International Journal of
Scientific Engineering and Technology Research

ISSN 2319-8885
Vol.03,Issue.09,
May-2014,
Pages:1623-1627

www.semargroup.org,
www.ijsetr.com

A Survey of Side lobe Suppression Methods for Cognitive Radio Applications

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Abstract: Efficient pooling of the radio spectrum is achieved by using a cognitive radio (CR), which is a multi-band, spectrally agile radio that employs flexible communication techniques. Orthogonal frequency division multiplexing (OFDM) has proven to be the prime candidate for spectrum pooling based wireless transmission systems as it can achieve high data rate communications. The large side lobes resulting from the use of OFDM result in high out-of-band (OOB) radiation. In this context a survey of sidelobe suppression methodologies for cognitive radio is presented. Various aspects of sidelobe problem are studied from a cognitive radio perspective and an efficient suppression method is introduced. Challenges associated with sidelobes are given and enabling suppression methods are reviewed.

Keywords: Cognitive Radio, OFDM, Out Of Band Radiation, Sidelobe Suppression.

I. INTRODUCTION

The need for higher data rates is increasing as a result of the transition from voice-only communications to multimedia type applications. Given the limitations of the natural frequency spectrum, it becomes obvious that the current static frequency allocation schemes cannot accommodate the requirements of an increasing number of higher data rate devices. As a result, innovative techniques that can offer new ways of exploiting the available spectrum are needed. Cognitive radio arises to be a tempting solution to the spectral congestion problem by introducing opportunistic usage of the frequency bands that are not heavily occupied by licensed users [1]. Efficient pooling of the radio spectrum is achieved by using a cognitive radio, which is a multi-band, spectrally agile radio that employs flexible communication techniques and detects the presence of primary user transmissions over different spectral ranges to avoid interference to the licensed users.

According to a report of the United States Federal Communications Commission (FCC) [2], there are large temporal and geographic variations in the utilization of allocated spectrum ranging from 15% to 85%. It is then clear that the solution to the spectrum scarcity problem is dynamically looking for the spectrum”white spaces” and using them opportunistically. In this paper, we use the definition of cognitive radio adopted by Federal Communications Commission (FCC): “Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets.” [3].

In cognitive radio terminology, primary users can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, secondary users, which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user and to change the radio parameters to exploit the unused part of the spectrum. One approach to share spectrum between primary and secondary spectrum users is opportunistic spectrum access (OSA), in which secondary user is allowed to identify and exploit local and instantaneous spectrum white space where the prime user is not present. Since secondary users may need to transmit over noncontiguous frequency bands, OFDM is an attractive candidate for modulation in OSA networks.

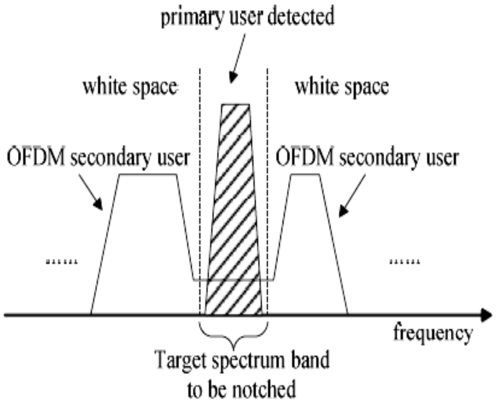

Fig.1. OFDM based OSA secondary user coexist with primary use.

In OFDM based OSA system, to enable coexistence with primary user, the constituent tones/subcarriers can be turned off at the prime user's channel, creating spectrum notches to limit interference perceived by primary user. The concept of the coexistence between an OFDM based OSA system and a primary user is illustrated in Fig.1. Orthogonal frequency division multiplexing (OFDM) has proven to be the prime candidate for spectrum pooling based wireless transmission systems as it can achieve high data rate communications, by collectively utilizing a number of orthogonally spaced frequency bands which are modulated by many slower data streams, and this division of the available spectrum into a number of orthogonal subcarriers makes the transmission system robust to multipath channel fading.

Furthermore, it is possible to turn off the subcarriers in the vicinity of the primary user transmissions, and thus the spectral white spaces can be filled up efficiently. Even though the secondary transmissions help in improving the spectral efficiency by transmitting in the spectral white spaces left unused by the primary users, the large side lobes resulting from the use of OFDM result in high out-of-band (OOB) radiation. Thus, the coexistence of the primary and the secondary users in the form of spectrum sharing is dependent on the suppression of the interference from the rental systems to the legacy systems. The basic idea is to improve the system performance of an OFDM-based cognitive radio by solving an important problem that makes the coexistence of the legacy and the rental systems a practical solution to the existing under-utilization of the radio spectrum.

A. System Operation and Cognitive Cycle

Figure2 gives the blocks of a CR system. The three fundamental tasks of the system are:

1. Spectrum Estimation: Gauge the radio spectrum scenario and perform radio scene analysis.

2. Channel State Estimation and Predictive Modeling: Accurate and timely channel state information (CSI) at the transmitter is important for accurate power control, prediction of channel capacity, and scheduling.

3. System Reconfiguration: based on the radio spectrum scenario and the channel state information, the system dynamically adapts transmission parameters such as power, spectrum, and modulation scheme and data rate.

The spectrum estimator senses the spectrum and detects the presence of interference regions and spectrum holes and the channel estimator gauges the channel to derive the channel state information. Based on this information the transmitter adapts one or more of the following: signal spectrum, modulation scheme, constellation size of code, data rate, and power. Consequently a pulse waveform that has little or no energy in the interference domains is constructed. The stream of data is modulated by the pulse waveform to obtain a transmission signal. The signal is then transmitted through the channel. At the receiver, the signal, corrupted by interference, is received and the data is detected using a suitable detector. Figure 2 illustrates the cognition cycle by which the system interacts with the environment and communicates.

B. Advantages of OFDM Based CR

1. OFDM is a multicarrier modulation technique that can overcome many problems that arise with high bit rate communications, the biggest of which is time dispersion.
2. The inter-symbol interference (ISI) is removed by extending the OFDM symbol with a cyclic prefix (CP). Using CP, OFDM reduces the dispersion effect of multipath channels encountered with high data rates and reduces the need for complex equalizers.
3. OFDM include high spectral efficiency.
4. Robustness against narrowband interference (NBI).
5. Removes Fading and Harmonic distortion.
6. Scalability and easy implementation using fast Fourier transform (FFT).
7. It is possible to allow the overlap of the individual subcarriers without leaving spectral guard bands, and still be able to avoid the adjacent subcarrier interference.
8. Faster transmission than FDM.
9. Bandwidth Efficiency.

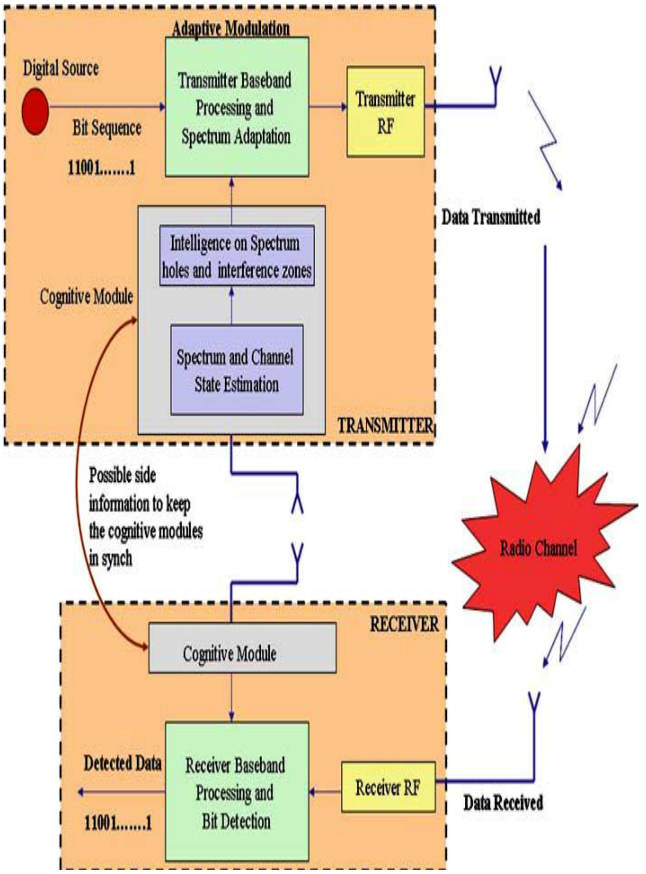

Fig2. System model of the Cognitive Radio transmitter, the major blocks include the spectrum and channel state estimator, adaptive pulse shaper (Transmission waveform shaping) and modulator. Receiver: The main components are the Signal base band processor and detector.

A summary of requirements and strength of OFDM in meeting them are presented in Table1 given below:

TABLE1: CR REQUIREMENTS AND STRENGTH OF OFDM

CR Requirements	OFDM's Strength
Spectrum sensing	Inherent FFT operation of OFDM eases spectrum sensing in frequency domain.
Efficient spectrum utilization	Waveform can easily be shaped by simply turning off some subcarriers where primary users exist.
Adaptation/Scalability	OFDM systems can be adapted to different transmission environments and available resources. Some adaptable parameters are FFT size, subcarrier spacing, CP size, modulation, coding, and subcarrier powers.
Advanced antenna techniques	Techniques such as multiple-input multiple-Output (MIMO) are commonly used with OFDM mainly because of the reduced equalizer complexity. OFDM also supports smart antennas.
Interoperability	With WLAN (IEEE 802.11), WMAN (IEEE 802.16). WRAN (IEEE 802.22), WPAN (IEEE 802.15.3a) all using OFDM as their physical layer techniques, interoperability becomes easier compared to other technologies.
Multiple accessing And spectral allocation	Support for multiuser access is already inherited in the system design by assigning groups of subcarriers to different users (i.e. orthogonal frequency division multiple access (OFDMA)).

II. SIDELOBE SUPPRESSION METHODS FOR COGNITIVE RADIO

Well-known techniques for sidelobe suppression are windowing the transmission signal in time domain [4] and the insertion of guard bands [5]. With the former method, the symbol duration is prolonged, where as with the latter the scarce spectral resources are wasted. Both methods reduce the system throughput and, in general, do not achieve sufficient side lobe suppression for overlay systems. Other proposed algorithms include the use of interference cancellation carriers (CC) [6], [7] and subcarrier weighting [8]. While CC technique can significantly suppress OFDM sidelobes, it results in an increase in the system peak-to-average-power ratio (PAPR) and the performance is sensitive to the cyclic prefix (CP) size. On the other hand, subcarrier weighting method causes an increase in the system bit error rate (BER), and the interference reduction is not as significant as it is with the CC method. Two optimal methods are proposed in [9] and [10]. The algorithm proposed in [9] spreads OF OM symbols in the time domain (A TS) to temper symbol changes but using this algorithm, the transmission rate reduction is high and the interference reduction is insignificant compared to the CC method. The proposed algorithm in [10] besides being too complex needs to know the channel coefficients between SU transmitter and PU receiver which is not a practical assumption. On the other hand, in the optimal scheme proposed in [10], the gain values achieved are data-dependent because even if the modulated data is of constant amplitude, as in the case of QPSK modulation, the phase of data symbols will affect the total interference when their interferences are adding up.

A. Filter-Based Approach

Filter-based approaches process signals in the time domain and aim at separating the SOI and interference signals based on their power-spectrum properties. The aim is to synthesize a filter that provides a desired frequency–response function, which enhances regions of the spectrum with high SINR and suppresses those with low SINR. An optimal (Wiener) filter can be derived when the power spectrum (covariance) of the SOI and interference are known. In case the covariance is unknown, adaptive filters can be used to adjust the weights of the filter. The filter-based approach, especially linear filter, is a matured technology that can be implemented with relatively low complexity. However, since it focuses only on the power spectrum of signals, it cannot suppress co channel interference or interference with similar waveforms. Also filters can increase the system complexity and introduce long delays. Therefore, applications of filter-based approach in IC for CR networks are limited.

B. Transform-Domain Approach

Transform-domain approaches first convert the received signal to the transform domain, remove certain transform components, and then use the inverse transform to synthesize the SOI. For example, an orthogonal frequency-division multiplexing (OFDM) CR receiver can process signals in the frequency domain and remove narrowband interference by excising the interfered sub bands. In practice, interference usually cannot be completely removed from the SOI using pure time- or frequency-based processing. Time–frequency analysis then provides a more powerful means for signal separation and classification. Time–frequency representations (TFRs) describe signals in the form of their joint time and frequency characteristics [8]. Widely used time–frequency analysis tools include the short-time Fourier transform (STFT), wavelet, and Chirplet. STFT introduces a time domain window into the Fourier transform and jointly examines the signal properties in both time and frequency domains.

The wavelet transform extends the STFT by applying different shapes of window functions in different frequency bands. Chirplet approaches analyze the time– frequency characteristics in a manner that its time–frequency atoms (Chirplet) are the rotated versions of STFT or wavelets in the time–frequency plane. TFRs are useful in separating signals with continuously varying frequency content, even when they have overlapping power spectrum. The transform-domain approach can be used to suppress co channel interference as long as the SOI and interfering signals have distinct components in the transform domain. A suppression gain of up to 20 dB has been demonstrated in certain OFDM applications. Moreover, only a medium computational load and low hardware complexity are required. The drawback of this approach is that it cannot be applied to cases where the interference has similar waveforms (i.e., same modulation and bandwidth) to the SOI. Nevertheless, in practice, CR can be designed to have dissimilar waveforms to the primary ones. Therefore, the transform-domain approach has great potentials in CR networks if combined with proper waveform design.

C. Active Interference cancellation

This technique based on frequency domain signal processing proposed as MB-OFDM (Multi Band OFDM) UWB (ultra wide band) system. Instead of turning off a large number of tones two special tones are defined at the edge of the interference band which sufficiently cancel the interference in that band. These two tones are known as the Active Interference Tones. The tone value can arbitrarily determined without affecting the information tones due to the orthogonality relationship. This technique can significantly suppress OFDM sidelobes, but it results in an increase in the system peak-to-average-power radio (PAPR), and the performance is sensitive to the cyclic prefix (CP) size. Moreover, due to the higher power used, using this technique affects the spectral flatness of the transmitted signal and can increase the inter-carrier interference (ICI) in case of a Doppler spread or a frequency offset error at the receiver.

D. Subcarrier Weighting Method

This technique, referred to as subcarrier weighting, is based on the multiplication of the used subcarriers with real-valued factors which are chosen such that the sidelobes are suppressed and no side information has to be transmitted. The real-valued subcarrier weights are determined in such a way that the side lobes of the transmission signal are minimized using an optimization algorithm which is capable to take several optimization constraints into account. A possible drawback of the subcarrier weighting method is degradation in bit-error rate (BER) versus signal-to-noise ratio (SNR) performance as, due to the weighting, the subcarriers do not receive equal amounts of transmission power. Also the interference reduction is not as significant as it is with the CC method.

E. Adaptive Symbol Transition (AST)

Similar to the windowing technique, the OFDM symbols are extended in time to reduce the effect of symbol transition. However, instead of using a predefined filter shape, the transition signal is optimized adaptively based on transmitted data and detected LU bands to reduce the interference to LU. In the AST technique suppresses OFDM sidelobes by extending OFDM symbols and using the extensions to smooth the transition between consecutive symbols. However, instead of using a predefined window shape (e.g., RC), we propose an adaptive method that calculates the value of the symbol extension based on LU center frequency and bandwidth.

F. Orthogonal Projection

This method uses signal pre-distortion for sidelobe suppression, and employs as few as one reserved subcarrier for recovering the distorted signal in the receiver. The use of orthogonal projection matrix leads to zero emission at some desired frequency points, while simultaneously suppressing emissions at neighboring frequencies. Using the reserved subcarriers, intersymbol interference (ISI) between data symbols introduced by pre-distortion matrix can be completely removed in the absence of noise.

III. COMPARISON OF VARIOUS SIDELOBE SUPPRESSION METHODS

The first method proposed for sidelobe suppression was filter method. The filter method is easy but complex as well as the suppression gain is not much effective hence the other method proposed as windowing the transmission signal in time domain and the insertion of guard bands. With the former method, the symbol duration is prolonged, where as with the latter the scarce spectral resources are wasted. Both methods reduce the system throughput and, in general, do not achieve sufficient side lobe suppression for overlay systems. Other proposed algorithms include the use of interference cancellation carriers (CC) and subcarrier weighting.

TABLE2: COMPARISON OF VARIOUS SUPPRESSION METHODS

	Filter	IC	SW	AST	OP
Suppression Gain	L	H	L	H	H
Hardware Complexity	H	H	H	L	L
Co Channel Interference	L	L	L	L	L
Channel Interference	L	L	L	L	L
PAPR Value	H	H	H	L,C	L
CP Size Dependency	N	Y	N	N	N

IC- Active Interference cancellation, L-LOW
SW- Subcarrier Weighting Method, H-HIGH
AST- Adaptive Symbol Transition, C-CONSTANT
OP- Orthogonal Projection, N-NONE, Y-YES

While CC technique can significantly suppress OFDM sidelobes, it results in an increase in the system peak-to-average-power ratio (PAPR) and the performance is sensitive to the cyclic prefix (CP) size. On the other hand, subcarrier weighting method causes an increase in the system bit error rate (BER), and the interference reduction is not as significant as it is with the CC method. Two optimal methods are proposed. The algorithm proposed in spreads OFDM symbols in the time domain (ATS) to temper symbol changes but using this algorithm, the transmission rate reduction is high and the interference reduction is insignificant compared to the CC method.

IV. USING HISTORY FOR PREDICTION

Modulated OFDM subcarriers suffer from high side lobes, which result in adjacent channel interference. We propose an adaptive optimal method that treats on OFDM signal in both time and frequency domains. By using this algorithm, it is possible to achieve a high value of side lobe suppression while the PAPR value of the transmitted signal is unchanged and the transmission rate reduction is lower than similar methods. It is similar to an adaptive symbol transition (AST) method, to suppress OFDM side lobes and shape the signal spectrum. Similar to the windowing technique, the OFDM symbols are extended in time to reduce the effect of symbol transition.

However, instead of using a predefined filter shape, the transition signal is optimized adaptively based on transmitted data and detected LU bands to reduce the interference to LU. In this context we will introduce a new adaptive optimal method to improve performance of CR. If there is an acceptable tolerance level to interference in the system then we are expected to design the system for both Power and Error. This proposed system is design to optimize power and error for an acceptable range to the interference in which the interference level would be optimized for a range in which the error and power levels will be in the minimized range.

V. CONCLUSION AND FUTURE SCOPE

In this context we will introduce a new adaptive optimal method to improve performance of CR. If there is an acceptable tolerance level to interference in the system then we are expected to design the system for both Power and Error. The new system can be optimized to power and error. The new adaptive method is expected not to increase the signal peak-to-average-power radio (PAPR) and keeps a low SNR loss. The new method is expected to reduce the interference further to less than −50 dB.

REFERENCES

[1] J. Mitola and G. Q. Maguire Jr., “Cognitive radio: making software radios more personal,” IEEE Personal Commun., vol. 6, no. 4, pp. 13–18, Aug.1999.

[2]Federal Communications Commission, “Spectrum policy task force report.” EE Docket No. 02-135, 2002.

[3] Federal Communications Commission, “Notice of proposed rulemaking and order: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies,” ET Docket No. 03-108, Feb. 2005.

[4] T. Weiss and F. Jondral, “Spectrum pooling: An innovative strategy for enhancement of spectrum efficiency,” IEEE Commun. Mag., vol. 42, pp. 8–14, Mar. 2004.

[5] IEEE, "802.lla standard, ISO/IEC 8802-11 : I 999/Amd I :2000(E), Highspeed Physical Layer in the 5 GHz Band, 1999.

[6] H. Yamaguchi, "Active interference cancellation technique for MBOFDM cognitive radio ," in Proc. IEEE European Microwave conf., vol. 2, pp. 1105-1108, Oct. 2004.

[7] S. Brands, I. Cosovic, M. Schnell, "Reduction of out-oi-band radiation in OFDM Systems by insertion of cancellatio carriers," IEEE commun. Lett, vol. 10, no. 6, pp. 420-422, June 2006.

[8] 1. Cosovic, S. Brandes, and M. Schnell, "Subcarrier weighting: a method for sidelobe suppression in OFDM systems," IEEE Commun. Lett., vol. 10, no. 6, pp. 444-446, June 2006.

[9] H. A. Mahmoud and H. Arsalan, "Sidelobe suppression in OFDM-based spectrum sharing systems using adaptive symbol trasision," IEEE Commun. Lett., vol. 12, no 2, pp. 133-135, February 2008.

[l0] G. Bansal, Md. Jahangir Hossain and V. K. Bhargava, "Optimal and suboptimal power allocation schems for OFDM-based cognitive radio systems," IEEE Transaction on Wireless Communications, vol. 7, no. II, pp. 4710-4717, Nov. 2008.

[11] Hisham A. Mahmoud, Tevfik Y¨ucek, and H¨useyin Arslan, “OFDM for Cognitive Radio: Merits and Challenges”, pp: 1-9.

[12] I. Cosovic and T. Mazzoni, “Suppression of sidelobes in OFDM systems by multiple choice sequences,” European Trans. Commun., vol. 1, 2006, pp. 623–630.

[13] Jian (Andrew) Zhang, Xiaojing Huang, , Antonio Cantoni, “Side lobe Suppression with Orthogonal Projection for Multicarrier Systems” paper accepted by IEEE Trans. On Communications in August 2011.

[14] H. A. Mahmoud and H. Arsalan, "Sidelobe suppression in OFDM-based spectrum sharing systems using adaptive symbol trasision," IEEE Commun. Lett., vol. 12, no 2, pp. 133-135, February 2008.

[15] T. Weiss, J. Hillenbrand, A. Krohn, and F. K. Jondral, “Mutual interference in OFDM-based spectrum pooling systems,” in Proc. IEEE Veh. Technol. Conf., vol. 4, May 2004, pp. 1873–1877.

[16] Negin Sokhandan ,Seyed Mostafa Safavi,“Sidelobe Suppression in OFDM-based Cognitive Radio Systems” published in 10th International Conference on Information Science, Signal Processing and their Applications (ISSPA 2010), IEEE2010.