Dynamic Spectrum Sensing Techniques in Cognitive Radio

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Abstract:

Spectrum sensing is an important and enabling function of cognitive radio system. Spectrum sensing detects the band of frequencies that are currently being used by licensed users thereby identifying the band of frequencies that are available for use in Cognitive radio system . This paper discusses about the various requirements of spectrum sensing in a cognitive radio system, various methods of spectrum detection that can be used for spectrum sensing and their relative merits and demerits with respect to their use in Cognitive radio.

KEYWORDS: *Cognitive radio, spectrum sensing, energy detector, pilot detector,   Cyclostationary feature detector.*

I.   Introduction:

A Cognitive radio (CR) is an intelligent radio system which adapts its transmission characteristics based on its operating environment and user requirements. It is envisioned as an ideal solution to the spectrum scarcity and spectrum under utilization that is being faced by the communication industry and regulators throughout the world.

"Spectrum sensing " is the as a key enabling functionality to ensure that cognitive radios would not interfere with licensed users, by reliably detecting their transmission. In addition, reliable sensing plays a critical role on communication links of cognitive radios since it creates spectrum opportunities for them.

In order to efficiently utilize the available opportunities, cognitive radios must sense frequently all degrees of freedom (time, frequency, space) while minimizing the time spent in sensing.

Spectrum Sensing Requirements

A cognitive radio transmitter has to reliability detect the signals of primary or licensed users to avoid hidden terminal problem and interference to their operation. This places restriction on the detection sensitivity of the cognitive radio detector. Taking the empirical numbers as a worst case condition, it can be estimated that sensing SNR falls into the negative range approximately from 0 to -35 dB [base paper].

In order to constrain interference, spectrum sensing design should achieve orthogonality between primary and cognitive transmission across different degrees of freedom. In addition to spatial domain, cognitive radio needs to consider the time domain to achieve orthogonality. This means that primary user frequency bands must be sensed periodically within some predetermined time interval. The sensing interval is set by the primary user system QoS tolerances [base paper].

The sensing interval requirement presents the maximum time a cognitive radio sensor could spend for primary user detection. On the other hand, cognitive radio system objective is to utilize the available spectrum resources as efficiently as possible. From the cognitive radio system design perspective, an effective time used for sensing should be minimized since cognitive radios cannot communicate during this time.

Therefore, it is imperative for a CR node to reliably detect a licensed user signal at negative SNR levels with shortest possible time for efficient operation.

II.   Spectrum Sensing Approaches

There are various approaches used [Survey Paper] for spectrum sensing. The popular and important are the following three approaches,

There are three different approaches used for spectrum sensing. They are,

    i.   Pilot detector(PD) method,
    ii.   Energy detector(ED) method,
    iii.   Cyclostationary   feature detector(CFD) method.

The licensed user signal detection is the test of the following two hypotheses:

a. under H_0 : licensed user signal is not present and there is only noise at input of the receiver,

b. under H_1 : licensed user signal and noise are present at the input of the receiver.

Discrete time model of this hypothesis test is:

$H_0 : y[n] = w[n]$ n = 1, ..., N   (1)

$H_1 : y[n] = s[n] + w[n]$ n = 1, ..., N   (2)

Where,

s[n] – primary user signal and w[n] – noise added to the primary user signal

y[n] – Actual received signal by cognitive radio receiver.

Before explaining about the different approaches in spectrum sensing, a brief explanation of few terms used given below.

Minimum no of samples required (N_{min}):

This is the minimum no. of samples required by the detection scheme, in order to reliably detect a primary user signal satisfying the given values of SNR, P_{fa} and P_d. Thus it denotes the minimum time required for detection at the given operating conditions.

Maximum no of samples (N_{max}):

This is the maximum number of samples that are available for a detection scheme for the purpose of detecting primary signal. In cognitive radio this refers to the maximum allowable detection time, as per of the Cognitive radio specifications or regulations. This also depends on the primary user characteristics.

a.   Pilot detector

Pilot detection method is coherent detection scheme in which the presence of a known signal or pattern indicates that a particular primary user is currently using the spectrum. Coherent processing achieves the best possible robustness with respect to noise. Since the pilot is simply added to the data bearing signal, the optimal detector is the matched filter that projects the received signal in the direction of the pilot.

The pilot detector is susceptible to frequency and phase offset between the transmitted and locally regenerated pilot signal or pattern.

Important formulae:

- The threshold level 'γ' is decided by 'Pfa' as

$$\gamma = Q^{-1}(P_{fa}) * \sqrt{\varepsilon_p * \sigma^2_w} \qquad \text{... (3)}$$

- The minimum no. of samples required to cancel out the effects of noise is given by,

$$N_{min} = 2 * [(Q^{-1}(P_{fa}) - Q^{-1}(P_d)]^2 SNR_p^{-1}$$

$$\text{... (4)}$$

Where $SNR_p = \rho_p / \sigma^2_w$, σ^2_w = Noise variance,

$$\rho_p = \frac{1}{N} \sum_{n=1}^{N} x_p(n)^2 , \varepsilon_p = \sum_{n=1}^{N} x_p(n)^2$$

are power of the pilot pattern and locally regenerated pilot pattern respectively

- The decision test is performed on the computed value of T(y). T(y) is computed as

$$T(y) = \sum_{n=1}^{N} y(n) x_p(n)^* \qquad \text{...(5)}$$

- The primary user signal is detected if

$$T(y) > |\gamma| \text{ otherwise it is not.}$$

b.   Energy Detector

An energy detector is the sub-optimal detector due to non coherent signal processing, which only integrates squared samples. The signal is detected by comparing the output of the energy detector with a threshold dependent on the estimated noise power.

Important formulae:

- The threshold level 'γ' is decided by 'Pfa' as

$$\gamma = Q^{-1}(P_{fa}) * \sigma^2_w \qquad \text{...(6)}$$

- The minimum no. of samples required to cancel out the effects of noise is given by,

$$N_{min} = 2 * [(Q^{-1}(P_{fa}) - Q^{-1}(P_d)) SNR^{-1} - Q^{-1}(P_d)]^2$$

$$\text{...(7)}$$

Where   SNR $= \sigma_s{}^2 / \sigma^2{}_w$, $\sigma_w{}^2$ = Noise
variance, $\sigma_s{}^2$ = Signal variance,

- The decision test is performed on the computed value of T(Y). T(Y) is computed as

$$T(Y) = \frac{1}{N_{fft}} \sum_{n=1}^{N_{proc}} Y(n)Y(n)^* \quad \text{...(8)}$$

where Y(n) is the Nfft point FFT computed from y(n).

- The primary user signal is detected if $T(y) > |\gamma|$ otherwise it is not.

c.   Cyclostationary Feature Detection(CFD) method

The CFD approach is more robust to random noise and interference from other modulated signals than the approaches of matched filter detection and energy detecti- on, because the noise has only a peak of spectral correlation function at the zero cyclic frequency and the different modulated signals have different unique cyclic frequencies.

- These features are detected by analyzing a spectral correlation function that is a two-dimensional transform, in contrast with power spectrum density being one dimensional transform.

- Different modulating signals which have same power spectral density do have distinguishable spectral correlation function which is useful in obtaining the features (carrier frequency, symbol rate etc.)   of the primary user transmission[Gartner paper].

Important formulae and Algorithm:

Given the input time series x[n],n=0,1,2,...,N and sampling intervals T, the Cyclostationary feature detection (CFD) is conducted through the following steps ,
1)   We first calculate N point FFT of the input time series x[n],0n=,1,2,...,N for the frequency spectrum X[k].
2)   The cyclic periodogram or spectral correlation function (SCF) be calculated as,

$$S_x^{\alpha}(f) = \frac{1}{N} \sum_{f=0}^{N-1} X_{N_{fft}}(n, f + \alpha/2) X_{N_{fft}}^*(n, f - \alpha/2)$$

where   α – is the cyclic frequency or the feature to be detected.

3)   The spectrum frequency and the cyclic frequency must satisfy the following conditions for the reliable spectrum estimation (Δf/Δα)>>1 (where Δa, Δf are the cyclic spectrum resolution and frequency resolution respectively).Therefore perform discrete time frequency smoothening on the SCF as,

$$\tilde{S}_{X_T}^{\alpha}(k)_{\Delta f} = \frac{1}{M} \sum_{m=0}^{M-1} S_{X_T}^{\alpha}(k)[kM + m]$$

4)   The detection is equivalent to the detection of a dc component in the SCF for a continuum of values of f and a discrete set of values of α (which is {α,}).
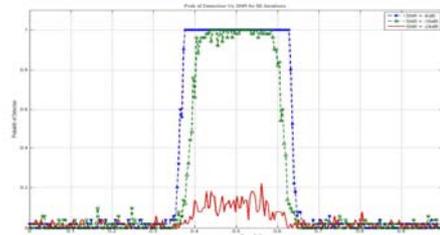
III.   Simulation results

Fig.1 Graph "Pd Vs SNR" of Energy Detector for various N_{max}
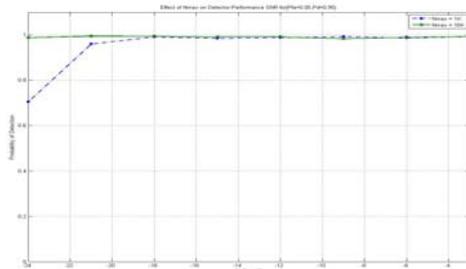
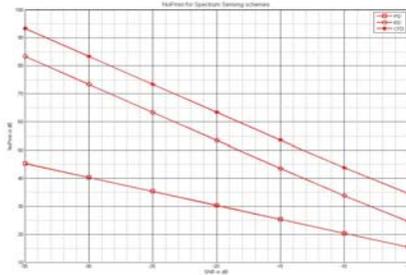Fig.2 Graph "Pd Vs SNR" of Pilot Detector for various N_{max}

Fig.3 Graph "SNR Vs NoPmin" comparison
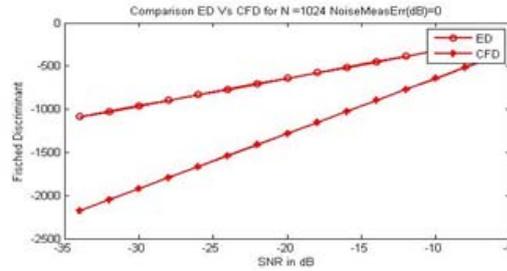for the the SS methods

Fig.4 Graph "SNR Vs Fischer Discriminant"
comparison for ED and CFD

IV.   Conclusion:

The following conclusions are drawn from the simulation work carried out

Sl.No	Description	Energy Detector(ED)	Pilot Detector(PD)	Cyclostationary Feature Detection(CFD)
1	Sampling Time requirements	Increases as SNR decreases @ $SNR^{-2.}$	Increases as SNR decreases @ $SNR^{-1.}$	Increases as SNR decreases @ K/SNR^{-2} where K=signal energy/feature energy.
2	Detection accuracy	Relatively Less	More	Good
3	Hardware complexity	Less	High, as we have build a matched filter for each primary user	Relatively High compared to ED but less than PD
4	Performance Sensitive to	Noise measurement Error,	Receiver frequency synchronization error	Sampling clock Offset, FFT size
5	Computational complexity	Less	More	Relatively High compared to ED
6	Sensitivity to Noise measurement error	More	More	Relatively less

V.   Related Research Papers

[1]   D. Čabrić, R. W. Brodersen, "Physical Layer Design Issues Unique to Cognitive Radio Systems," *16th IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC 2005)*, September 11-14, 2005.[2]

[2]   D. Cabric, S. Mishra, and R. W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in 38th Asilomar Conference on Signals, Systems and Computers, Nov. 2004.

[3]   W. A. Gardner, "Spectral correlation of modulated signals: Part I – analog modulation," IEEE Transaction on Communications, vol. 35, June 1987.

[4]   W. A. Gardner, W. A. Brown, and C. K. Chen, "Spectral correlation of modulated signals: Part II - digital modulation," IEEE Transaction on Communications, vol. 35, June 1987.

[5]   *Yingpei Lin and Chen He ,*SUBSECTION-AVERAGE CYCLOSTATIONARY FEATURE DETCTION IN COGNITIVE RADIO, IEEE Int. Conference Neural networks & Signal Processing, June 2008