precoded OFDM and conventional OFDM is 6.8 and 8.6 respectively.

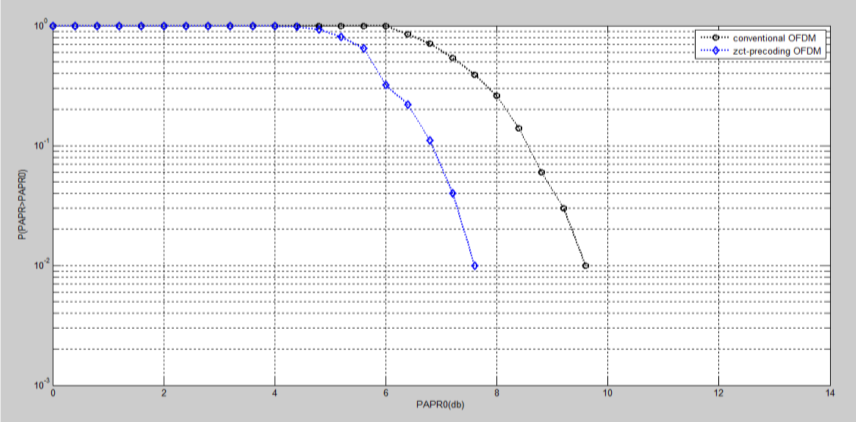


Figure 3. Comparison of PAPR reduction for the ZCT precoder with conventional OFDM for M=16QAM

Observation Table:

From the table 1 PAPR gain for the both the conventional OFDM and ZCT p recoded OFDM can be presented for the different modulation schemes and it can indicated that the PAPR gain for the ZCT percoded OFDM can be less than the conventional OFDM at the clip rate of 10^-1.

Table 1: CCDF comparison of PAPR between conventional OFDM and ZCT precoder

Type of modulaion (M-QAM) M=4,16,64,256	PAPR gain of ZCT Precoded OFDM(db)	PAPR GAIN OF CONVENTIONAL OFDM (db)
4-QAM	6.2	8.6
16-QAM	6.8	8.6
64-QAM	7	8.6
256-QAM	7.2	8.6

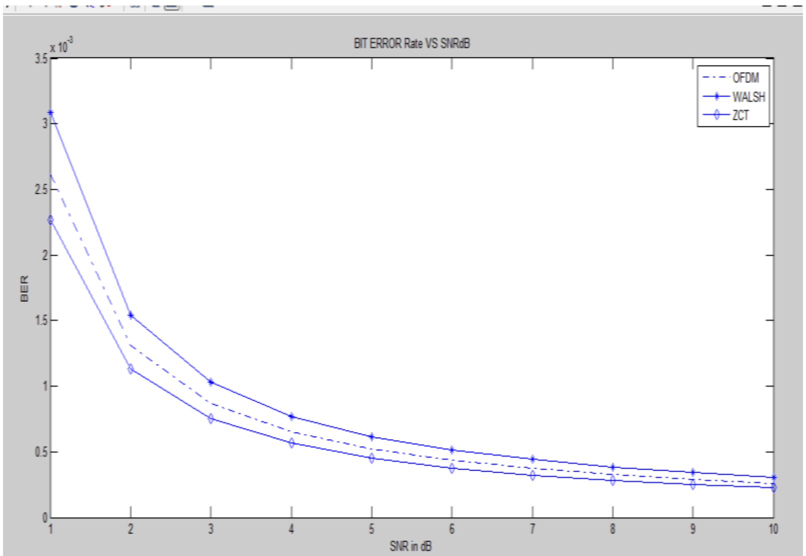


Figure 4. BER comparison of ZCT precoded OFDM with the conventional OFDM and walsh hadamard for M=16QAM

From figure 4 there can be shown the BER performance of the system in which at the same SNR value BER performance of the ZCT precoded OFDM is better than the conventional OFDM and walsh hadamard.

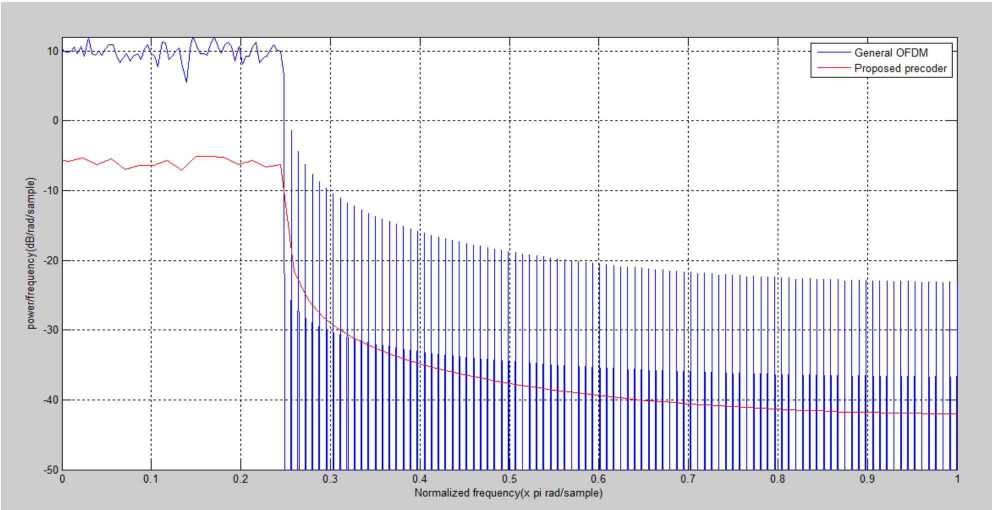


Figure 5. Comparison of Out of band radiation(OOBR) Reduction by using the Adaptive precoding with the conventional OFDM for M=16QAM

From figure 5 there can be shown the more suppression in the out of band upto 42 db which ensure the interference free environment for the primary users operated in the adjacent band. As the different no of the suppression point can be chosen than there can be more suppression occurs in the out of band .

V. CONCLUSION

CR is an exciting and promising technology that offers a solution to the spectrum crowding problem. On the other hand, OFDM technique is used in many wireless systems and proven as a reliable and effective transmission method. OFDM technique is a better candidate for CR systems due to its inherent capabilities. This paper identified the challenges of OFDM based CR systems i.e., OOBR and PAPR. This paper presented survey of different precoding techniques for OOBR suppression and reduction in PAPR and use the two different adaptive and ZCT precoder appropriately without sacrificing the BER performance and with the less computational complexity.

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