SCF Based Cyclostationary Spectrum detection for Mobile Radio signals

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Abstract — Spectrum sensing problem is one of the most challenging issues in Cognitive Radio (CR) systems in licensed as well as unlicensed bands. It basically determines the vacant bands and makes use of these available bands in an opportunistic manner. CR may be exploited to design wireless sensor nodes to form wireless sensor networks (WSNs), which are traditionally assumed to employ fixed spectrum. A CR Sensor Node (CRSN) can access the mobile radio channel as long as it does not cause interference to the primary users who have the priority to access the channel with a specific license to communicate over the allocated band. Signal detection for spectrum sensing is one of the major functionalities distinguishing CRSNs from traditional WSNs. In this paper authors present a method of detection and identification of mobile radio signals using the concept of cyclostationary spectral analysis based on Spectral Correlation Density (SCD) function. SCD functions of several signals used for mobile radio communication like BFSK, BPSK, GMSK and CDMA have been simulated in MATLAB and analysis have been made based on the results, which can be used to classify and identify these signals for identifying underutilized frequency bands.


INTRODUCTION

SPECTRUM is an essential functionality of mobile communication system [1]. A certain number of frequency bands remain underutilized enormously at certain times and locations. So spectrum sensing is basically a procedure to search these empty frequency bands, which is an essential functionality of Cognitive Radio Sensor Node (CRSN) since these nodes can operate on spectrum bands of the licensed primary users in an opportunistic manner. The objective of spectrum sensing is to make a decision on the binary hypothesis testing based on the received signal. The two hypotheses which are defined as H0 and H1 are modeled as:

1. H0: the frequency band is empty and the received signal is noise only:
   \( y(t) = n(t) \)

2. H1: the frequency band is occupied and the received signal is PU signal interfered by noise.

\( y(t), x(t), \) and \( n(t) \) denote the received signal, the signal transmitted by primary user and the noise respectively.

In general, there can be three types of spectrum sensing techniques, which include: Energy Detection [2], Matched Filter Coherent Detection [3], and cyclostationary Feature Detection [4]. Energy detection is highly susceptible to in-band interference and changing noise levels. Cyclostationary detection is superior to simple energy detection and match filtering process. The idea behind the theory of cyclostationarity is that man made signals possesses hidden periodicities like chip rate and carrier frequency that may be reproduced by sine-wave extraction operation which produces features at frequencies that depend on these periodicities. Since second-order cyclostationality is based on quadratic nonlinearities, two frequency parameters are used for sine-wave extraction function. As a result, Spectral Correlation Density (SCD) is obtained, which can be represented in bi-frequency plane. The spectral correlation characteristic of cyclostationary signals gives a richer domain signal detection method. The detection process is done by searching the cyclic frequencies of different kinds of modulated signals. In addition, information such as carrier frequency, chip rate could be
calculated according to cyclic frequencies. This spectral correlation based method is popular due to the fact that it is robust against noise and interference.

The organization of the paper is as follows. After the introduction in section I, section II provides an overview of cyclostationary signal processing followed by SCD functions of several digital modulated mobile radio signals. Simulation environment and results are provided in section III. Section IV concludes the paper with some highlights on future works.

II. CYCLOSTATIONARY SIGNAL PROCESSING

A. Overview

As introduced by Gardner, the second order cyclostationary uses quadratic nonlinearities to extract sine-waves from a signal. A continuous-time signal \( x(t) \) is said to be cyclostationary (in wide sense), if it exhibits a periodic auto-correlation function which is given by

\[
R_x(t, \tau) = E \{ x(t) x^*(t-\tau) \} \quad (1)
\]

where, \( E[\cdot] \) represents statistical expectation operator. Since \( R_x(t, \tau) \) is periodic, it has the Fourier series representation

\[
R_x(t, \tau) = \sum_{\alpha} R_x^{\alpha}(\tau)e^{j2\pi\alpha t} \quad (2)
\]

where sum is taken over integer multiple of fundamental cycle frequencies, \( \alpha \). The term \( R_x^{\alpha}(\tau) \) in (2) is known as cyclic autocorrelation function, which is defined as:

\[
R_x^{\alpha}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)x^*(t-\tau)e^{-j2\pi\alpha t}dt
\]

(3)

The spectral correlation is an important feature of the second order cyclostationary signals. If the signal \( x(t) \) exhibits cyclostationarity with cyclic frequency \( \alpha \), in time domain, then it also exhibits spectral correlation at shift \( \alpha \) in frequency domain. So the SCD could be measured by the normalized correlation between two spectral components of \( x(t) \) at frequencies \( (f + \alpha/2) \) and \( (f - \alpha/2) \) over an interval \( T \) as given by

\[
S_x^\alpha(f) = \frac{1}{T} \int_{-T/2}^{T/2} x(t)x^*(t-\tau)e^{-j2\pi\alpha t}dt \quad (5a)
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\]

(5b)

Where \( F\{.\} \) = Fourier Transform operator, \( X_T(f) = \frac{1}{T} \int_{-T/2}^{T/2} x(t) e^{-j2\pi ft}dt \)

B. SCD of Different Signals

Cyclic spectral analysis is a very useful tool for signal classification due to the following reasons:

Different types of modulated signals (FSK, BPSK, GMSK, DS-CDMA) with overlapping power spectral densities have highly distinct SCDs. There is no spectral correlation exhibited by stationary noise. The spectral correlation density function contains phase and frequency information related to timing parameters in modulated signals (carrier frequencies, pulse rates, chipping rates in spread spectrum signaling, etc). SCD of several digital modulated signals used in mobile communications have been described in this section.

i) Binary Frequency Shift Keying (FSK)

An FSK signal is represented as follows [6]:

\[
S_x^\alpha(f) = \frac{1}{T} \int_{-T/2}^{T/2} x(t)x^*(t-\tau)e^{-j2\pi\alpha t}dt
\]
The SCD function of an FSK signal is given by [6] :

\[ S_{fi}^f(f) = \frac{1}{4T} \sum_{n=-\infty}^{\infty} W_n \mathcal{C} \left( f - f_m - f_c + \frac{\alpha}{2} \right) G^* \left( f - f_m - f_c - \frac{\alpha}{2} \right) + \alpha \left( f + f_m + f_c + \frac{\alpha}{2} \right) G^* \left( f + f_m + f_c - \frac{\alpha}{2} \right) \]  

where, \( \Phi_0 \in (0, \pi) \) and \( a(t) \) is the amplitude.

The SCD of above signal is given by

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algorithm in MATLAB version:7.5.0.342(R2007b). The plots of SCD functions are shown in Fig. 1, Fig.2 & Fig.3 respectively.

Fig.1 SCD estimate of BFSK signal Parameters:Δf = 512 Hz, Δα = 16 Hz, fC1 = 1024, fC2 = 3048 and fs = 8192 Hz.

For the zero frequency shift, the spectral correlation density is equivalent to standard power spectral density. Here α = 0 line shows sinc2(2x) at f = 2400 Hz which is equal to carrier frequency. It is also clear from the figure that the greater correlation exist at almost twice the carrier frequency = 4900 Hz.

Fig.2 Surface plot of SCD estimate of BPSK signal Parameters:Δf = 512 Hz, Δα = 16 Hz, fC = 2048 Hz and fs = 8192 Hz.

IV. CONCLUSION

In this paper we showed that spectral correlation based detection method for spectrum sensing could be used to increase the spectral efficiency in mobile WSN. We performed MATLAB simulation of SCD functions of several digital modulated signals commonly used for mobile radio communications. As cyclostationarity is one of the properties of modulated signals, therefore, simulation results prove that it can be used as a measure for signal feature detection through spectral correlation density function. Unique signal feature properties of various digital modulated signals like BFSK, BPSK, GMSK and DS-CDMA modulated signals have been analyzed in this paper by using spectral correlation function. SCD of white noise shows no spectral correlation density, which provides an easy method of channel sensing and spectrum allocation. But, this detector suffers from higher computational complexity which has just become manageable. Our future work is directed towards enhancement of this algorithm, which would lead to lower computational complexity and processing delay.

References


