Chapter 12
Compressive Spectrum Sensing:
Wavelet-Based Compressive Spectrum Sensing in Cognitive Radio

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ABSTRACT

In this chapter, the authors discuss how compressive sensing can be used in wideband spectrum sensing in cognitive radio systems. Compressive sensing helps decrease the complexity and processing time and allows for higher data rates to be used, since it makes it possible for the signal to be sampled at rates lower than the Nyquist rate and still be reconstructed with high accuracy. Different sparsifying bases for compressive sensing are presented in this chapter and their performance is compared. The design of these matrices is based on different types of wavelet transforms, including the discrete wavelet transform and the stationary wavelet transform; the latter having shown a clear improvement in performance over the former. The authors present different ways of implementing these transforms in a compressive sensing framework. Additionally, different types of reconstruction methods including the genetic algorithm and the auxiliary function method are also presented and their impact on the overall performance is discussed.

INTRODUCTION

The problem of spectrum scarcity has become of critical importance with the increase in the number of wideband communication systems. The main goal of cognitive radio is to efficiently utilize the spectrum by allowing unlicensed (secondary) users to opportunistically access licensed parts of the spectrum that are momentarily unoccupied by licensed (primary) users. In order to avoid interference with primary users, secondary users must sense the spectrum in order to determine which parts of the spectrum are

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unoccupied by primary users, these unoccupied frequency bands are called spectrum holes (Haykin, 2005; Ma & Juang, 2009). The goal of spectrum sensing is to identify these spectrum holes. Spectrum sensing methods have evolved from using tunable band pass filters to sense one narrowband frequency at a time to more efficient methods like wavelet edge detection and compressive sensing.

For narrowband systems, a tunable band pass filter (BPF) operating at a narrowband range can be used to sense the spectrum, one band at a time. For wideband systems, an early approach was to use a series of narrowband BPFs. In this case the filter range of each BPF is preset. However, this architecture requires a large number of components and therefore increases the cost and complexity of the system (Divakaran, Manikandan, & Hari, 2011; Polo, 2011). Another method is the windowed Fourier transform, otherwise known as the Short Time Fourier Transform (STFT). The Fourier transform gives time averaged values for the frequency components of the signal but does not provide information on the time of occurrence of these frequencies, but using the STFT, the signal is first divided into smaller time segments using a suitable window function, then the Fourier transform of each of these segments is obtained. Breaking the signal into smaller segments and identifying the frequency components of each time segment provides time resolution, however, it suffers low frequency resolution, high variance of estimated power spectrum as well as side lobes of large magnitude (Divakaran, Manikandan, & Hari, 2011; Merry & Steinbuch, 2005).

The periodogram is another method quite similar to the STFT, where the spectrum signal is truncated using a rectangular window function, and the spectral density plot is obtained by squaring the Fast Fourier Transform (FFT) of the truncated signal. This method suffers from spectral leakage and lack of time-frequency localization due to the truncation of the signals which results in a Dirichlet Kernel in the frequency domain (Haggstrom, 2016). To alleviate the shortcomings of the periodogram; multi-taper spectral estimation can be used as an alternative, since it reduces spectral leakage by using multiple orthogonal filters. Multi-taper refers to the method used for estimating power spectra using an orthogonal set of data tapers, such as Slepian sequences, which allow us to trade spectral resolution for reduced variance of the estimate without compromising its bias (Divakaran, Manikandan, & Hari, 2011; Wang & Zhang, 2009). However, this method involves excessive computations and cannot completely eliminate the spectral leakage problem while better methods can.

When the information of the primary user signal is known to the cognitive user, the optimal detector in stationary Gaussian noise is the matched filter, which maximizes the received signal-to-noise ratio (SNR); this is known as coherent detection. Such information includes the preamble, signaling information for synchronization, pilot patterns for channel estimation, and modulation orders of the transmitted signal. The matched filter method is fast and achieves optimum performance but its main disadvantage is its dependence on primary user information as well as hardware complexity. Moreover, in case of channel fading, time dispersion and Doppler shifts may affect synchronization and ultimately the performance of the matched filter (Bagwari & Singh, 2012; Divakaran, Manikandan, & Hari, 2011).

The cyclostationary features (or periodicity) of the signal can be exploited to determine the presence of primary users in a frequency band, this type of sensing is called cyclostationary feature detection. Almost any transmitted signal has periodic features as a result of being coupled with sinusoidal carriers for modulation, cyclic prefixes or repeated spreading code sequences, which have built-in periodicity (Bagwari & Singh, 2012). This periodic behavior can be observed in the mean, autocorrelation and other statistical features of the signal. Cyclostationary feature detection provides accurate information about the spectral occupancy even in high noise levels, but the location of the band edges cannot be precisely determined (Adoum & Jeoti, 2010; Divakaran, Manikandan, & Hari, 2011).

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