Performance Analysis of Signal feature detection using Spectral Correlation Function for Cognitive Radio Environments

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Abstract In this paper, signal feature detection method using SCF(Spectral Correlation Function) is discussed. In the 802.22 WRAN system, spectrum sensing is fundamental technique of CR and signal feature method is technique for spectrum sensing. As most of the modulated signals have cyclostationarity, SCF is effective for signal feature detection method based on CR environment. We analyzed main signal patterns using the SCF method and compared main special points of several signal types by simulation factors as follows: center carrier frequency, modulation type, signal pattern, and so on.

Keyword: Cognitive Radio, SCF, Wireless Regional Area Network, Statistical Signal Processing

1. Introduction

Nowadays, the CR(cognitive radio) is taking the attention in 802.22 WRAN systems because of our limited spectral resources. The fundamental technique of CR is spectrum sensing[1]. In 802.22 WRAN systems we can divide the method of a spectrum sensing into the energy detection and the signal feature detection.

An energy detection method is to detect the signal by taking the operation FFT and average of the signal to be received. This method accomplishes simple FFT operation so it has the advantage which the time is short to deal the signal. But it is difficult of detect exactly correct signal. Otherwise, the feature detection method is to use characteristic of the cyclostationary. It uses correlation of received signal.

Usually energy detection method is firstly accomplished. But if we want more information like as modulation type, data rate, etc, at that time, we have to use signal feature detection.

The spectral correlation is an important characteristic property of modulated signals, which is cyclostationary. It exhibits as correlation between pairs of the spectral components whose difference of the central frequencies is called cycle frequency. The utilization of this spectral redundancy in the spectral correlation transformed space enables substantial performance improvement in the signal parameter estimation.

In this paper, we study a spectral correlation function and apply it to other modulated signal for feature detection. In the second part, the characteristic of spectral correlation function are described, then the feature detection methods using spectral correlation function are discussed. Some simulation results are shown in the fourth part. At last, some conclusions are drawn..

2. Cyclic Autocorrelation

A modulation signal of primary user is containing generally original periodic things like as a sine wave of single carrier system, pulse train of UWB system, PN of CDMA and CP(Cyclic Prefix) of OFDM System. These periodic things are used typically in the receiver for estimation for a phase of carrier, pulse timing and a multiple route arrival in receiver.

So the transmission data has a stationary random process personality. Also modulated data has cyclostationay because of statistical periodic between its mean and autocorrelation. Generally for a signal analysis of a stationary random process, we use a autocorrelation function and a power spectrum density function. Otherwise for cyclostationary signal we can use a spectral correlation function because the correlation of frequency factor exists due to his periodic characteristic.

In general, a complex received signal x(t) is said to exhibit second-order cyclostationarity if there exists a cycle frequency α = 0 for which the cyclic autocorrelation defined as [2]

$$R_{xx}^{\alpha}(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} R_{xx}(t,t+\tau)e^{-j2\pi\alpha t}dt.$$

$$R_{xx}(t,t+\tau) = E\{x(t)\cdot x(t+\tau)\}$$

$R_{xx}(t,t+\tau)$ 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 can be expressed as

$$R_{xx}(t,t+\tau) = \sum_{\alpha} R_{xx}^{\alpha}(\tau)e^{j2\pi\alpha t}$$

Where $R_{xx}^{\alpha}(\tau)$ denotes the Fourier coefficients.

$$R_{xx}^{\alpha}(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} R_{xx}(t,t+\tau)e^{-j2\pi\alpha t}dt.$$

$R_{xx}^{\alpha}(\tau)$ is called cyclic autocorrelation and α is called the cycle frequency parameter.

3. Spectral Correlation Function for signals

The spectral correlation function that we want to know and use is the Fourier transforms of the cyclic autocorrelation.

$$S_{xx}^{\alpha}(f)=\int_{-\infty}^{\infty}R_{xx}^{\alpha}(\tau)e^{-j2\pi f\tau}d\tau.$$

Signal feature detection using SCF find unique characteristic of modulated signal.

3.1 AM Signal

Generally AM modulation signal defines as follows[3].

$$x(t)=a(t)p(t)\,,\quad p(t)=\cos(2\pi f_0 t+\phi_0)$$

$a(t)$ is amplitude and $p(t)$ is periodic carrier frequency.
SCF of AM signal is as follows.

$$S_{xx}^{\alpha}(f)=\begin{cases}\frac{1}{4}S_{a}(f+f_0)+\frac{1}{4}S_{a}(f-f_0), & \alpha=0\\ \frac{1}{4}S_{a}(f)e^{\pm j2\phi_0}, & \alpha=\pm 2f_0\\ 0, & otherwise\end{cases}$$

The above 5 requirements can be summarized into 2 categories: capability of constructing complicated attack scenario, and capability of generating packets assimilating real network environment.
This paper intends to develop a network attack packet generator using a NP that can satisfy the above requirements and also provide a real network traffic capability and a real-like test environment for the security system test and development.

3.2 FSK signal

Generally FM modulation signal defines as follows[4].

$$x(n)=\sum_{k=-\infty}^{\infty}\cos(2\pi(f_c-f(n))n)h(n-kT_b),$$

$$f(n)=\sum_{m=1}^{M}\delta_m(n)f_m$$

SCF of FM signal is as follows.

$$S_{xx}^{\alpha}(f)=\frac{1}{4T}\sum_{m=1}^{M}w_m[G(f-f_m-f_c+\frac{\alpha}{2})\cdot G^{*}(f-f_m-f_c-\frac{\alpha}{2})+$$
$$G(f+f_m+f_c+\frac{\alpha}{2})\cdot G^{*}(f+f_m+f_c-\frac{\alpha}{2})],\alpha=\frac{n}{T}$$

3.3 PSK signal

3.3.1 BPSK signal
Generally BPSK modulation signal defines as follows[5].

$$x(t)=a(t)\cos(2\pi f_0 t+\phi_0)\quad \phi_0\in(0,\pi)$$

$a(t)$ is amplitude and $p(t)$ is periodic carrier frequency.
SCF of BPSK signal is as follows.

$$S_{xx}^{\alpha}(f)=\begin{cases}\frac{1}{4T_c}Q(f+\frac{\alpha}{2}\mp f_0)Q^{*}(f+\frac{\alpha}{2}\mp f_0)e^{-j[2\pi(\alpha\mp f_0)t_0\mp 2\phi_0]}, & \alpha=\pm 2f_0+\frac{k}{T_c}\\ \frac{1}{4T_c}Q(f+\frac{\alpha}{2}-f_0)Q^{*}(f-\frac{\alpha}{2}-f_0) & \\ \quad +\frac{1}{4T_c}Q(f+\frac{\alpha}{2}\mp f_0)Q^{*}(f+\frac{\alpha}{2}\mp f_0), & \alpha=0\\ 0, & otherwise\end{cases}$$

3.3.2 QPSK signal
Generally QPSK modulation signal defines as follows[5].

$$x(t)=a(t)\cos(2\pi f_0 t+\phi_0)\qquad ,$$
$$\phi_0\in(\pi/4,3\pi/4,-3\pi/4,-\pi/4)$$

$a(t)$ is amplitude and $p(t)$ is periodic carrier frequency.
SCF of BPSK signal is as follows.

$$S_{xx}^{\alpha}(f)=\begin{cases}\frac{1}{4T_c}Q(f+\frac{\alpha}{2}-f_0)Q^{*}(f-\frac{\alpha}{2}-f_0) & \\ +\frac{1}{4T_c}Q(f+\frac{\alpha}{2}\mp f_0)Q^{*}(f+\frac{\alpha}{2}\mp f_0), & \alpha=0\\ 0, & otherwise\end{cases}$$

3.4 CDMA signal

Every CDMA signals spread baseband signals according to the length of PN code. Although it is spread, it basically will have the characteristic according to only the modulation type. So CDMA signal will be detected by using any modulation type such as BPSK or QPSK like as 3.3.1 or 3.3.2.

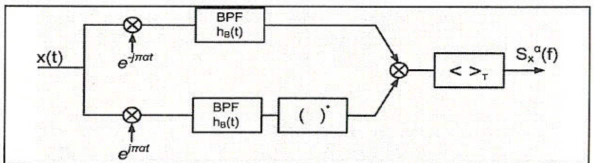
4. Simulation

In this chapter we confirmed the unique signal feature using SCF through the simulation. Common parameters to use in this paper are as follows for a simulation experiment except for FM signal.

[Table 1] Main Simulation parameters

Parameter	Value
Carrier frequency (f_c)	125 MHz
BandWidth	20MHz
Sampling Frequency	800MHz

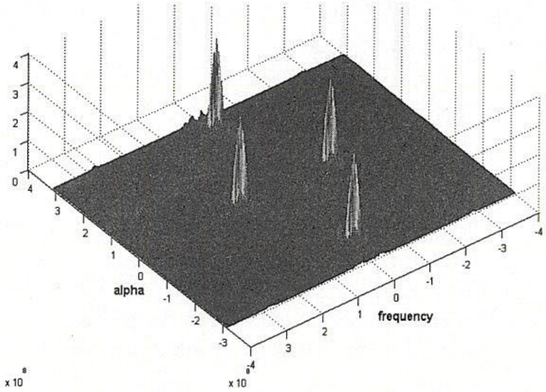
To compare signal features, we used above common parameter except modulation type. The (Fig.1) is structure of this SCF generation which we consider in this paper.



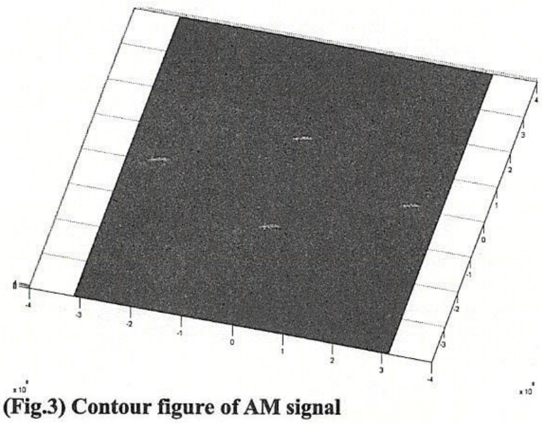
(Fig.1) Spectral Correlation Function Generation

4.1 AM signal

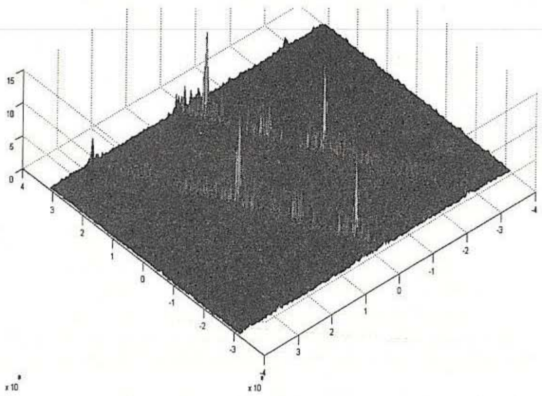
AM Signal feature using SCF is as follows. When α (cyclic frequency) is 0, signal feature is detected where f_C is 125MHz. Also when f_C = 0, the signal feature was detected where α is 250MHz which is the twice of f_C. We can know we show the shape of flat eye shape of the signal.



(Fig.2) Signal Feature Detection of AM signal using Spectral Correlation Function.



(Fig.3) Contour figure of AM signal



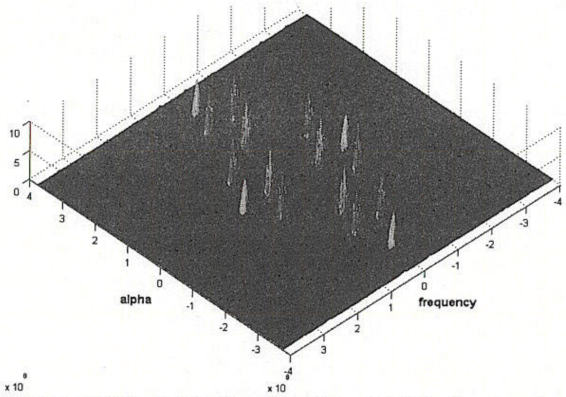
(Fig.4) Signal Feature Detection of AM signal using Spectral Correlation Function with $E_b/N_0 = 0dB$

Also we can know the characteristic of the signal feature when eb/n0 is 0dB.

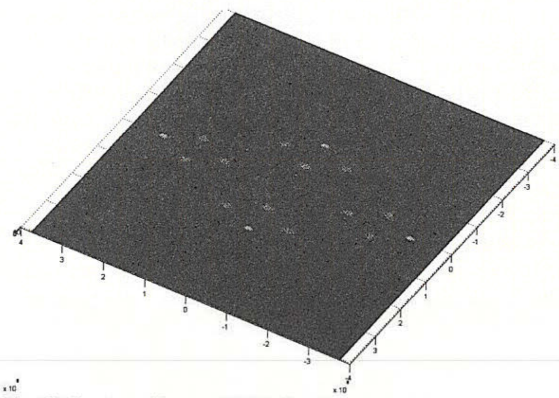
4.2 FM Signal

FM Signal feature using SCF is as follows. A carrier Frequencies which are used in the experiment are the 150MHz and the 75MHz. When α (cyclic frequency) is 0, the signal feature is detected where f_C are both 150MHz and 75MHz. Also when f_C = 0, the signal feature was detected where α are both 300MHz and 150MHz which is the twice of f_C. By each correlation of carrier signals, detected signal feature consist a lozenge form.

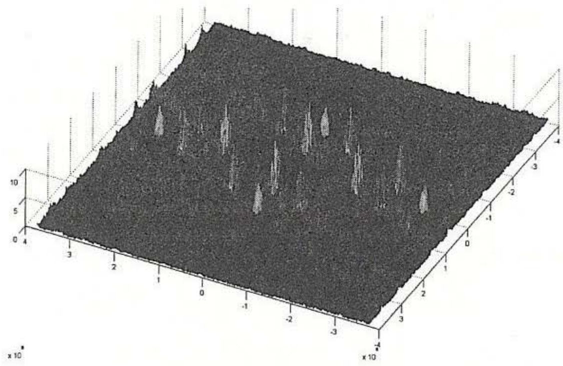
Also we can know the characteristic of the signal feature when eb/n0 is 0dB.



(Fig.5) Signal Feature Detection of FM signal using Spectral Correlation Function.



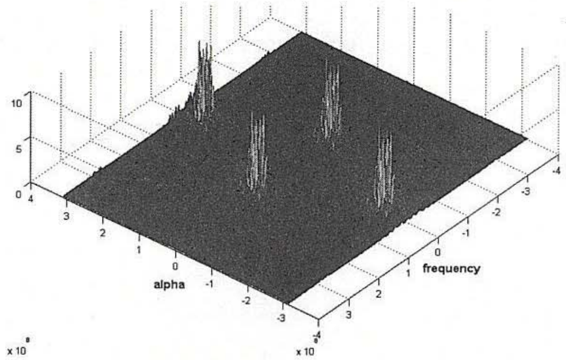
(Fig.6) Contour figure of FM signal



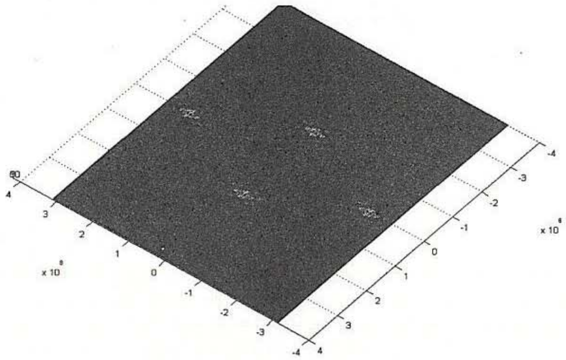
(Fig.7) Signal Feature Detection of FM signal using Spectral Correlation Function with $E_b/N_0 = 0dB$

4.3 BPSK Signal

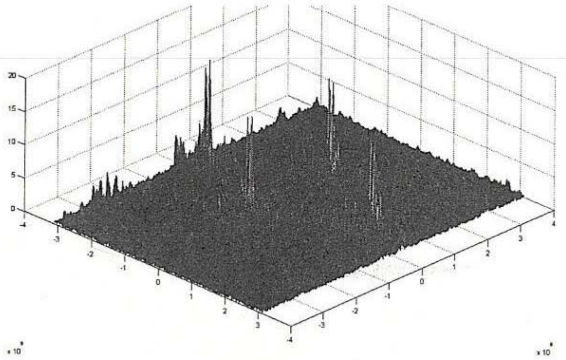
BPSK Signal feature using SCF is as follows. When α is 0, signal feature is detected where f_C is 125MHz. Also when f_C = 0, the signal feature was detected where α is 250MHz which is the twice of f_C. It is similar to AM signal. But BPSK signal detection feature is thicker than AM signal.



(Fig.8) Signal Feature Detection of BPSK signal using Spectral Correlation Function.



(Fig.9) Contour figure of BPSK signal

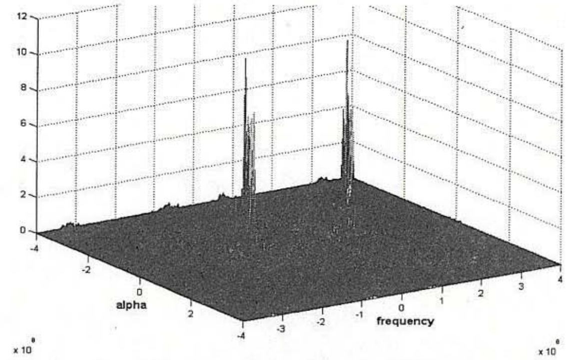


(Fig.10) Signal Feature Detection of BPSK signal using Spectral Correlation Function with $E_b/N_0 = 0dB$

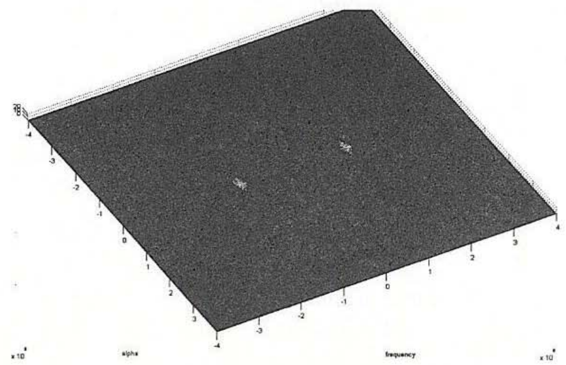
It also has the characteristic of the signal feature when eb/n0 is 0dB.

4.4 QPSK Signal

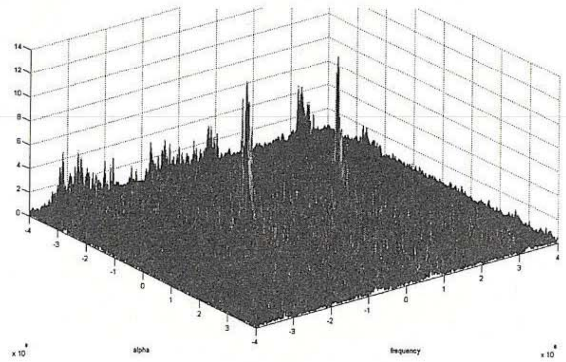
QPSK Signal feature using SCF is as follows. When α is 0, signal feature is detected where f_C is 125MHz. But when f_C = 0, the signal feature was not detected where α is 250MHz which is the twice of f_C. It is unique characteristic of the QPSK signal feature.



(Fig.11) Signal Feature Detection of QPSK signal using Spectral Correlation Function.



(Fig.12) Contour figure of QPSK signal

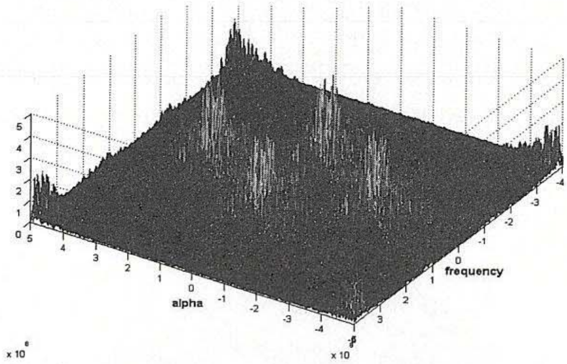


(Fig.13) Signal Feature Detection of QPSK signal using Spectral Correlation Function with $E_b/N_0 = 0dB$

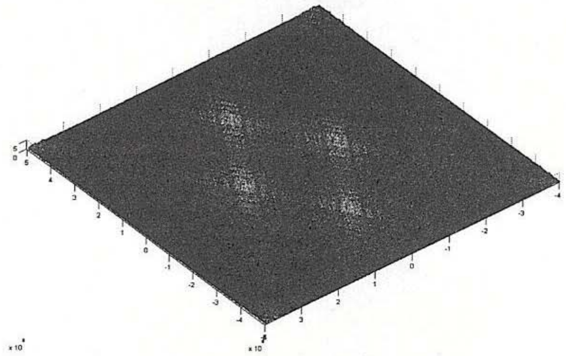
4.5 CDMA Signal

(Fig.14) is the result of a feature detection of CDMA signal which use 8bit of PN code and BPSK modulation. Signal feature were detected to more wide form because of the characteristic of CDMA which does the spreading by

PN code. Also we could confirm the characteristic of BPSK signal at the same time.



(Fig.14) Signal Feature Detection of CDMA signal using Spectral Correlation Function (PN:8, BPSK)



(Fig.15) Contour figure of CDMA signal

5. Conclusion

As most of the modulated signals have cyclostationarity, it is effective for signal feature detection through the spectral correlation function. This method has the advantage to get various information compared an energy detection method.

In this paper, we confirmed that modulated signals has unique signal feature through spectral correlation function. Also we analyzed main signal patterns using the SCF method. We can compare main special points of each signals; center carrier frequency, modulation type, signal pattern, and so on. So we think spectral correlation function is very helpful to detect signal for spectrum sensing of 802.22 WRAN Cognitive Radio Environment.

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