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WIDEBAND SPECTRUM SENSING FOR COGNITIVE RADIO NETWORKS USING TIME-FREQUENCY ANALYSIS

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Abstract: In the existing spectrum framework, majority of the spectrum bands are entirely allocated to specific licensed services. In TV broadcasting Most of licensed bands are unused; this leads to wastage of spectrum. With Cognitive Radio (CR) technology, Federal Communications Commission (FCC) offers these unused licensed bands to unlicensed users. Cognitive Radio can efficiently deal with the rising demand and shortage of the wireless spectrum. To utilize spectrum effectively, CR permit secondary users to use licensed users spectrum bands based on spectrum sensing results. This paper presents a new wideband spectrum sensing method based on Time-Frequency Analysis. Several realistic signals are taken under different noisy conditions for analysis using Modified S-Transform (MST) to verify its superiority in spectrum sensing.

Key Words: *Narrowband Spectrum Sensing, Wideband Spectrum Sensing, Wavelet Transform, Energy Detection, Time-Frequency Analysis, Composite Signal, primary User (PU), Secondary User (SU)*

I. INTRODUCTION

The main aim of Cognitive Radio is efficient utilization of the offered radio spectrum. The available spectrum is limited and getting busy gradually due to drastic raise in wireless communication applications. It has founded that the offered radio spectrum is not utilized efficiently due to fixed allotment of the available spectrum. Every wireless service provider has a special license to use a fixed frequency band. Majority of the useful spectrum allocated to specific users and it is very hard to find unoccupied bands to set up latest services or to improve existing services. To avoid this problem, Cognitive Radio creates opportunity for dynamic spectrum access. Cognitive Radios developed to offer more reliable and communication for all users of the network and to take an action for efficient utilization of the existing radio spectrum [1, 2].

A CR network is a new thinking of wireless communication to resolve the radio spectrum allocation problem [3]. Spectrum sensing is the most important part of the cognitive radio. It involves spectral detection, channel estimation and channel state prediction [4, 5]. A huge research is going in spectrum sensing for CR network [5, 6]. The spectrum sensing techniques are classified in different ways, based on primary user's data available and sensing capability. If primary user's data is available for sensing then the techniques are called as cooperative spectrum sensing techniques, e.g. matched filter detection, energy based detection, feature based detection. If primary user's data is not available then techniques are called non-cooperative spectrum sensing techniques, e.g. wavelet-based frequency detection. Among the all the spectrum sensing techniques most of the detection techniques are consider under cooperative spectrum sensing techniques[7-9], because they need perfect knowledge of the primary users. In other way the sensing techniques can be categorized as narrowband and wideband spectrum sensing techniques. In a

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narrowband sensing methods only one primary user is consider at a time and apply the technique for identifying the presence of user. For wideband sensing a parallel filter banks and detectors are needed.

If SU has a priori awareness about licensed user information then matched filter based detection is consider. The main advantages of this method is it needs a short time to achieve a certain probability of detection, high processing gain. The limitations of this method are it needs perfect prior knowledge of PU signaling information such as modulation type, frequency used and bandwidth. This method has very high power consumption due to a large receiver algorithms are needs to be executed for spectrum whole identification. This method is feasible only when licensed users are cooperative. There are some other methods for detecting PU by verifying the cyclostationarity features of the received signal. These features are exist in signal due to the periodic nature of the signal or due to its statistical features. The computational complexity of this method is high and also it requires significantly longer observation time. The performance of this method will degrade due to the poor estimate of the cyclic spectral density when an insufficient number of samples are considered for detection. Energy detection uses energy detector to find the existence or absence of signal in the band [9]. In this threshold consideration for detecting primary users is a very challenging task. Its performance is poor under low SNR. There are other sensing techniques which use wavelet transform for wideband sensing and to reduce computational complexity [10-13]. In Wavelet based spectrum analysis, the characteristics of mother wavelet function significantly affect the performance of sensing.

Based on the motivations, this paper presents a new wideband spectrum sensing method using Time-Frequency Analysis technique to reduce complexity and false alarm. Time–Frequency analysis have been used in dealing with all practical wideband signals. The Modified S-Transform [MST] allows a signal to be analyzed in time and frequency simultaneously [14-16]. We propose an approach based on time-frequency analysis to estimate different frequency components time to time from the received data for wideband sensing.

This paper is organized as follows. Section II describes our proposed method time-frequency analysis using Modified S-Transform. Simulation results of spectrum sensing under different noisy conditions using MST presented in Section III. Conclusion and remarks are presented in Section IV.

II. PROPOSED ALGORITHM

Time–Frequency analysis have been successfully used in dealing with wideband signals. The Modified S-Transform [MST] allows a signal to be analyzed in time and frequency simultaneously. We propose an approach based on time-frequency analysis to estimate different frequency components time to time from the received data for wideband sensing.

2.1 S-Transform

If h(t) is a time series then its S-Transform is given by [14, 15]

$$S(f,\tau,\sigma) = \int_{-\infty}^{\infty} h(t)g(t-\tau)e^{-i2\pi ft}\,dt \tag{1}$$

Here *g(t)* is the Gaussian windowing function and σ represents window width.

Let

$$p_1(t,f) = h(t)e^{-i2\pi ft} \tag{2}$$

Therefore,

$$\begin{aligned} S(f,t,\sigma) &= \int_{-\infty}^{\infty} p_1\,(t,f).\,g(t-\tau)dt \\ &= p_1(t,f) * g(t,\sigma) \end{aligned} \tag{3}$$

Here * denote convolution

If $S(f, \tau, \sigma)$ and $B(f, \alpha, \sigma)$ are Fourier Transform pair then

$$S(f,\tau,\sigma) = \int_{-\infty}^{\infty} B(f,\alpha,\sigma)\, e^{-i2\pi\alpha\tau}\, d\alpha \quad (4)$$

From convolution theorem,

$$\{p_1(t,f) * g(t,\sigma) \leftrightarrow \int_{-\infty}^{\infty} p_1(f,\alpha) e^{-2\pi\alpha t}\, d\alpha$$

Where $p_1(f,t) = h(t).e^{-i2\pi f t}$

The frequency domain representation of $P_1(f, t)$is

$$p_1(f,\alpha) = H(\alpha) * \delta(\alpha - f) \quad (5)$$

The FT of $S(f, \tau, \sigma)$ is given as

$$B(f,\alpha,\sigma) = [H(\alpha) * \delta(\alpha - f)].G(\alpha,\sigma) \quad (6)$$

Substitute equation (6) in equation (4) then

$$S(f,\tau,\sigma) = \int_{-\infty}^{\infty} \{[H(\alpha) * \delta(\alpha - f)].G(\alpha,\sigma)\} e^{-i2\pi\alpha\tau}\, d\alpha$$

$$B(f,\alpha,\sigma) = \int_{-\infty}^{\infty} S(f,\tau,\sigma)\, e^{i2\pi\alpha\tau}\, d\tau$$

$$B(f,\alpha,\sigma) = [H(\alpha) * \delta(\alpha - f)].G(\alpha,\sigma)$$

$$[H(\alpha) * \delta(\alpha - f)] = \frac{B(f,\alpha,\sigma)}{G(\alpha,\sigma)}$$

Since *LHS* term is the forward translation of $H(\alpha)$.

Recover $H(\alpha)$ from the above equation is

$$H(\alpha) * \delta(\alpha - f) = H(\alpha - f)$$

$$H(\alpha - f) = \frac{B(f,\alpha,\sigma)}{G(\alpha,\sigma)}$$

$$H(\alpha - f) * \delta(\alpha, f) = \left[\frac{B(f,\alpha,\sigma)}{G(\alpha,\sigma)}\right] * \delta(\alpha + f)$$

$$H(\alpha) = \frac{B(f,\alpha + f,\sigma)}{G(\alpha + f,\sigma)}$$

Hence $S(f, \tau, \sigma)$ is the Stockwell transform of $h(t)$ at $t = \tau$.

Here σ represents the width of the window $g(t)$.

In general the standard deviation σ (f) of the Gaussian window 'g' of the standard S-transform in equation (1) is

$$\sigma(f) = 1/|f| \quad (7)$$

Thus the window g(t) is

$$g(t,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-t^2}{2\sigma^2}} \quad (8)$$

With $\sigma(f) = 1/|f|$ becomes

$$g(t,\sigma) = \frac{f}{\sqrt{2\pi}\sigma} e^{\frac{-t^2 f^2}{2}} \quad (9)$$

and

$$G(\alpha, f) = e^{\frac{-2\pi^2\alpha^2}{f^2}} \quad (10)$$

B. Reformulated S-Transform

For analysis of the signal with different resolutions in our work we consider the standard deviation *σ (f)* to be [16]

$$\sigma(f) = k/(a + b\sqrt{|f|}) \quad (11)$$

Here a, b are constants, and the value of k must satisfy the condition $k \le \sqrt{a^2 + b^2}$. Thus, modified Gaussian is extending of the original Gaussian window and is being varied with frequency. The modified version of the window is given by

$$w(t, f) = \frac{a + b\sqrt{|f|}}{k\sqrt{2\pi}} e^{-\frac{(a+b\sqrt{f})^2 t^2}{2k^2}}, k > 0 \quad (12)$$

Here t, τ are the time variables and scaling factors *k, b* can be manage the number of oscillations in the window. By increasing *k*, the window expands in time domain which leads to increasing the frequency resolution in frequency domain. When *b=0* and *k=1* we can get the STFT.

With modified Gaussian window the generalized S- transform can be rewritten as

$$S(\tau, f) = \int_{-\infty}^{\infty} Y(\alpha + f) e^{(-2\pi^2\alpha^2K^2)/(a+b\sqrt{|f|})^2} e^{2i\pi\alpha\tau} d\alpha \quad (13)$$

For discrete time signal the discrete version of the S-Transform can be written as

$$S[j, n] = \sum_{m=0}^{N-1} Y[m + n] e^{(-2\pi^2 m^2 K^2 /(a+b\sqrt{|f|}^2))} e^{i\frac{2\pi mj}{N}} \quad (14)$$

Where *Y[m + n]* is shifted in time with the amount of ‘n’ of the $Y[m]$.

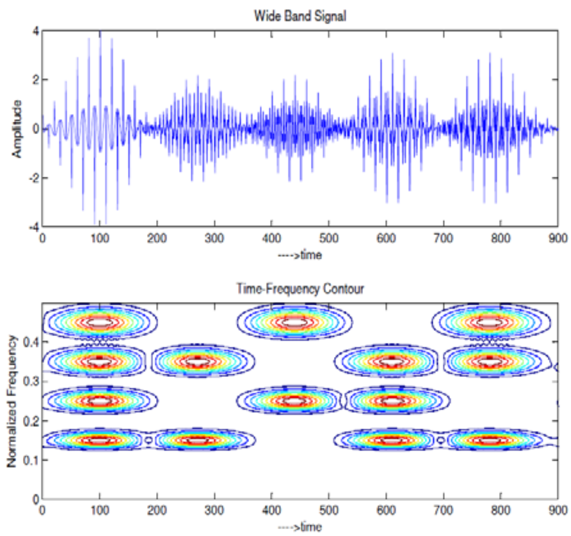
III. EXPERIMENT AND RESULT

To illustrate the interesting features of the proposed technique, an input wideband signal x(t) shown in Fig. 1 is employed. It consists of five active parts. Summary of x(t) activities is given in Table I. The wideband signal x(t) consists of five independent signals each signal present for short duration of time.

Table I The parameters of Wideband Signal

Active Part	Signal Component	Frequency Components f (10^7) Hz	Signal Delay (10^2)
1	S1	15, 25, 35 & 45	1
2	S2	15 & 35	2.7
3	S3	25 & 45	4.4
4	S4	15, 25 & 35	6.1
5	S5	15, 35 & 45	7.8

In this example we consider the channel has four primary users and the carrier frequencies of these four users are 150, 250,350 and 450 MHz's. Here we designed a signal with five different time slots, at each slot some primary users are present and some are absent.



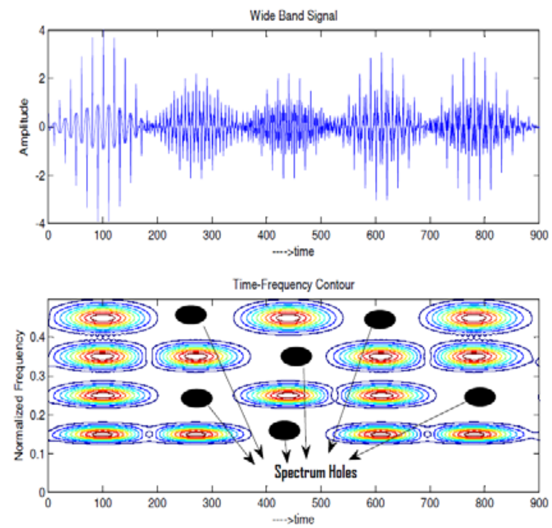


Figure 1. Analysis of Wideband Signal without Noise **Figure 2. Spectrum Holes at different instants of Time**

Fig. 1-6 show the time-frequency contours of wideband signal with MST 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 MST.

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.

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.

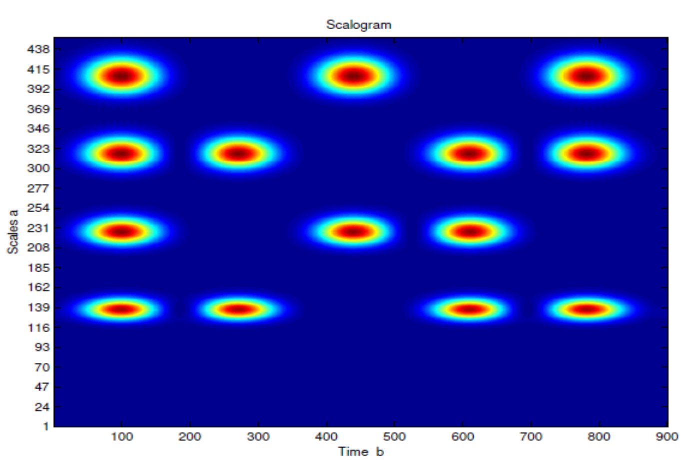
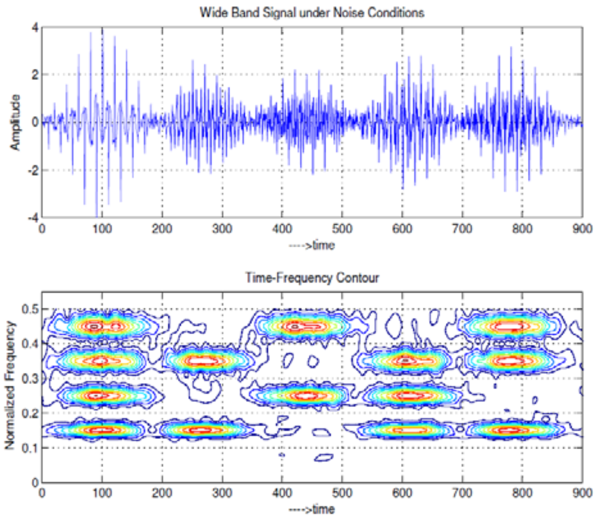


Figure 3. Scalogram of Wideband Signal

Fig. 4-7 shows spectrum sensing at different noise conditions. From this analysis it clearly shows that the proposed method clearly sensing the channel even at 0 dB noise condition.



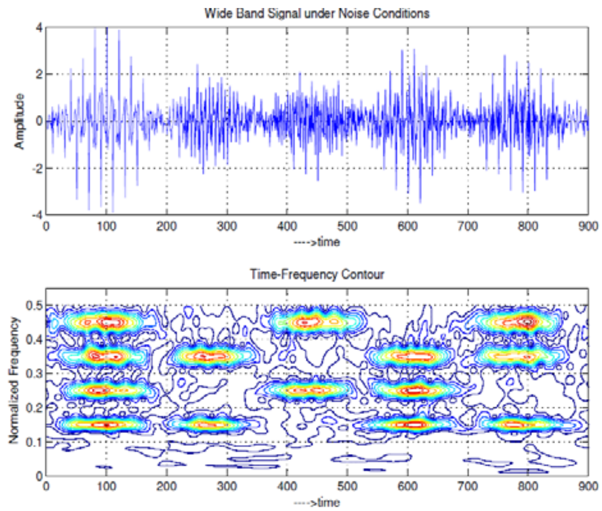
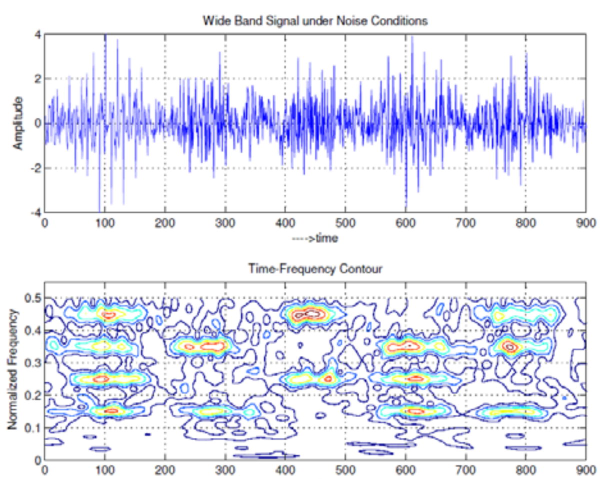


Figure 4. Spectrum Sensing at 10 dB Noise **Figure 5. Spectrum Sensing at 5 dB Noise**

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.



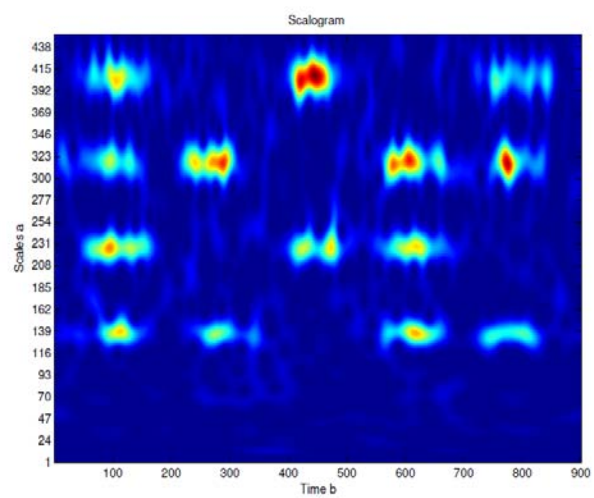


Figure 6. Spectrum sensing at 0 dB Noise **Figure 7. Scalogram at 0 dB Noise**

IV. CONCLUSION

This paper presents a new approach for wide band spectrum sensing in cognitive networks. This work introduced a new spectrum sensing algorithm called Time-Frequency Analysis using modified S-Transform. All the exciting methods for spectrum sensing are applicable only for narrowband sensing. But the proposed works proved, wideband sensing is possible with Time-Frequency Analysis. Under the noisy environment all the existing methods gave more false alarms. The proposed method gives the best results even under high noisy conditions.

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