SPECTRUM OCCUPANCY DETECTION FOR COGNITIVE RADIOS USING WAVELET TRANSFORM ANALYSIS

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ABSTRACT

With the introduction of 2G and 3G services, wireless cellular networks around the world have experienced an exponential increase in service demand. This ever increasing demand seems to put more pressure on the limited radio spectrum in the coming years; as a consequence, spectrum policy makers and network operators are now seeking solutions for this apparent spectrum scarcity. Cognitive radios (CR) have been identified as one of the solutions to this problem and cognitive terminals are capable of sensing the neighboring environment, locating spectrum holes within a short period of time and opportunistically utilizing such frequency bands without causing harmful interference. Therefore, for CR deployment sensing and identification of spectrum holes to make communication is one of the main tasks. This paper examines the application of wavelet transform techniques assisting in identifying spectrum holes in non overlapping spectrum bands. Wavelets are used to identify the spectrum sub band edges on the basis of signal irregularities and power spectral density levels.

Key words: spectrum sensing, Cognitive Radio

1. INTRODUCTION

Cognitive Radios extend the functionality of software defined radios to adapt to its environment intelligently to achieve reliable communication using unoccupied licensed frequencies. Recent surveys have been indicated that less than two percent of the spectrum is used at a given point of time in the United States. Moreover, spectrum usage of the licensed frequency bands below 3 GHz has been shown an enormous variation in both time and space domains [1]. This variation provides cognitive radio terminals to opportunistically use such bands and combat apparent spectrum scarcity problem and eventually increase the overall spectral efficiency. To make use these opportunities, detecting such low occupancy bands within a short period of time is very crucial.

Detecting spectrum white spaces is generally done by sensing and analyzing transmitted signals. Several techniques including Fast Fourier Transform (FFT) [2], energy detection [3] and cyclostationary feature detection [4] have been developed for spectrum sensing. The most popular technique for waveform analysis is the Fourier Transform and it has been widely used to obtain the frequency spectrum of a signal. However, the Fourier Transform is only suitable for stationary signals, i.e., signals whose frequency content does not change with time. Moreover, the Fourier Transform tells how much of each frequency exists in the signal, but it does not tell at which time these frequency components occur.

Signals coming from cognitive terminals are non-stationary and they show different characteristics at different time or space. In order to analyze these signals, both frequency and time information are needed simultaneously. i.e., a time–frequency representation of the signals is needed. The wavelet transform addresses the above issue to a certain extend and it provides a low cost solution for detecting radio signals in both time and frequency domain.

As this process does not require a great deal of computation, data could be processed and analyzed quickly. As cognitive terminals need to quickly switch into different frequency bands during the operation, decision time is very vital and techniques which can rapidly detect spectrum opportunities will benefit for efficient operations.

This paper is organized as follows. Section 2 introduces wavelet transform followed by the proposed solution for wideband spectrum-hole detection in Section 3. Section 4 is focused on experimental results investigating the applicability of continuous wavelet transform technique in edge detection. Section 5 concludes the paper

2. WAVELET TRANSFORM: AN OVERVIEW

The wavelet transform (WT) has been found to be particularly useful for analyzing signals which can be described as an aperiodic, noisy, intermittent or transient and so on. Its ability to examine signals simultaneously in both time and frequency has expanded its application better than the traditional Short Time Fourier transforms (STFT).

Wavelet analysis uses a small wave like function known as a wavelet with finite energy. Wavelets are used to transform a signal under investigation into another representation which presents the signal information in more useful form. This transformation of the signal is known as the wavelet transform. The original wavelet function, known as a mother wavelet, is used to generate all the basis functions. A few commonly used wavelets are shown in Figure 1. Wavelets can be manipulated in two ways: it can be moved along the frequency axis to various locations (translation parameter) and also it can be stretched or squeezed, thus concentrating the energy (scaling factor). The wavelet transform is computed at various locations of the signal and for various scaling factors of the wavelet, thus filling up the transform plane: this is done in a smooth continuous fashion for the continuous wavelet transform or in discrete steps for the discrete wavelet transforms (DWT).

It is important to create a mother wavelet which provides an efficient and useful description of the signal of interest. It is not easy to do so, but based on several general characteristics of the wavelet functions it is possible to determine the most suitable wavelet for a specific application.

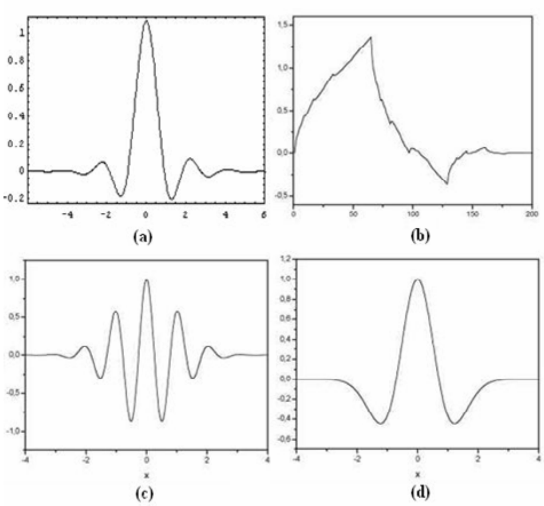

Figure 1: Some mother wavelets: (a) Coiflet wavelet (b) Daubechies wavelet (c) Morlet wavelet and (d) Mexican hat or Paul wavelet

3. WIDEBAND SPECTRUMHOLE DETECTION

The primary objective in spectrum sensing is to identify the frequency locations of non-overlapping spectrum sub bands and categorize them into white spaces where the power spectral density (PSD) level being low. White spaces are usually known as spectrum holes that need to be picked up by cognitive users for opportunistic use. From the cognitive radio point of view, identification of unoccupied frequency bands is more important than identifying detailed signals over the entire wideband.

In order to find opportunities, the entire wideband must be considered as a train of consecutive frequency sub bands, where the power spectral characteristics is smooth within each sub band but exhibits a discontinuous change between adjacent sub bands (Figure 2(a)). Such changes are irregularities in PSD, which carry key information on the locations and intensities of spectrum holes.

In [5], use of wavelet transforms to detect and estimate local irregular spectrum structures has been proposed and discussed. The signal spectrum over a wide frequency band can be decomposed into elementary building blocks of sub bands that are well characterized by local irregularities in frequency. In [5], 1st and 2nd order derivatives of the wavelet transforms of the PSD are used to identify local maxima and thus locating the frequency boundaries of each sub band.

Compared to [5], the proposed approach uses a one-dimensional wavelet transforms technique to detect rising and falling edges of the signals and thus locates the boundaries of each sub band where PSD is low. As this method does not require finding derivatives, the method is significantly faster.

3.1 Continuous Wavelet Transform

The continuous wavelet transform is an alternative approach to the Short Time Fourier Transforms (STFT) and it was developed in order to overcome the resolution problem. The wavelet analysis is done in a similar way to the STFT. More specifically, the signal is multiplied with a wavelet function and the transform is computed separately for different segments of the time. The main difference between the CWT and the STFT is that the width of the window is changed as the transform is computed for every single spectral component, which is probably the most significant characteristic of the wavelet transform [6]. The CWT can be defined by the following formula:

$$CWT_x^{\psi}(\tau,s) = \Psi_x^{\psi}(\tau,s) = \frac{1}{\sqrt{|s|}} \int x(t)\psi^*\left(\frac{t-\tau}{s}\right)dt \qquad (1)$$

Where, τ and s are translation and scale parameters respectively. $\psi(t)$ is the transforming function and also called the mother wavelet. According to [7] the transformed signal is a function of the variables τ and s.

3.2 Wavelet Edge Detection:

To explain the application of wavelet transform for edge detection, consider an example of a discontinuity shown in Figure 2(a), where a constant signal $x(t) = 1$, suddenly drops to a constant negative value, $x(t) = -1$. To examine how the wavelet identifies such a discontinuity, a sliding wavelet window is considered at three different locations namely A, B and C. The selected Mexican hat mother wavelet consists of two negative lobes and one positive lobe.

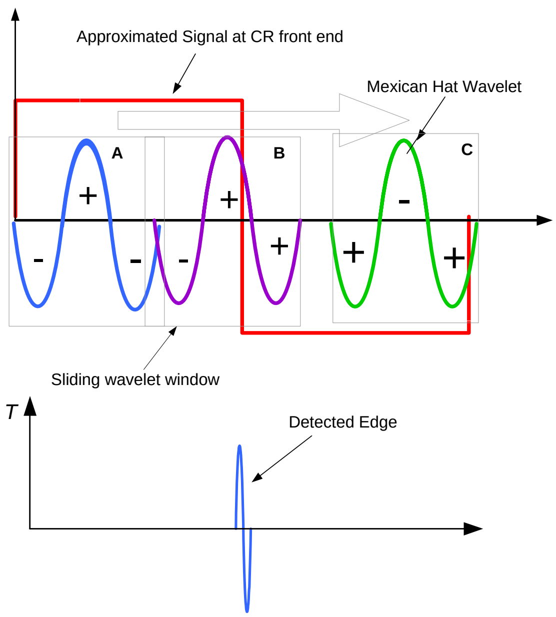

Figure 2: A schematic illustrations of the wavelet integration of a signal discontinuity

At location A, as the detected signal is positive within the window and also the front and end lobes of the wavelet are out of phase with the signal. The contribution to the transform integral (T) is negative. The middle lobe of the wavelet is in phase with the signal and therefore the contribution is positive. Therefore, the positive and negative contributions act to cancel out each other resulting in a valley near to zero.

At location B, the wavelet is just beginning to traverse the discontinuity. The left-hand lobe of the wavelet produces a negative contribution to the integral. The right-hand lobe of the wavelet produces an equal positive contribution, leaving the central hump of the wavelet to produce a significant positive value for the integral at this location. At location C, again the contribution for the integral is zero. Examining the transform integral, it can be seen that at the falling edge of a signal produces an impulse whose sign changes from positive to negative. Similarly, at a rising edge, it produces a similar impulse whose sign changes from negative to positive.

4. EXPERIMENTAL RESULTS

In this work, the one dimensional continuous Wavelets in the MATLA Toolbox© were used to obtain the wavelet transform. Two signals shown as in Figure 3(a) and 4(a) are used to investigate the applicability of wavelet transform for spectrum hole detection The first signal (Figure 3(a)) has a band range of [1000, 1200] Mhz.

The signal consist of five bands (B_1, B_3, B_5, B_7 and B_9) which shows high PSD and four bands (B_2, B_4, B_6, B_8) in which the signal shows low PSD close to noise floor level. Figure 3(b) displays the wavelet transforms obtained using Harr mother wavelet at scale factors equals to 2^4. It can be clearly seen from the Figure 3(b) that, for every rising edge the transform produces a negative impulse and furthermore for every falling edge it produces a positive impulse. Scanning the integral plot from left to right, the spectrum band between two consecutive pluses, in which their signs change from positive to negative, identifies as a spectrum white space (SW). Figure 4(a) displays another signal with a number of discontinuities in the frequency band of [500,700] MHz. Mexican hat wavelet was used for the transform and the obtained integral plot is shown in Figure 4(b). Here, the impulses generated for the discontinuities are relatively small than that generated with Harr wavelet, indicating that the performance is significantly depends on the selected mother wavelet.

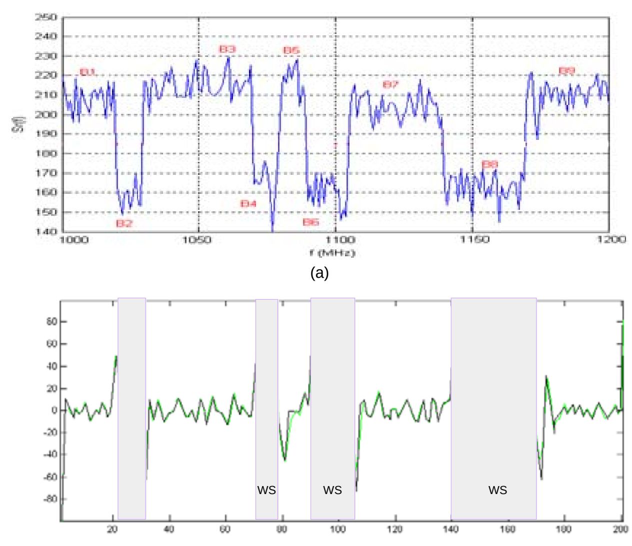

Figure 3: (a) Actual signal PSD, (b) Harr wavelet transforms at scale 2^4.

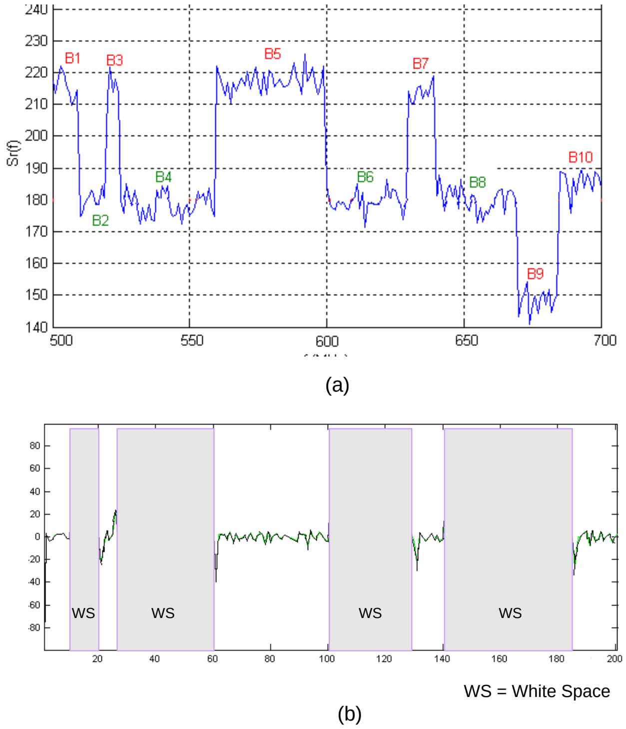

Figure 4: (a) Actual signal PSD, (b) Mexican hat wavelet transform at scale 2^4

5. CONCLUTIONS

This paper exploits the application of wavelet transform techniques to identify the frequency locations of non overlapping spectrum bands based on signal irregularities and power spectral density level of transmitting signals. Two signals consisting several spectral opportunities are considered to investigate the applicability of wavelet edge detection. Harr and Mexican hat wavelet families are used for the transformation with different scale factors. It can be seen that Harr wavelet displays high amplitude impulse than Mexican hat, clearly identifying the signal discontinuities of the observed signals. In real world situations, actual signals appearing at CR terminals tend fluctuate over the time and in such cases, a probabilistic model must be used for the detection of spectrum holes. Currently, the developed model only supports static signals which are generated off line. Extending the current model to handle real signals has already been initiated.

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