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Spectrum Sensing Using Time-Frequency Analysis

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ABSTRACT

To exploit limited spectrum efficiently CR technology allows unlicensed users to access licensed spectrum bands. Since licensed users have priorities to use the bands, the unlicensed users need to continuously monitor the licensed user's activities to avoid interference and collisions. To obtain reliable results of the licensed user's activities is the main task for spectrum sensing. Based on the sensing results the unlicensed users should adapt their transmit powers and access strategies to protect the licensed communications. This paper presents a new spectrum sensing method based on Time-Frequency Analysis. Several realistic signals are taken under different noisy conditions for analysis using Frequency Slice Wavelet Transform (FSWT) to verify its superiority in spectrum sensing.

I. Introduction

The issue of spectrum underutilization in wireless communication can be solved in a better way using Cognitive Radio (CR) technology. Cognitive radios are designed in order to provide highly reliable communication for all users of the network, wherever and whenever needed and to facilitate effective utilization of the radio spectrum. Cognitive radios have the potential to jump in and out of unused spectrum gaps to increase spectrum efficiency and provide wideband services. In some locations and/or at some times of the day, 70 percent of the allocated spectrum may be sitting idle. The FCC has recently recommended that significantly greater spectral efficiency could be realized by deploying wireless devices that can coexist with the licensed users.

The Federal Communications Commission (FCC) is responsible for regulation of interstate telecommunication, management and licensing of electromagnetic spectrum within the United States and it enforces requirements on inter station interference in all radio frequency bands. They license segments to particular user's in particular geographic areas. A few, small, unlicensed bands were left open for anyone to use as long as they followed certain power regulations. With the recent boom in personal wireless technologies, these unlicensed bands have become crowded with everything from wireless networks to digital cordless phones.

The traditional techniques use a particular wavelet function for the problem of edge detection as explained in [1], followed by energy detection or periodicity detection [2], [3]. But a single wavelet function vastly. Hence an adaptive algorithm for analyzing the spectral characteristics and choosing the optimum wavelet function for better edge detecting capability is proposed in this paper. For the regions in the PSD which has sharp and pointed peaks, Haar wavelet function is utilized and for the regions in the PSD which shows gradual variations in the peaks, Gaussian wavelet function is utilized. By obtaining the continuous wavelet transform of the spectrum's PSD using the multi-scale versions of the chosen wavelet, edge detection is achieved by noting the local extrema of the modulus first derivative of the smoothed signal. This method of adapting to the slope characteristics of the PSD data has proven to yield better edge detection and thus to estimation of spectral boundaries with a greater resolution. By calculating the energy of the obtained sub-bands, precise information on spectral occupancy is ascertained. This paper proposes an adaptive wavelet based edge detection technique as a modification to the traditional Spectral Sensing techniques proposed in [4], [5].Simulated FM spectrum is used to test the performance of this approach.

Based on the motivations, this paper presents a new automatic modulation recognition method using time-frequency analysis called Frequency Slice Wavelet Transform. Time–frequency tools have been successfully used in dealing with analysis of non-stationary signals[6-8] The FSWT is an extension of the Short Time Fourier Transform in frequency domain and it allows a signal to be analyzed in terms of both time and frequency simultaneously. The rest of the paper is organized as follows. Section 2 briefs the Traditional Spectrum Sensing methods that were in use prior to Time-Frequency Analysis. In Section 3 the proposed technique is explained in detail. This is followed by simulation results of spectrum sensing using TFA. Finally, Section 5 contains the summary of the paper.

II. Spectrum Sensing Methods

Spectrum sensing is essentially a case of energy detection, where the presence or absence of meaningful data at a particular frequency band is to be found out. Presence of data implies an increase in Energy from the noise floor, or the presence of some noise-like signal with higher order

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periodicity. Traditional approaches operate in narrowband and consist of a series of FIR filters which are tuned for the particular frequency range. While this approach is good enough for narrow bandwidths, it is found inefficient when the dynamic range of operation of Cognitive Radios increases. For ultra-Wideband Cognitive radio systems, this approach has very high complexity. However, to understand the features of Wavelet based algorithms, it is suggested that the reader has first-hand knowledge on the traditional methods, so that the discussion is directed only towards those aspects of Spectrum Sensing which are not achieved using these methods.

A. Periodogram

The Periodogram was one of the most commonly used Spectrum Sensing techniques until better methods were developed to replace it. In this method, the infinite length sequence is truncated using a rectangular window function, and the FFT is obtained. Square of FFT gives an approximate Spectral Density plot. The major issue with this method is because of the abrupt truncation of the signals. As explained in [9],[10] this results in a Dirichlet Kernel in the frequency domain, described by the width of main lobe and side lobes. This in turn leads to spectral leakage at the discontinuities. Also, this method failed to provide time-frequency localization.

B. Matched Filter Approach

This is a pilot detection method. This is the fastest approach for spectrum sensing, but fails because of the fact that prior knowledge about the primary user's modulation type, pulse shaping and packet format is required. Timing and synchronization is essential to achieve coherence. But due to channel fading effects, there is a chance for time dispersion and Doppler shifts which ultimately affect synchronization. There is much literature available in [11] regarding the implementation of matched filters.

C. Cyclo-stationary Feature Detection

Any type of observable periodicity can be considered as first order periodicity. In the transmitted data, because of the modulation techniques or due to source coding, a certain periodicity is added to the signal which can be observed only through non-linear time invariant transformations of the time series [12]. This type of second order periodicity is called cyclostationarity. Generally the mean, autocorrelation and other statistical features show periodic behaviour. This can be exploited to determine the presence or absence of data in a frequency band. The advantage is that, this is the only method which provides accurate information about spectral occupancy in very low SNR bands. However the boundaries cannot be accurately determined. Hence this technique combined with boundary detection is often used for developing algorithms. A detailed treatment about computing the Cyclic Spectrum Density is available in [13].

III. Frequency Slice Wavelet Transform

A. Mathematical Model of FSWT

Suppose $\hat{h}(\omega)$ is the Fourier transformation of the function $h(t)$, for a signal $p(t)$ the frequency slice wavelet transform (FSWT) is defined in the frequency domain as

$$F_f(t,\omega,\sigma)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\hat{p}(v)\hat{h}^*((v-\omega)/\sigma)e^{jvt}dv \tag{1}$$

Where $\hat{h}(\omega)$ is called frequency slice function (FSF) and the scale σ is a constant or a function of ω, t, and v. The'*'means the conjugate of the function. Here ω and t are the observed frequency and time, v is the assured frequency. From the above equation we can say that FSWT is another extension of the STFT in the frequency domain.

On the contrast between FSWT and CWT in equation (1) can be rewritten as

$$F_f(t,\omega,\sigma)=\frac{1}{2\pi}e^{j\omega t}\int_{-\infty}^{\infty}\hat{p}(v+\omega)\hat{h}^*(\frac{v}{\sigma})e^{jvt}dv \tag{2}$$

In frequency slice wavelet transform we always consider even functions as frequency slice functions.

For example if

$\hat{h}(\omega)=e^{-1/2\omega^2}$

then the equation (14) becomes

$$F_f(t,\omega,\sigma)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\hat{p}(v)e^{-\frac{1}{2}(\frac{v-\omega}{\sigma})^2}e^{jvt}dv \tag{3}$$

where σ is a constant or function of ω or v or both.

If σ = $\frac{\omega}{k}$ then above equation can be rewritten as

$$F_f(t,\omega,\sigma)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\hat{p}(v)e^{-\frac{1}{2}(k.\frac{v-\omega}{\omega})^2}e^{jvt}dv \tag{4}$$

where k is a constant it is consider according to the frequency resolution ratio (η_h) of the FSF.

The frequency resolution ratio of a FSF is given by

$$\eta_h=\frac{half-widthoffreqwindow}{centrefrequcy} \tag{5}$$

The value of 'k' is given by

$$k=\frac{\Delta\eta_h}{\eta_h} \tag{6}$$

where $\Delta\eta_h$ is the bandwidth of FSF.

B. Computational steps of FSWT

i.Calculate the forward Fourier transform of the signal using the FFT function.

ii.Generate the Fourier transform of the frequency slice function.

iii.Shift the spectrum of the FSF along the entire signal spectrum of the signal.

iv.Multiply the complex conjugate of the shifted FSF spectrum with the corresponding signal spectrum.

v.Calculate the inverse Fourier transform using IFFT function.

vi.Calculate the amplitude of the resulting complex signal

IV. Simulation Results

For Spectrum sensing we consider the channel having four users operating at different carrier frequencies. The frequencies of four users U_1, U_2, U_3, and U_4 are 150 KHz, 250 KHz, 350 KHz, and 450 KHz respectively.

Table 1. The parameters of Wide Band Signal.

S. No.	Signal Parts	User information (U)
1	S1	U_1, U_2, U_3, U_4
2	S2	U_2, U_4
3	S3	U_1, U_3
4	S4	U_2, U_3, U_4
5	S5	U_1, U_2, U_4

Fig. 1-3 show the time-frequency contours of wideband signal with FSWT under different noise conditions, and these contours clearly represents the absence or present of the user. Fig. 1 (a) shows the typical wideband signal. Fig. 1(b) gives the normalized time-frequency contour from FSWT.

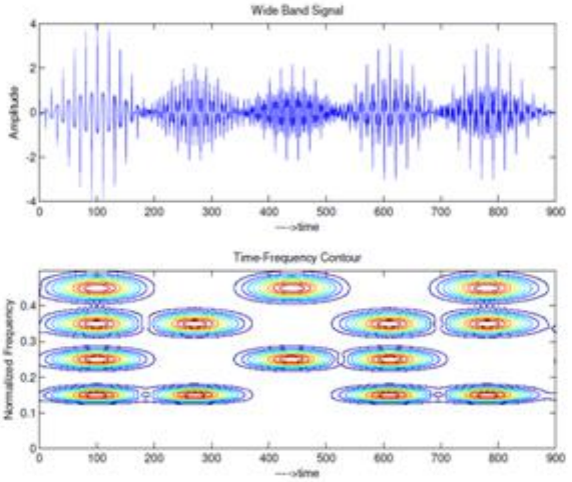

Figure 1. Analysis of Wideband Signal without Noise.

Fig. 2(b) gives the information about the users information. At the first time interval all the four primary users are present in the channel. But at the second time interval second and fourth users are absent where as first and third users are present. Similarly at different instances the absence of primary user is represented with black spots.

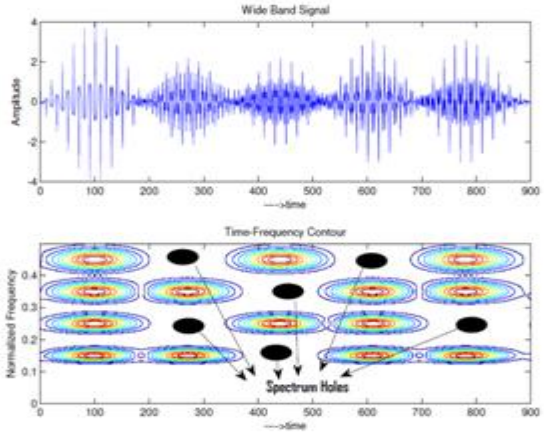

Figure 2. Spectrum Holes at different instants of Time.

Fig. 3 gives the information about the energy of each user. This clearly shows where the energy is present where it is absent. So it clearly visualizes the presence/absence of the primary user. The red color points where the energy is maximum.

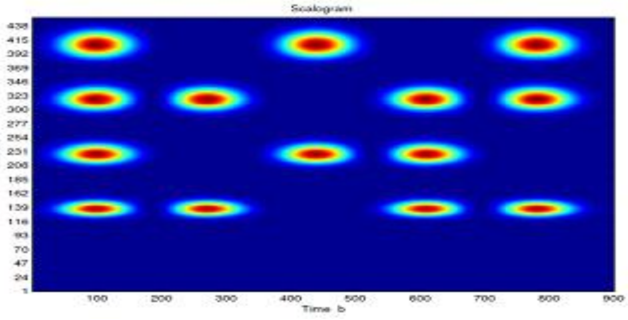

Figure 3. Scalogram of Wideband Signal.

All the existing spectrum sensing techniques are narrowband spectrum sensing techniques. They take only one user information at a time and finds whether the user is present or not. For parallel search we need parallel banks it leads to increase in the circuit complexity. So this proposed method suitable for wideband spectrum sensing and the circuit complexity of proposed method is very low in terms of mathematical calculations.

V. Conclusion

This paper has proposed a new approach for spectrum sensing using time-frequency analysis. The Frequency Slice Wavelet Transform (FSWT) with a variable window (Gaussian window) as a function of signal frequency is used to generate Time-Frequency contours which were better localized than Wavelet Transform. In future this method can be widely applied to image processing, Radar signal detection and classification and seismic signal processing.

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