Spectral Correlation Based Signal Detection Method for Spectrum Sensing in IEEE 802.22 WRAN Systems

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***Abstract* — In this paper, signal detection methods for spectrum sensing in IEEE 802.22 wireless RAN systems are discussed. As most of the manmade signals can be treated as cyclostationary random process, the spectral correlation function is effective for detecting of these signals. In WRAN systems, due to the specific detection environment, the computational complexity of the spectral correlation based method is significantly reduced. Peak detection in the high SNR environment together with contour figure based unique patterns search method in the low SNR environment are proposed for the primary user signal detection.**

***Keywords* — Cyclostationary, spectral correlation function, spectrum sensing, cognitive radio, IEEE 802.22 wireless RAN.**

1. Introduction

Nowadays, as the technology development, our limited spectral resources has been used sufficiently, especially the frequencies below 3GHz. But not all of them are used efficiently. In fact, a certain number of frequency bands are underutilized in spectacularly times and locations. This point of view is supported by recent studies of the FCC's (Federal Communication Commission) Spectrum Policy Task Force who reported vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15% to 85% [1]. In order to overcome this kind of problems, the IEEE is planning to establish an international standard, called IEEE 802.22 Wireless RAN to utilize the idle spectral bands of TV user, which is between 54MHz and 862 MHz.

One of the new features of WRAN systems is the implementation of CR (cognitive radio) technique. The fundamental of CR is spectrum sensing, whose function is to detect the current spectrum environment and to find the empty frequency bands. The frequency band here is defined as the band of TV signal whose bandwidth is 6MHz for ATSC DTV system. In the operating band of WRAN systems, there is another kind of primary user, which is wireless microphone user with 200 KHz signal bandwidth. In order to detect these two signals, we propose to use the spectral correlation based detection method in this paper. Compared with the conventional energy measurement methods, the proposed method has a better performance in AWGN channel, especially in the low SNR environment.

In the second part, the characteristic of the primary user signals are described, then the detection methods are discussed and the proposed method is described in detail in the third part. Some simulation results are shown in the fourth part. At last, some conclusions are drawn.

2. Primary Signal Characteristics

In the WRAN systems, the primary user signals are DTV (in our case ATSC) signal and wireless microphone signal.

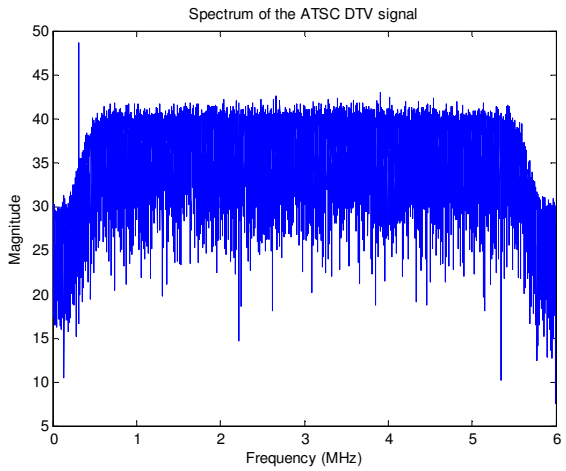

Figure 1. Spectrum of ATSC DTV signal

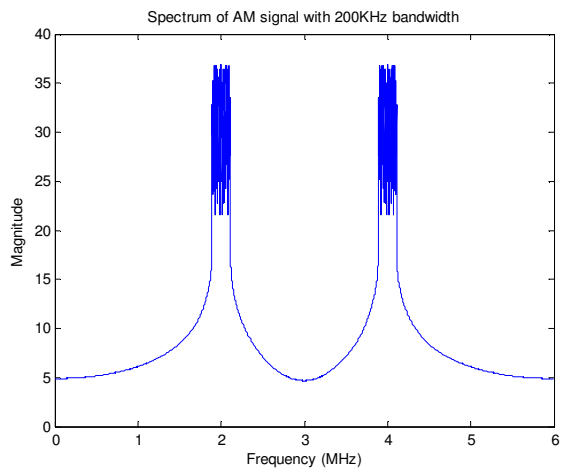

Figure 2. Spectrum of Wireless Microphone signal (AM modulated)

The spectrum of the ATSC DTV signal is shown as in Figure 1. The bandwidth is 6MHz. It is an 8-vsb modulated signal with pilot located at 2.6912MHz in the 6MHz bandwidth.

The spectrum of the AM modulated Wireless Microphone signal is shown in Figure 2. The bandwidth is 200KHz according to the FCC Part 74 regulation. Comparing to the TV signal bandwidth, it is a narrowband signal.

These two types of signal compose the primary user signals in our discussion. Both of them exhibit peak values in the 6MHz bandwidth. This property will be used in our detection procedure as discussed in the following parts.

3. Signal Detection Method

1). Radiometry Based Peak Detection

The conventional methods for signal detection which are usually based on energy measurement and are referred to as radiometry were first proposed by Urkowitz in 1967 [2]. Based on the property of exhibited peak values in the primary user signals, a straightforward method is measuring the energy around the peak area in the received signal spectrum. This procedure is shown in Figure 3.

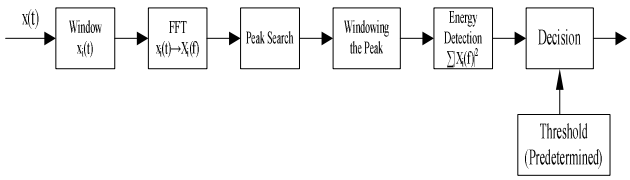

Figure 3. Radiometry Based Peak Detection

The spectrum of the received signals is calculated by passing them through the FFT device. Then search for the peak values in the spectrum. After locating the peak position, a window is used to select the peak energy measurement range. At last the detection decision is made by comparing the energy in the window to a predetermined threshold. Since the radiometric approaches simply measure the received energy in selected frequency and time interval, they are unable to realize the changing background noise and interference level. Also, in the low SNR environment, the peaks will drown in the noise; therefore it is difficult to detect the peak values in the spectrum. In this paper, we propose to use the spectral correlation property of primary user signals. This proposed method is detailed in the following part.

2). Spectral Correlation of Cyclostationary Signals

In the cyclostationary signal processing theory, the signal of interest is modeled as a cyclostationary random process in stead of a stationary random process as in the radiometric methods. It is defined that a process, say X(t), is said to be cyclostationary in the wide sense if its mean and autocorrelation are periodic with some period, say T [3]:

$$m_X(t+T) = m_X(t) \tag{1}$$

$$R_X(t+T+\frac{\tau}{2}, t+T-\frac{\tau}{2}) = R_X(t+\frac{\tau}{2}, t-\frac{\tau}{2}) \tag{2}$$

$R_x(t+\tau/2,\ t-\tau/2)$, which is a function of two independent variables, t and τ, is periodic in t with period T for each value of τ. It is assumed that the Fourier series representation for this periodic function converges, so that R_x can be expressed as

$$R_X\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) = \sum_{\alpha} R_X^{\alpha}(\tau) e^{j2\pi\alpha t} dt \tag{3}$$

for which $\{R_X^{\alpha}\}$ are the Fourier coefficients,

$$R_X^{\alpha}(\tau) = \frac{1}{T}\int_{-Z/2}^{Z/2} R_X\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) e^{-j2\pi\alpha t} dt \tag{4}$$

$\{R_X^{\alpha}(\tau)\}$ is referred to as the cyclic autocorrelation (CA) function, and α is called the cycle frequency parameter. For α=0, CA is the conventional autocorrelation function. The conventional power spectral density function is defined by the Fourier transform of the autocorrelation function. In contrast with that, the Fourier transform of the CA function is defined as the cyclic spectral density (CSD) function:

$$S_x^{\alpha}(f) = \sum_{\tau=-\infty}^{\infty} R_X^{\alpha}(\tau) e^{-j2\pi f\tau} \tag{5}$$

It was proved in [3] that the cyclic spectral density function could be measured by the normalized correlation between two spectral components of x(t) at frequencies (f+α/2) and (f-α/2) over an interval of length Δt.

$$S_{xT}^{\alpha}(f)_{\Delta t} = \frac{1}{\Delta t}\int_{-\Delta t/2}^{\Delta t/2} \frac{1}{\sqrt{T}} X_T(t, f+\alpha/2) \bullet \frac{1}{\sqrt{T}} X_T^{*}(t, f-\alpha/2) dt \tag{6}$$

This function is also called the spectral correlation function. In (6) the spectral of x(t) over the time interval [t-T/2,t+T/2] is defined by:

$$X_T(t,v) = \int_{t-T/2}^{t+T/2} x(u) e^{-j2\pi vu} du \tag{7}$$

The ideal measurement of the SCF for the received signal x(t) is given by:

$$S_x^{\alpha}(f) = \lim_{T\to\infty} \lim_{\Delta t\to\infty} S_{xT}^{\alpha}(f)_{\Delta t} \tag{8}$$

The spectral correlation characteristic of the cyclostationary signals gives us a richer domain signal detection method. We can accomplish the detection task by searching the unique cyclic frequency of different modulated signals. Also, information such as the carrier frequency, chip rate could be calculated according to the unique cyclic frequencies. Another motivation of implementing the spectral correlation function for signal detection lies on its robustness to random noise and interference. Spectral correlation of the noise is unique large at

cyclic frequency equals to zero comparing to that at other cyclic frequencies.

The spectral correlation functions of the primary user signals are shown in Figure 4 and Figure 5 respectively.

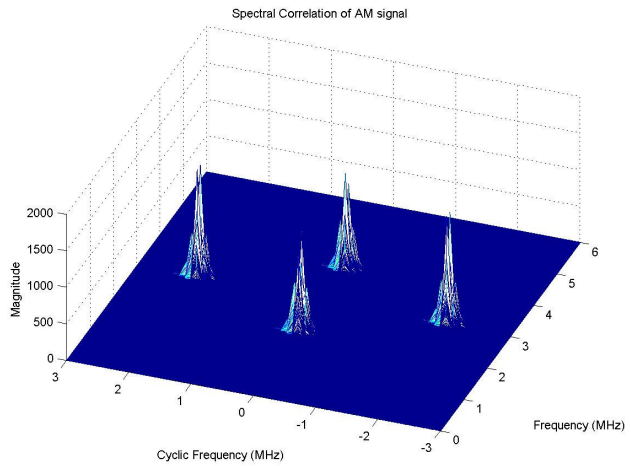

Figure 4. Spectral Correlation of Wireless Microphone signal (AM modulated)

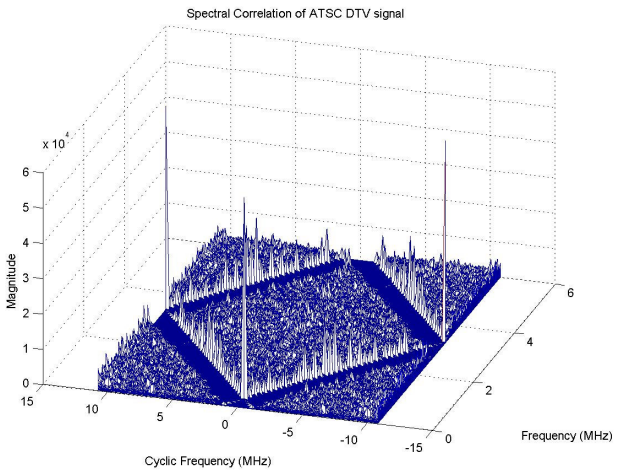

Figure 5. Spectral Correlation of ATSC DTV signal

Peak value can be seen in both the zero cyclic frequency and unique cyclic frequencies. The peaks in zero cyclic frequency can be used in the radiometry based detection while the peaks in unique cyclic frequencies can be used in our proposed detection method.

3). Spectral Correlation Based Detection

Although spectral correlation based methods exhibit many advantages, the computational complexity is a bottleneck for its implementation. As all the frequencies should be searched in order to generate the spectral correlation function, the calculation complexity is huge compared to the radiometry based methods.

In our proposed detection procedure for WRAN systems, the minimum detection bandwidth equals to the TV channel bandwidth which is 6MHz. The carrier frequency information for the ATSC DTV signal is known in the detector, and the possible carrier frequency range for the wireless microphone signals is also known if the detected frequency band is selected. Therefore, the calculation of the spectral correlation function in the selected band can be reduced significantly. It makes the implementing of the spectral correlation based detection method meaningful.

The proposed method is described as shown in figure 6. There are three stages in this method. First the spectral correlation function of the received signal is generated by searching the whole detected bandwidth. After that the unique cyclic frequencies are searched in the second stage. Based on the searching results, a detection decision is made in the last stage.

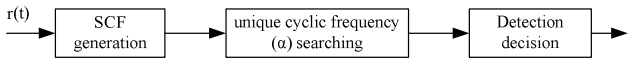

Figure 6. Primary user signal detection procedure

A). SCF generation

The spectral correlation function is calculated based on (6) following the procedure as shown in figure 7. We pass both of

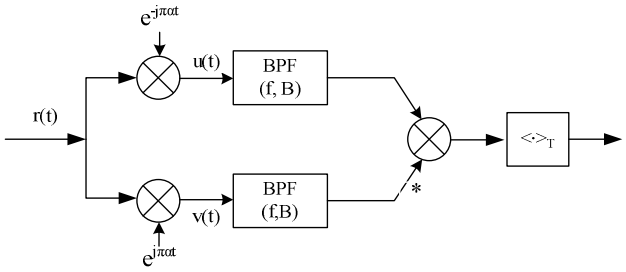

Figure 7. Spectral Correlation Function Generation

the two frequency translates u(t) and v(t) of the received signal r(t) through the same set of bandpass filters with center frequency f and bandwidth B [5]. As the detection band is selected, the computational complexity is not as large as that of searching the whole frequency range.

B). Unique cyclic frequency searching

The generated spectral correlation function of the received signal is used to search for the unique cyclic frequencies. The method is to detect the peak values in the frequency-cyclic frequency plane. The primary signals SCF as shown in figure 4 and figure 5 exhibit peaks at the unique cyclic frequency and zero cyclic frequency.

C). Detection decision

The detection decision is based on the searching results of unique cyclic frequency searching stage. As we have explained, the noise does not exhibit cyclostationarity. Therefore, if no unique cyclic frequencies are found, it means that there is no signal in the detected band. Otherwise, the band is used by the primary users.

4. Simulation Results

In order to evaluate the performance of the proposed spectral correlation based detection method, simulations were

carried out in AWGN environment.

The spectral correlation function of both ATSC DTV and wireless microphone signals are shown with different noise levels.

When E_b/N_0 equals to -5dB, as shown in figure 8 and figure 9, the peak values of the primary user signals in unique cyclic frequencies can obviously be seen. And at cyclic frequency equals to zero, the peaks in power spectral density can also be detected by the radiometry based method.

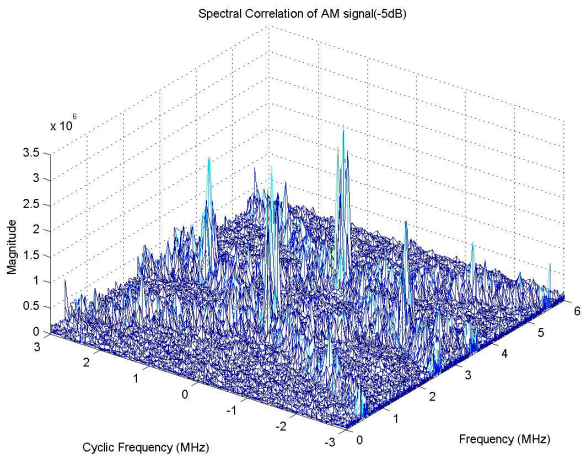

Figure 8. Spectral Correlation of AM signal with E_b/N_0=-5dB

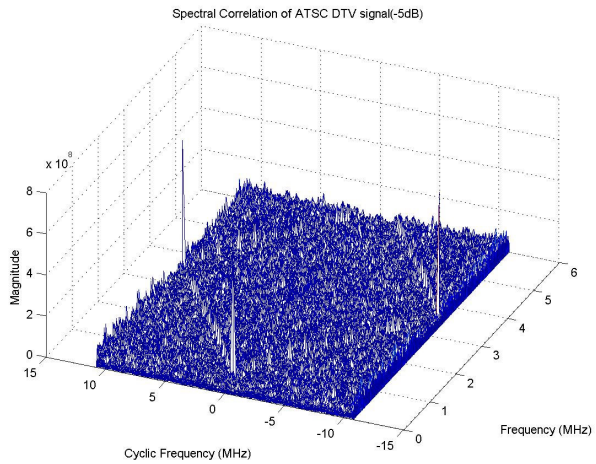

Figure 9. Spectral Correlation of ATSC DTV signal with E_b/N_0=-5dB

In the lower E_b/N_0 levels, take -10dB for example, the peaks in the spectral correlation whelmed by the noise. Although the spectral correlation of the noise is zero when the cyclic frequency does not equal to zero, the peaks are whelmed by the noise due to the cross-spectral correlation between the signals and noise. Therefore, the spectral correlation based peak detection is used for the low noise level environment.

For the high noise level environment, the noise robust advantage of spectral correlation detection method for the cyclostationary signal vanishes due to the effect of cross-spectral correlation between the signals and noise. In order to maintain the noise robust advantage of the detection method, the contour figure of the spectral correlation function which describes the visibility of the cyclostationary signals among noise is used for searching the unique patterns of different primary user signals. The contour figure

Figure 12 shows the contour figure of the AM modulated signal in the noise free environment. Four clear point of the signal are seen. The unique pattern is the intersection point which denotes the unique cyclic frequency of the AM modulated signal.

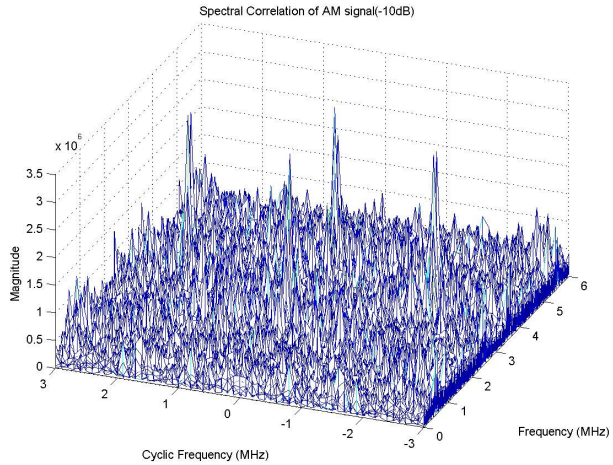

Figure 10. Spectral Correlation of AM signal with E_b/N_0=-10 dB

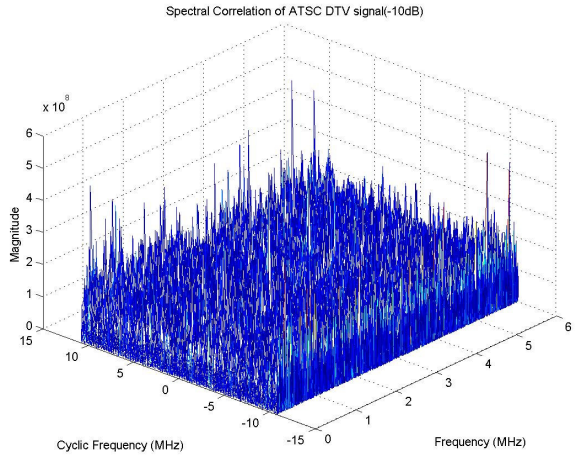

Figure 11. Spectral Correlation of ATSC DTV signal with E_b/N_0=-10dB

The dark line is caused by the cross-spectral correlation effect. The intersection points of these dark lines denote the unique cyclic frequency which distinguished the AM modulated signal from the noise. The back ground areas are caused by the noise. As the noise level increasing, the background areas get darker and the visibility of the lines and intersection points decreases. The consequence is the difficulties for detection increasing. This point of view can be proved by the figures from 13 to 15. When E_b/N_0 is around -20 dB, as shown in figure 15, the dark line and the intersection points can also be seen but with some difficulties.

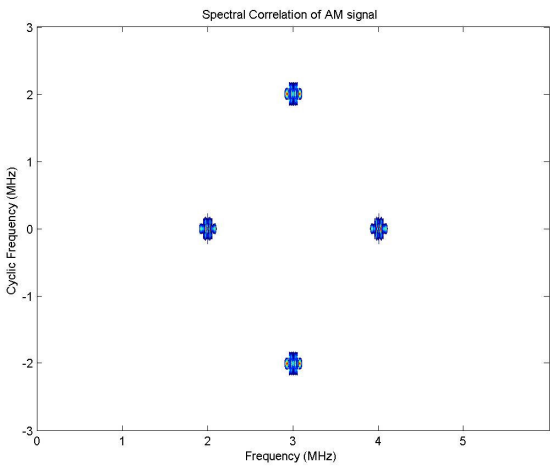

Figure 12. Contour figure of AM signal noise free

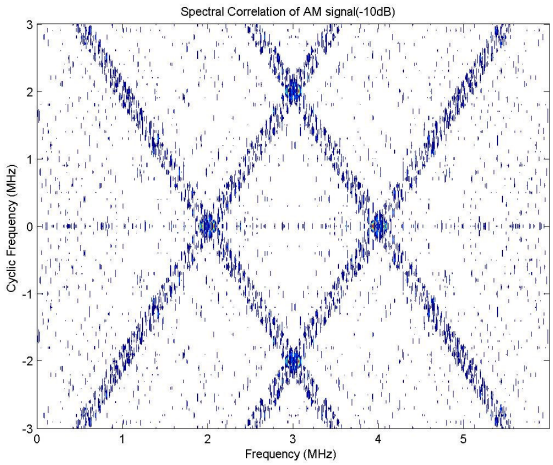

Figure 13. Contour figure of AM signal with E_b/N_0=-10dB

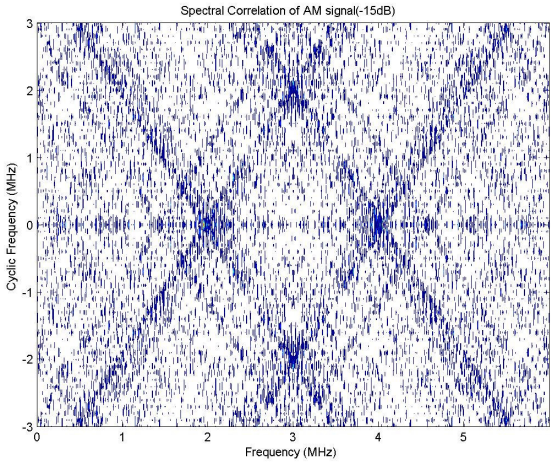

Figure 14. Contour figure of AM signal with E_b/N_0=-15dB

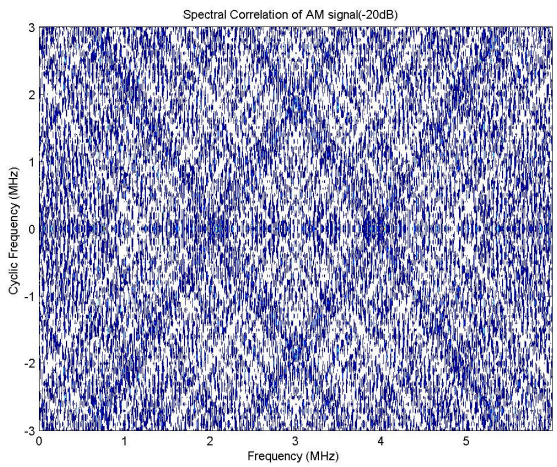

Figure 15. Contour figure of AM signal with E_b/N_0=-20dB

For ATSC DTV signals, the contour figure is different from that of AM modulated signals. The unique pattern is a white foursquare band which denotes the roll-off area in the spectrum of the ATSC DTV signal. Figure 16 shows the idea

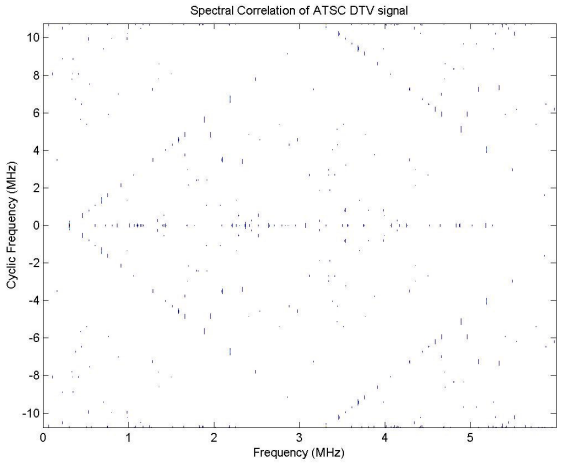

Figure 16. Contour figure of ATSC DTV signal noise free

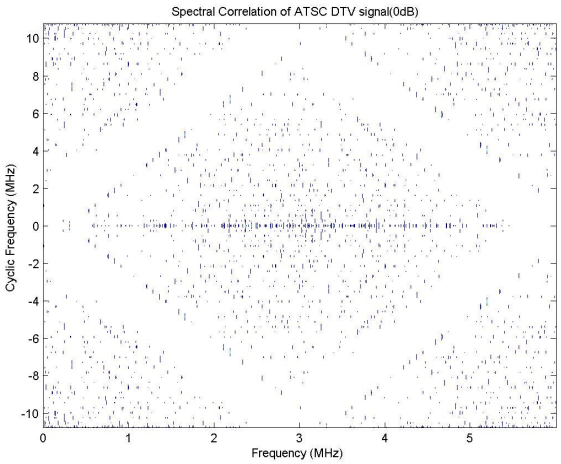

Figure 17. Contour figure of ATSC DTV signal with E_b/N_0=0dB

contour figure of the spectral correlation function of the ATSC DTV signals, the white foursquare band is visible. As the noise level increasing, the noise effect increases, therefore the white foursquare band gets darker and more likely to the background. It makes the visibility of the white foursquare band worse. This point of view is supported by the figures as shown below.

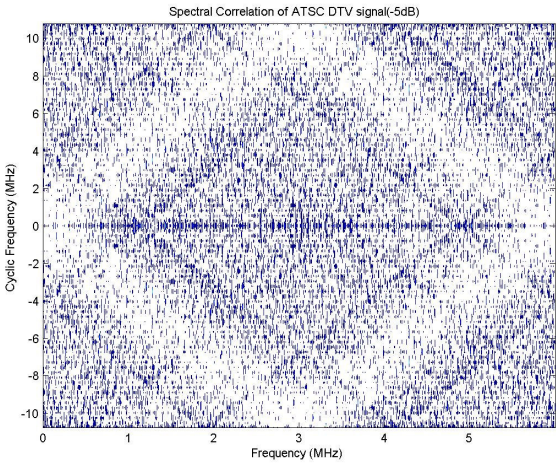

Figure 18. Contour figure of ATSC DTV signal with E_b/N_0=-5dB

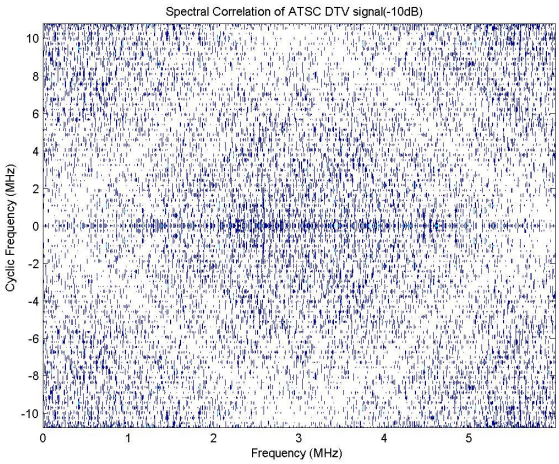

Figure 19. Contour figure of ATSC DTV signal with E_b/N_0=-10dB

We find that the signal component in the unique cyclic frequencies is easier to be detected by the proposed spectral correlation based peak detection in low noise level. When the noise level increasing, a contour figure based method is proposed to detect the unique patterns of the primary user signals. For AM modulated signal the pattern is the intersection point which denotes the unique cyclic frequency while for ATSC DTV signal it is a white foursquare band which denotes the roll-off area of the signal.

5. Conclusions

Since spectrum sensing is the most important procedure of the cognitive radio technique, we proposed a spectral correlation based peak detection method to check whether the primary user signal exists in the high E_b/N_0 noise environment. In the low E_b/N_0 noise environment, a better performance can be got with the help of contour figure of the spectral correlation function by searching the unique patterns.

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