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Reduction of Out of Band Radiation Using Modified Constellation Expansion in OFDM based Cognitive Radios

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Abstract: Out of band radiation (OOBR) is one of the major problems in OFDM based Cognitive Radios. In the spectrum sharing scenario, OOBR generates appreciable interference to the primary user, even if its spectrum band is not used. The basic cause of this OOBR is the rectangular shaped OFDM symbol. To mitigate the effects of the OOBR, a number of techniques have been proposed in the literature. These techniques shape the OFDM symbol either in time or in frequency domain. Time domain techniques achieve OOBR reduction by using smoother windows. But this reduces the overall throughput of the system. In frequency domain techniques, some of the subcarriers are either used as guard band or reserved for interference cancellation. These subcarriers do not carry any data and as such reduce the spectral efficiency of the system. In this paper, we use different variants of Constellation expansion (CE) technique to reduce OOBR. CE techniques do not suffer from throughput reduction or spectral efficiency loss, as the original symbols are mapped to a higher order constellation set and the symbol sequence is replaced by a new sequence that produces minimum OOBR. We study different mapping techniques based on single bit or two bit mapping of CE technique. We show through simulations that two bit mapping of CE technique gives appreciable improvement over the basic CE technique.

Keywords: Out of band radiation, Constellation Expansion, OFDM, Cognitive Radio.

1. Introduction

Growing demand for mobile communications on one hand and limited availability of free spectrum on the other, has created a need for efficient spectrum utilization. Cognitive radio (CR) technology [1, 2] is a solution to the problem of spectrum under-utilization. Using CR technology, unlicensed users (also called secondary users) can coexist with the licensed users (also called primary users) subject to certain interference constraints [1-3]. To keep the interference produced by secondary users (SU's) to minimal level, spectrum shaping techniques are used. Orthogonal frequency division multiplexing (OFDM) provides a simple way to spectrum shaping by deactivating the subcarriers corresponding to the primary users (PU's). However, this deactivation is not sufficient to minimize the interference to the PUs, as the OFDM symbols are rectangular shaped [4] and hence cause large amount of out of band radiation (OOBR).

In current scenario, several OOBR suppression techniques have been proposed in the literature to suppress the interference to PU's. Time domain windowing [5–6] is the simplest approach and lengthens the symbols using smooth shaping windows such as Raised Cosine window. This however, reduces the useful data rate. Insertion of guard bands [5] on either side of PU band is also a simple approach to reduce interference. But it reduces the number of useful subcarriers. Both of the above approaches lead to a reduction of spectral efficiency of the primary user [5]. Subcarrier weighting (SW) [7], is another approach to reduce OOBR. In this technique all the subcarriers are multiplied by complex weights so to minimize the sidelobe power. Since the data subcarriers are perturbed, this approach has the side effect of increasing the bit-error-rate (BER) of the system [7]. In [8], the multiple choice sequences (MCS) approach is introduced to reduce the sidelobes of OFDM subcarriers. In MCS approach, the original data sequence is transformed into a set of sequences and the sequence with minimum sidelobe power is used for transmission. Since the transmitted sequence needs to be mapped back to the original sequence, some side information needs to be sent to the receiver, thereby reducing the effective data rate [8]. In the active interference cancellation (AIC) technique [9], few subcarriers are reserved and weighted and are inserted in the PU band and at the edges of PU band to suppress the sidelobes, whereas in the adaptive symbol transition (AST) method [10], this is achieved by optimally extending the time domain symbols to reduce

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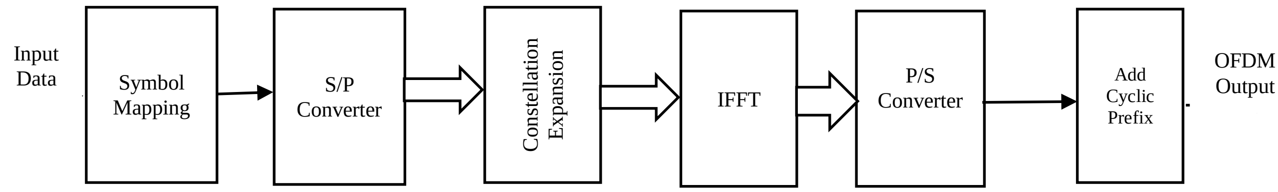

Figure 1. System Model

the sidelobes. However, both techniques mitigate the interference at the cost of a decrease in the data throughput. In [11], N-continuous OFDM approach is proposed. In this approach, few subcarriers are reserved to create a smooth transition between consecutive OFDM symbols. More the number of these subcarriers, smoother is the transition between the OFDM symbols and lesser is the OOBR. This technique also suffers from a reduction in the data throughput.

In this paper, we study different variants of constellation expansion (CE) technique [12], to reduce the out of band interference power from the secondary users to the primary users. We study CE technique by varying the type of mapping, number of iterations and the width of PU band. The results are compared through simulations done in MATLAB.

This paper is organized as follows. In Section II, the system model for the proposed technique is introduced. In Section III, we discuss the Constellation Expansion technique with single symbol mapping along with simulation results. In Section IV, we discuss Constellation Expansion with symbol pair mapping and show through simulations, the improvement obtained in OOBR reduction. Finally in Section 5, we present the Conclusions of this study.

2. System Model

In this study we consider an OFDM based cognitive radio system with N subcarriers. Secondary users in the system are assumed to have the knowledge of spectrum occupied by primary users and make use of suppression techniques to reduce out of band radiation (OOBR). A system model is shown in Figure 1. An input data bit stream d(n) is symbol mapped using phase shift keying (PSK) and is converted to a parallel data stream of N bits.

This data stream is passed through the OOBR suppression unit before being fed to IFFT block for modulation. This parallel data stream is converted to serial data by P/S block. To overcome the effect of delay dispersive channel, a cyclic prefix is added to this modulated data. This baseband OFDM signal is passed through transmitter's radio frequency chain to amplify the signal and up-convert it to the desired frequency. The focus of our work in this study, is the OOBR suppression unit. We have divided our study into two parts: In the first part, we compare different variants of the original Constellation expansion technique [12] to reduce the OOBR. In the basic CE technique, the baseband symbols are mapped to a higher constellation in a random fashion and the constellation symbol sequence that produces minimum OOBR, is selected for transmission. In the second part of our study, we discuss modification to the basic CE technique, by mapping a pair of baseband symbols to the higher order constellation.

3. Constellation Expansion with Single Symbol Mapping

In the Constellation Expansion (CE) technique [12], each symbol is randomly mapped to a corresponding symbol from higher constellation space before modulation. If an n bit/symbol modulation scheme having 2^n constellation points, is mapped to an (n+1) bit/symbol modulation scheme with $2^{(n+1)}$ constellation points, then for each constellation point we have to make a choice from two higher order constellation points. Since the number of possible sequences is double than the original number of sequences, the sequence which generates minimum OOBR is selected for transmission. However, there is a slight degradation in error performance as the Euclidean distance between possible constellation points decreases in higher order constellation space.

A. Simulation Results & Discussion

We consider an OFDM system with 128 subcarriers and the primary band is assumed to span over 16 and 32 subcarriers in two different cases. A cyclic prefix of 64 length is added to each OFDM symbol to overcome the effect of delay dispersive fading. In each case, we deactivate the subcarriers coinciding with the primary user band. This approach is termed as carrier nulling approach. However, the sidelobe power generated by the adjacent

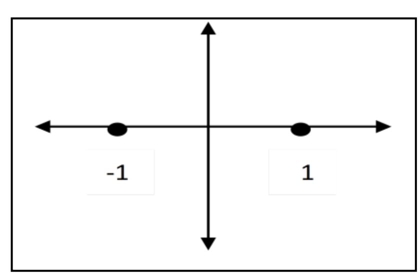

Figure 2. Original Constellation

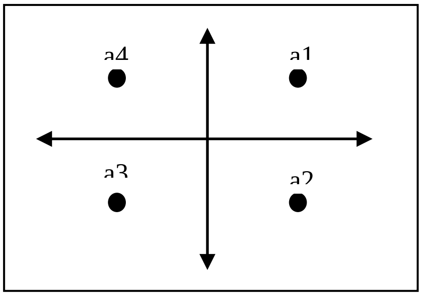

Figure 3. Expanded Constellation

TABLE I. SYMBOL MAPPING

Symbols	Constellation Mapping		
	90 degree phase difference between successive symbols		*180 out of phase*
-1 -1	a1 a2	a1 a4	a1 a3
-1 1	a2 a3	a4 a3	a2 a4
1 -1	a3 a4	a3 a2	a3 a1
1 1	a4 a1	a2 a1	a4 a2

subcarriers creates appreciable interference to the primary band as shown in Fig. 4. To reduce the sidelobe power in primary band, different variants of constellation expansion [12] are used. Simulations are performed for four different scenarios with primary band (PU) spanning over either 16 or 32 subcarriers. In constellation expansion form BPSK to QPSK, either both real and imaginary parts of QPSK point are selected randomly or one of them is fixed. We name the resulting four scenarios as:

- 16 Subcarrier PU band with fixed mapping
- 16 Subcarrier PU band with random mapping
- 32 Subcarrier PU band with fixed mapping
- 32 Subcarrier PU band with random mapping

Figure 5 shows the average normalized interference power in PU band using different variants of constellation expansion technique. Following observations are made from Fig. 5:

- It is observed that more reduction in average interference is observed for wider PU bands than narrower ones. This is because active subcarriers are more far from the center of the PU band in wider PU bands.

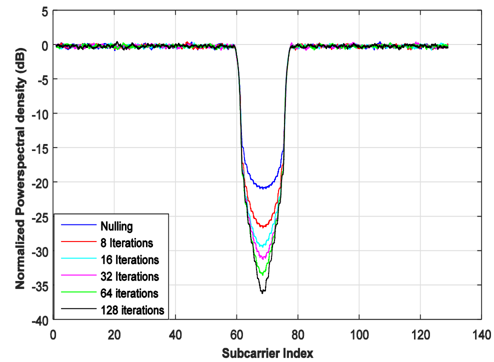

Figure 4. OOBR using Constellation Expansion (fixed mapping) for PU spanning over 16 subcarriers

- *Effect of mapping technique:* In constellation expansion, original constellation points are mapped to a higher order constellation. Each constellation point has a real and an imaginary part. During mapping from lower to higher order constellation, either one or both of these dimensions are used. In this study, we have termed the former as *"Fixed mapping"* and the later as *"Random mapping"*. Mapping over only one dimension (*Fixed mapping*) leads to lesser number of random sequences than if both dimensions (*Random mapping*) are used. Thus the chance of finding a sequence with lesser OOBR is more in random mapping than in fixed mapping. It is observed in Fig. 5, that more OOBR reduction is achieved in random case than in fixed case.

- *Effect of number of iterations:* In constellation expansion, mapping from lower to higher order constellation set is done randomly. It is therefore not necessary that the mapped sequence will generate minimum OOBR and as such each OFDM symbol needs to be mapped multiple times to obtain the sequence that generates minimum OOBR. It is expected that increase in number of iterations will gives us a bigger set to choose a sequence with minimum OOBR. Thus OOBR reduction increases with the number of iterations, as shown in Fig. 5. However, the decrease in OOBR seems to saturate as the number of iterations is increased. Thus there is not much benefit in using large number of iterations.

4. CONSTELLATION EXPANSION WITH SYMBOL PAIR MAPPING

In the modified CE technique, we group two baseband symbols and map them together to a higher order constellation space of Fig. 3. The mapping is shown in

Table 1 for a BPSK signal. As shown in the Table, two types of mappings for a symbol pair are possible. The successive symbols in the pair can have a phase difference of 90^o or 180^o. In the 90^o case two more possibilities are there depending on whether the second symbol in the pair leads or lags the first.

In Figures 6 & 7, the effect of symbol pair mapping on OOBR reduction is shown. A pair of BPSK symbols is mapped to QPSK constellation with a phase difference of 90^o and 180^o in two different cases. For 90^o case, no performance improvement in OOBR reduction is achieved. However, for 180^o case, an appreciable reduction is achieved. A reduction of around 45 dB is achieved for 16 subcarrier PU band, in contrast to around 35 dB for original CE with 128 iterations. For 32 subcarrier PU band, the reduction achieved is around 54 dB and 40 dB for 180^o case and original CE with 128 iterations, respectively. It is thus observed that Symbol pair mapped CE with 180^o phase

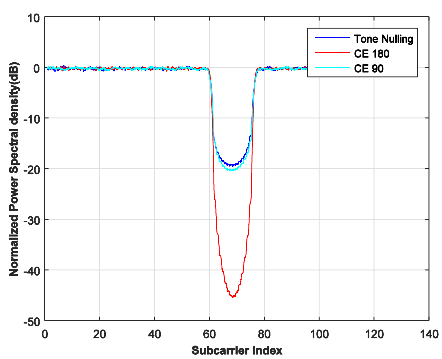

Figure 5. Effect of different number of iterations of Constellation Expansion on OOBR

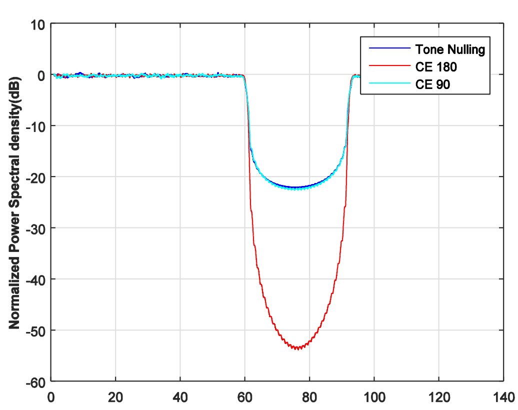

Figure 6. OOBR reduction using Constellation Expansion with symbol pair mapping (16 subcarrier PU band)

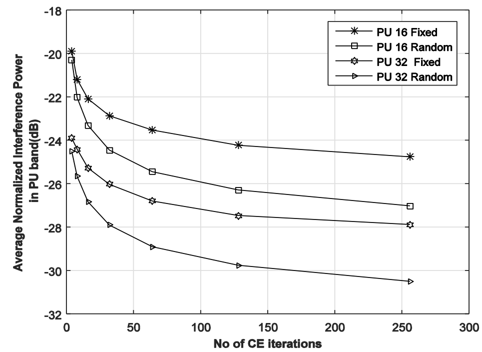

Figure 7. OOBR reduction using Constellation Expansion with symbol pair mapping (32 subcarrier PU band)

difference, provides better reduction. This is attributed to the fact that adjacent symbols in the expanded set are out of phase and thus try to cancels each other's radiations in the PU band. Further in this case, no iterations are involved in mapping the symbols to higher order constellation, so this technique is faster than the original CE technique [12].

5. CONCLUSIONS

Reducing out of band radiation is of prime importance in OFDM based cognitive radios. In this paper, we study constellation expansion with single bit and two bit mapping for suppression of out of band radiation. In single bit case, mapping from lower to higher order constellation is randomly done over either single or both dimensions of the complex constellation. In two bit case, mapping of two bits in pair is done in such a manner that there is either 180^o or 90^o phase difference between the mapped bits in the pair. Two different types of primary bands spanning over 16 and 32 subcarriers are chosen for simulations.

It is observed that more reduction is achieved in wider PU band than over narrow PU band. For instance, in 32 PU band case, we achieve a reduction of around 3 dB more than for 16 PU band case, for same number of iterations. This is attributed to the fact that for wider bands active subcarriers carrying data are more far from the center of the PU band and hence produce less OOBR at the center of the PU band. It is also observed that, mapping over two dimensions of the complex constellation offers more reduction (around 2-3 dB) than over single dimensions. This occurs due to more randomness achieved in mapping over both real & imaginary dimensions of the complex symbol. It is further observed that more OOBR reduction is achieved with the increase in number of iterations. However, the effect is more pronounced for lower range of iterations than over the higher range.

For two bit mapping, 180^o phase shift case gives appreciable increase of around 25-30 dB more than the carrier deactivation technique. This reduction is achieved using fixed mapping and thus saving the complexity involved in more number of iterations for single bit mapping. The increased performance of 180^o phase shift case, is attributed to the cancellation caused by adjacent out of phase symbols.

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