IMPLEMENTATION OF CYCLIC PERI- ODOGRAM DETECTION ON VEE FOR COG- NITIVE

IMPLEMENTATION OF CYCLIC PERIODOGRAM DETECTION ON VEE FOR COGNITIVE RADIO

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Abstract—A Cyclic Periodogram Detection (CPD) algorithm is proposed for weak signal detection in Cognitive Radio environment. The algorithm is implemented using Agilent VEE Pro. Simulation results show that a BPSK signal can be effectively detected at -20 dB SNR.

Keywords: Cognitive Radio, CSD, CPD, VEE

1. Introduction

Fast developing of wireless communications makes spectrum allocation more and more difficult. New spectrum utilization schemes such as Cognitive Radio (CR) [1,2] is recently proposed and becomes a hot research topic. With CR, spectrum allocated to a primary user is sensed and opportunistically used by secondary users. When the allocated spectrum is not fully utilized by the primary user, CR scheme achieves spectrum utilization improvement.

Weak signal detection is crucial to CR. To avoid affecting the primary user, which pays for the spectrum, secondary users must have the ability of detecting the existence of primary users. Due to reasons such as fading of wireless channels, a secondary user is required to detect signals with a power 30 dB lower than the receiver sensitivity of the primary user.

Several schemes are proposed to detect very weak signals, such as Cyclic Spectrum Detection (CSD) [3,4], higher-order moments (cumulants) estimation [5], and cooperative detection [6]. In this paper, we investigate the CSD scheme, which is able to detect signals effectively at -20 dB Signal-to-Noise Ratio (SNR). We propose an implementation algorithm of the CSD scheme on sampled versions of the signal, named Cyclic Periodogram Detection (CPD) algorithm, which can be effectively and efficiently carried out in a real environment.

Agilent Visual Engineering Environment (VEE) Pro [7] is a graphical developing environment targeted at automated measurements and tests. With this powerful tool, we build a virtual instrument that implements the proposed CPD algorithm. The virtual instrument works on a sampled version of input signal, and outputs cyclic spectrum of the signal. If the interested primary user signal exists in the input signal, it will be found in the cyclic spectrum.

The remainder of this paper is organized at follows. Section 2 gives the proposed CPD algorithm. Section 3 implements this algorithm on VEE. Section 4 investigates performance of the proposed algorithm and implementation. Section 5 concludes this paper.

2. Cyclic Periodogram Detection Algorithm

Cyclic spectrum is defined to describe cyclostationary processes. A modulated process obtained by varying some parameters, such as amplitude, frequency, or phase, of a sinusoidal carrier is an example of cyclostationary process. A cyclostationary process X(t) exhibits periodicity in its mean and autocorrelation function, that is:

$$\mu_X(t+T) = \mu_X(t)$$
$$R_X(t+T,\tau) = R_X(t,\tau), \qquad (1)$$

where $\mu_X(t) = E\{X(t)\}$ and $R_X(t,\tau) = E\left\{X(t+\frac{\tau}{2})X^*(t-\frac{\tau}{2})\right\}$ are mean and autocorrelation function of X(t), respectively, $E\{\cdot\}$ is the expectation operator, and T is the cyclostationary period.

Expending $R_X(t,\tau)$ by Fourier series at period T, we obtain:

$$R_X(t,\tau) = \sum_\alpha R_X^\alpha(\tau)\exp(j2\pi\alpha t), \qquad (2)$$

where

$$R_X^\alpha(\tau) = \frac{1}{T}\int_{-T/2}^{T/2} R_X(t,\tau)\exp(-j2\pi\alpha t)dt \quad (3)$$

and α is named as cycle frequency, which is the frequency of second-order periodicity with the process X(t).

The cyclic spectrum is defined as Fourier transform of $R_X^\alpha(\tau)$, that is:

$$S_X^\alpha(f) = \int_{-\infty}^{\infty} R_X^\alpha(\tau)\exp(-j2\pi f\tau)d\tau. \qquad (4)$$

To analysis cyclostationary signals at time t, time-variant cyclic periodogram is defined as:

$$S_X^\alpha(t,f) = \frac{1}{T}X(t,f+\frac{\alpha}{2})X^*(t,f-\frac{\alpha}{2}), \qquad (5)$$

where $X(t,f) = \int_{t-T/2}^{t+T/2} x(w)\exp(-j2\pi fw)dw$.

Based on the above theory, a CPD algorithm working on sampled signal is proposed, which follows the following steps:

a) Divides input sample sequence into L blocks, with each block contains N samples;

b) Takes discrete Fourier transform of the N samples in each block l, $x_l[n], n = 0,1,\ldots,N-1, \ l = 0,1,\ldots,L-1$:

$$X_l[k] = \sum_{n=0}^{N-1} x_l[n]\exp(-j2\pi\frac{kn}{N}), \quad k = 0,1,\ldots,N-1;$$

c) Calculates

$$T_l^\alpha[k] = \frac{1}{N}X_l[k+\frac{\alpha}{2}]X_l^*[k-\frac{\alpha}{2}],$$
$$k = 0,1,\ldots,N-1, l = 0,1,\ldots,L-1;$$

d) Averages the results of step (c) over all blocks:

$$T^\alpha[k] = \frac{1}{L}\sum_{l=0}^{L-1}T_l^\alpha[k], \quad k = 0,1,\ldots,N-1;$$

e) Smoothes in frequency domain to obtain the cyclic periodogram:

$$S^\alpha[k] = \sum_{m=0}^{M-1} T^\alpha[kM+m]. \qquad (6)$$

The cyclic periodogram estimation of Equ. (6) has a frequency resolution of $\Delta f = \frac{M}{NT_s}$ and a cycle frequency resolution of $\Delta\alpha = \frac{1}{NT_s}$, where T_s is the sampling interval.

3. Implementation on VEE Pro

Using the Instrument Manager of VEE Pro, data can be conveniently collected from GPIB, USB, or LAN instruments, as well as from PXI modules. For the convenience of debugging, we also implement a data source module, which simulates the collected data from real world.

VEE Pro provides plenty built-in modules which can be used for various functionalities. The proposed CPD algorithm is implemented using these built-in modules. A module has input ports on its left side and output ports on its right side. Data follows from the left to the right. A module has also control ports, located on its upper side and bottom side. The module is activated when a control signal arrives at one of its upper control ports and outputs activation signal to other modules from its bottom control ports or output ports.
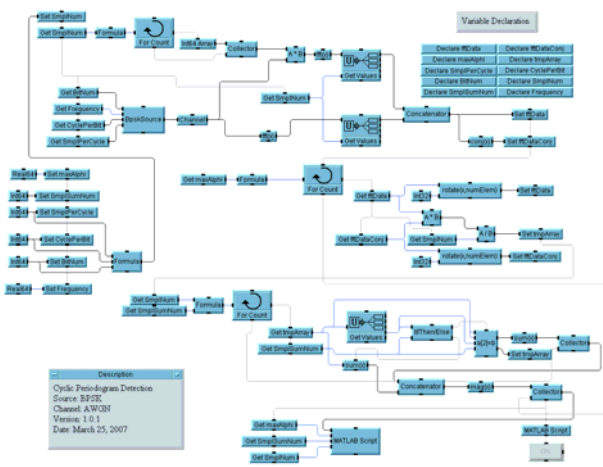

Figure 1. Implementation of the CPD algorithm on VEE Pro.

Figure 1 is the implementation of the CPD algorithm on VEE Pro. This is the top-level view. Some of the blocks in this figure are actually Objects, which are collections of modules for closely related functions. When double clicked, an Object will be expanded and we go to a lower level view.

VEE Pro has built-in MATLAB script and signal processing toolbox. In this implementation, the output 3D figure is plotted by MATLAB functions written in a MATLAB script.

4. Performance Evaluation

We use Binary Phase-Shift Keying (BPSK) signal as an example primary user signal to evaluate the proposed CPD algorithm and its implementation on VEE Pro.

A BPSK signal can be expressed as:

$$x(t) = \sum_{n=-\infty}^{\infty} a_n q(t - nT) \cos(2\pi f_c t), \qquad (7)$$

where $a_n = \pm 1$ is the nth information symbol, $q(t)$ is the pulse shaping function, T is symbol length, and f_c is the carrier frequency. In Equ. (7), we assume that the signal is aligned at time $t = 0$ and the initial carrier phase is 0.

By using Equations (3) and (4), cyclic spectrum of the BPSK signal can be derived:

$$S_x^\alpha(f) = \begin{cases} \dfrac{1}{4T}\left[Q(f+f_c+\dfrac{\alpha}{2})Q(f+f_c-\dfrac{\alpha}{2}) + Q(f-f_c+\dfrac{\alpha}{2})Q(f-f_c-\dfrac{\alpha}{2}) \right] & \alpha = \dfrac{p}{T} \\[2mm] \dfrac{1}{4T}\left[Q(f+\dfrac{p}{2T})Q(f-\dfrac{p}{2T}) \right] & \alpha = \dfrac{p}{T} \pm 2f_c \\[2mm] 0 & \text{Otherwise} \end{cases} \qquad (8)$$

where p is any integer, and $Q(f)$ is Fourier transform of the pulse shaping function $q(t)$. Equ. (8) shows that $S_x^\alpha(f)$ is non-zero at $\alpha = \dfrac{p}{T}$ and $\alpha = 2f_c \pm \dfrac{p}{T}$.

In the implementation, we assume the following parameters: $f_c = 50MHz$, $T = 0.32us$, the sampling frequency $f_s = 800MHz$, $q(t) = \begin{cases} 1, 0 \le t < 1 \\ 0, \text{otherwise} \end{cases}$, block size is $N = 4096$, smoothing number $M = 32$, and α is investigated in the range $[0, 135MHz]$.
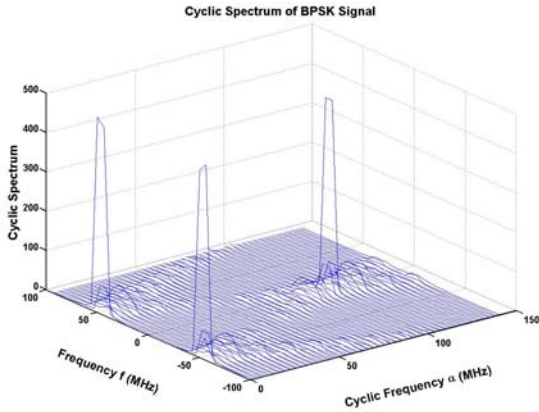

Figure 2. Cyclic Spectrum of BPSK.

Figure 2 shows the cyclic spectrum of the BPSK signal without noise. We find that it has large peak values at $\alpha = 0, f = \pm f_c$ and $\alpha = 2f_c, f = 0$. These peak values help detect the signal when it is overwhelmed by noise or other types of signals.

Figure 3 gives the detection performance of the BPSK signal under Additive White Gaussian Noise (AWGN). The result shows that the signal can by effectively detected using the CPD algorithm at an SNR as low as -20 dB.
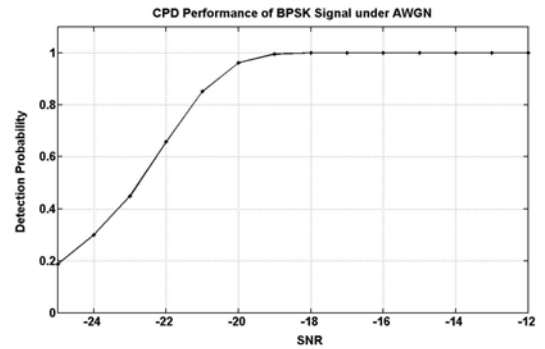

Figure 3. CPD Performance of BPSK under AWGN.

5. Conclusions

Weak signal detection is crucial to Cognitive Radio. Cyclic spectrum detection exploits the second-order periodicity in a cyclostationary signal, which helps detect weak signals. For a finite length sampled sequence of the signal to be detected, this paper proposes a cyclic periodogram detection algorithm. The algorithm is implemented on Agilent VEE Pro. Performance is evaluated through simulations. Simulation results show that a BPSK signal can be effectively detected at an SNR as low as -20 dB.

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