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Efficient Hardware Architecture for Cyclostationary Detector

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Abstract

Objectives: Cognitive radio is evolved for utilising the unused spread spectrum effectively in wireless communication. The foremost concept is sensing the holes (white spaces) in the frequency spectrum allotted and it facilitates a way that how effectively and efficiently the bandwidth is used.**Methods/Analysis:**There are various methods available for sensing the spectrum and one such a sensing method is cyclostationary detection. The method of cyclostationary feature mainly focuses on detecting whether the primary user is present or absent. By using cyclic cross-periodogram matrix, the calculation of threshold of a signal is carried out to find the existence of noise or signal. **Findings:**The difficulty in evaluating the targeted threshold is evaded by training an artificial neural network by extracted cyclostationary feature vectors which are obtained by FFT accumulation method. **Novelty /Improvement:**This paper proposes hardware architecture for cyclostationary detection.

Keywords: Cognitive Radio, Cyclostationary, FFT Accumulation Method, Neural Network, SpectrumSensing

1. Introduction

There is drastic and massive change in the appel for number of applications in wireless communication systems. Some statutory bodies are involved strongly in framing standards to regulate and allocate the available spectrum bands to specific communication technologies. Several such organizations which are working on standards[1] for frequency allocation, are European Telecommunications Standards Institute (ETSI), the International Telecommunication Union (ITU) and the European Conference of Postal and Telecommunications Administrations (CEPT).Spectrum is a scarce resource, and licensed spectrum is supposed to be used by the spectrum owners only.

As per the OFCOM's report[2], a significant quantity of white space is available in the designated spectrum. It summarizes that above 50% of the space is 150 MHz interleaved and still more it is of 90% for 100 MHz interleaved frequency in a band of spectrum and also the cognitive Radio may be used in bands such as the 800 MHz (channels 61-69) in future.

Spectrum sensing is considered as the most important concern in the cognitive radio technology. At the Royal Institute of Technology in Stockholm, Mitola[3]has conceived the concept of cognitive radio. This gave an answer for congested spectrum problem based on the adaptable usage of the frequency bands[4].Provided the licensed users should not have occupied these frequency bands. The components in the cognitive radio have the ability to measure, sense, learn the parameters related to the radio channel[5,6] and also have the information regarding the availability of radio spectrum, power, the user requirements, applications and also its operating restrictions. In the dialect of cognitive radio, the Primary User (PU) is the user who has higher priority on the usage of allotted frequency spectrum. Secondary user is the user who has lower priority.

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The secondary user should access the spectrum without creating any interference to the existing primary user. The secondary user too will have the cognitive radio capabilities, like sensing the presence of primary user using the spectrum and also it will have the capability to vary its own parameters in order to utilise the unused band in the spectrum. Spectrum sensing should be done properly. If not done so, we will arrive at erroneous information pertaining to electromagnetic environment. Not only this, the unlicensed user will try to interfere with the spectrum allotted for the licensed user and also it will not search for the white spaces. As a result of this the performance of the cognitive radio system and the primary user[7] may get degraded.

Cyclostationary feature detection is more suitable choice than matched filter and energy detector techniques[8]. The matched filter detector which is a coherent type detector requires prior knowledge about primary user's waveform. A non-coherent energy detector does not require any such sort of prior knowledge about waveforms. The energy in the each channel is measured and checks whether it crosses a certain threshold for the existence of a primary user. Considering the major issue regarding the receiver such as sensitivity, at sometimes we need to maintain the threshold level to lower level even below noise floor. This is the case when we may fail in detection. Because of the presence of CR user's interference, the noise is most likely nonGaussian and this makes the problem more complicated. The short comings of energy detector is, it is susceptible to interference and noise levels[9] and it cannot discriminate signal power and noise power.

Most of the signals encountered in wireless communications are cyclostationary, whereas the noise is stationary. The signals from primary users are transmitted in periodic manner and this arrangement is said to be cyclostationarity which is used to detect the presence of primary users. In Cyclostationary Feature Detection, the level of computation is highly complex, its sensing time is more and another shortcoming is, we need to know some prior information regarding primary user. For this detection process, we need to set a threshold level. Now the spectrum's periodic cyclic frequencies are constantly examined and if the cyclo autocorrelation function is lower than the threshold level, then that frequencies is said to be vacant. Similarly, if the signal is above the threshold, then we can conclude the presence of primary users[10]. Sinusoidal carriers, repeating codes, cyclic prefixes, hopping sequences, pulse trains are some of the important features of a wireless communication signal which is cyclostationary and because of the signal's mean value, autocorrelation function it exhibits periodicity. We are interested in periodicity of a signal because of its usefulness in performing the functions like detection, identification and estimation of the received signal[11].The block diagram of cyclostationary detection is shown in Figure 1.

In a particular signal due to modulation and coding, the statistical features like mean and auto correlation changes with respect to time and so, the signal exhibits regenerative periodicity which is the distinctive property of cyclostationary process[6].

Cyclostationary feature detection can be achieved by following methods[1]

1. FFT Accumulation Method (FAM).
2. Striped Spectrum Correlation Method (SSCM).

We arrive at cyclic cross periodogram which is time smoothed represented in matrix form using these methods. In the cross periodogram the signal's correlation values are imported.The matrix will bring out the signal or noise which is dealt as an input to the detector. The size of the matrix is got decided by the sampling rate and the cyclic frequency. Threshold value is predicted by an Artificial Neural Network (ANN). Interconnection of neurons forms an ANN.By properly training the ANN the value of cyclic cross periodogram threshold is determined in the cyclostationary feature detection process.

2. Spectrum Sensing

For many years now, to detect the signal CR spectrum sensing system model is adopted. As per the theory of signal detection[10] the spectrum sensing by CR is modeled as follows. The signal received by the primary user can be charecterised as x(n) = s(n) + w(n) which includes the primary user's signal s(n) and the white noise w(n).

The intention of spectrum sensing is to make a decision between the two binary hypotheses i.e.,

H_0 also called the null hypothesis which gives information regarding the absence of the primary user signal:

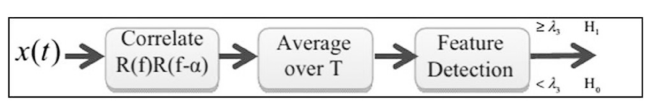

Figure 1. Block diagram of cyclostationary detection.

$$x(n) = w(n) \quad (1)$$ and

H_1 is a hypothesis that speaks about the presence of primary user signal: $x(n) = s(n) + w(n)$ (2)

Probability of missed detection (P_{md}) and Probability of false alarm (P_f) are the two vital factors used in Spectrum detection.When a busy channel is found unoccupied (idle), Misseddetection occurs.

This means that the detector has not detected the signal H_1 hypothesis. When an unoccupied (idle) channel is found to be busy, false alarm occurs. If this is the case we may come into conclusion that the null hypothesis (H_0)[11] might have a probability to detect the signal. From the above discussion we can arrive to the conditions such as:

$$P_{md} = P_r(H_0/H_1) \quad (3)$$

$$P_f = P_r(H_1/H_0) \quad (4)$$

The Probability of detection, P_d, is defined as

$$P_d = P_r(H_1/H_1) = (1 - P_{md}) \quad (5)$$

Spectrum sensing is another crucial parameter apart from the above mentioned parameters for the analysis. When the PU wants to come back to use their licensed spectrum there should not be any interference. So, the sensing time should be maintained as short as possible. IEEE 802.22 standard on cognitive radio has formulised on the sensing time, that it should be not more than two seconds[12]. Frequency resolution, bandwidth, power and area consumption are the other essential implementation parameters which to be considered.

3. Cyclostationary Feature Detection Algorithm

Data signal is a modulated stationary random signal where it's mean and auto correlation shows periodicity. Due to the Cyclostationarity feature this modulated random signal is detected even if the background noise is present. Signal x(t) is considered to be second order cyclostationary, if its mean and autocorrelation are periodic with a period T_0, i.e.:

$$Mx(t+T_0) = Mx(t) \quad (6)$$

$$Rx(t+T_0, \tau) = Rx(t, \tau) \quad (7)$$

Rx (t, τ) which is a periodic function can be stated as

$$R_x(t,\tau) = \sum_{n=-\infty}^{n=+\infty} R_x^{\frac{n}{T_0}}(\tau) e^{j2\pi\frac{n}{T_0}t} \quad (8)$$

Which is a cyclic autocorrelation function.

Let cyclic frequency α represent the frequencies $\{n/T_0\}_{n\in Z,}$. From the Fourier transform of the cyclic autocorrelation function (7) the spectral correlation density (SCD)can be obtained as

$$S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha(\tau) e^{i2\pi f\tau} d\tau \quad (9)$$

The SCD is treated as an estimation only, because all the signals which are analysed is spread over a finite time interval Δt.Normally to estimate the SCD, time smoothing and frequency smoothing methods are used. Among these methods time smoothing method is considered to be more computationally efficient[12]. SCD that was defined by the time-smoothed cyclic periodogram given by

$$S_x^\alpha(f) = S_{x_{Tw}}^\alpha(t,f)_{\Delta t} \quad (10)$$

Where Δt is the total observation time of the signal. For the time discrete expressions of SCD, we define the sampled signal

$$x(n) = x\left(n.\frac{1}{f_s}\right) \quad (11)$$

Where f_s indicates the sampling frequency and n=1, 2...N represents the total number of discrete samples within the observation time. The Figure 2 gives the block diagram for Principle of cyclostationary Detector.

A neural network is trained to optimize the threshold value to detect whether the signal is present or not.The ANNs are built with neuron which consists of n number of inputs along with weights of each input.The actual functionality of a neuron is represented by the summation part[13].Depending on the application, the summation node's output is fed to an activation function. The Figure 3 shows the general representation of neural network.

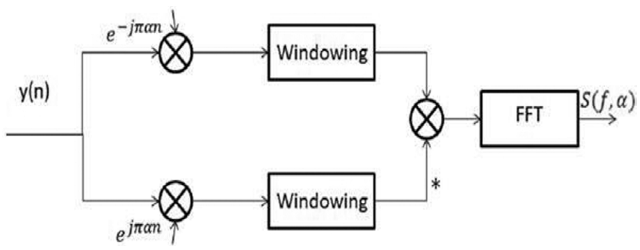

Figure 2. Principle of cyclostationary Detector.

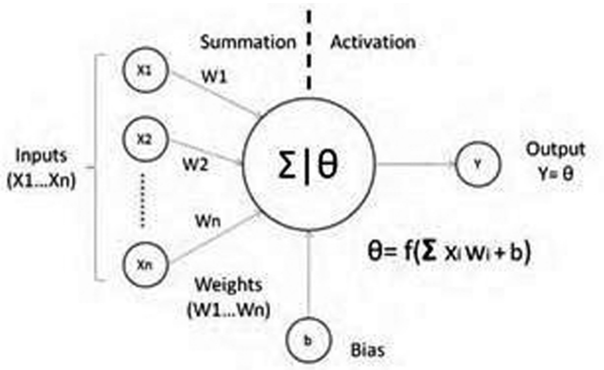

Figure 3. Representation of a Neuron with n number of inputs, weights of each input and activation function.

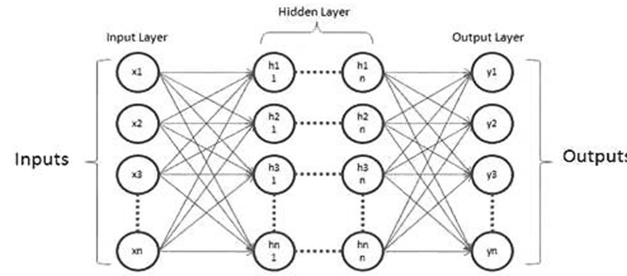

Figure 4. An artificial neural network model along with n inputs, hidden and output layers.

For back propagation neural network application, hyperbolic tangent (tanh) sigmoid function (tansig)[14,15] is oftenused activation function. The Figure 4 gives the back propagation neural network

The sigmoid function is given below

$$f(n) = \frac{e^n - e^{-n}}{e^n + e^{-n}} \tag{12}$$

The error is calculated as per the following equation

$$E = \Sigma_i E_i \tag{13}$$

$$E_i = \frac{1}{2}\Sigma_i \left(t_i - y_i\right)^2 \tag{14}$$

E represents the summation of all the errors, E_i is Error due to single output (y_i), corresponding target t_i and the weights are updated after the error calculation by using the following method.

$$\Delta W_i = \epsilon((t_i - y_i)x_i) \tag{15}$$

$$W_i = W_i - \Delta W_i \tag{16}$$

where,ΔW_i is change in weight of the i^{th} connection corresponding to the input x_i and W_i is the value of the old weight, $\epsilon > 0$ is the learning rate used in calculating weight change.

4. Hardware Implementation of Cyclostationary Detection Algorithm

Due to modulated signal's periodicity, the Spectral redundancies occurs and by these spectral components are widely separated and correlation is maintained by the Cyclostationary signals[16]. With the operating frequency of 5 GHz, the cyclic cross periodogram is realized with executing IEEE 802.11a signal as input to FFT accumulation method.

Cyclostationary feature detection is described in following steps:

The points of cyclic frequency are determined, the complex envelopes are estimated with a sliding N' point FFT, followed by a downshift in frequency to baseband. Some of the dominant cyclic features is analysed using Sliding windows. These windowed signals are Fourier transformed and computed in frequency domain. For each window frame the spectral correlation functionis applied and by taking its mean, normalization is done. By means of spectral correlation function, the primary user can be detected.

OFDM signals scheme helps us better in this process because of its flexibilities in digital communications techniques. The input to FAM which is OFDM Signal contains 64 sub-carrier out of which 52 are pilot and data subcarriers, 11 are guard sub-carriers and 1 is DC null. The OFDM signal is formed by totally 64 points IFFT. There are 4 pilot subcarriers out of 64 subcarriers and the data subcarriers are present at the positions other than pilot subcarriers. The index point 0 is the DC null. Figure 5 gives the FFT Accumulation method architecture.

The FAM is implemented by forming a two dimensional arrays from X (kT), where k varies from 0 to N-1. In this, the columns representing constant frequencies are obtained by applying Hamming window to the input, Fast Fourier Transformed and then down converted to baseband.

The major hardware part of the cyclostationary detection algorithm is FFT. The usage of pipelined architecture for FFT with radix-2^2 was a milestone. Then, radix-2^2 was extended to radix-2^k. During the literature

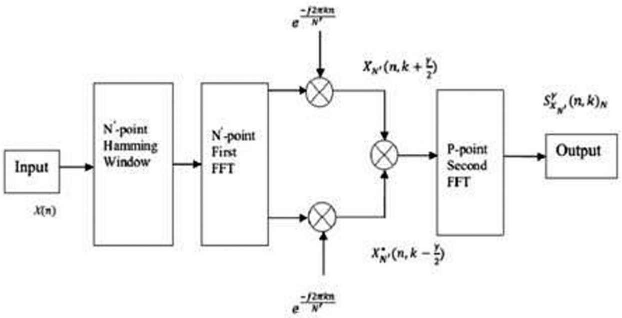

Figure 5. Architecture of FFT Accumulation method.

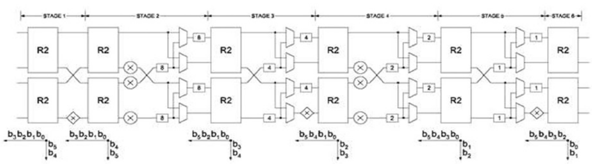

Figure 6. Proposed 64 point feedforward architecture.

survey, we had observed that for radix-2^k single-path delay feedback (SDF) type architectures many algorithms were found and for multi-path delay commutator (MDC) i.e., feedforward type many designs were not proposed. Hence for this feature detection we are intending to use radix-2^k feedforward (MDC) FFT architectures. In this architecture radix-2^k which is a power of 2 can be used on any number of samples in parallel. With these type of designs,we can arrive at better throughputs, thereby enabling them to suit for high speed applications. But for processing the samples in parallel, it requires a few hardware resources.64 point FFT architecture is shown in the Figure 6 is proved as more hardware-efficient and make them very attractive for the computation of the FFT.

5. Conclusion

In this paper, to predict the thresholds an artificial neural network has been trained from the features of cross-periodogram matrix of signal statistics. FFT accumulation method has been implored for detecting the presence of signal or noise. The proposed ANN Scheme clearly indicates the strength of the artificial neural network to detect the presence of spectrum holes. The proposed hardware architecture will improve the performance of the detector. By using data sets of different noise strength the threshold level has to be predicted for better accuracy and efficiency of the neural network in the presence of increased noisy datawill be included in Future work.

6. References

1. Federal Communications Commission (FCC) _ Spectrum Policy Task Force Report; 2002. p. 2–135.
2. OFCOM, Digital dividend: cognitive access, Consultation on licence-exempting cognitive devices using interleaved spectrum; 2009 Feb 16.
3. MitolaJ, MaquireGQ. Cognitive radio: Making software radios more personal, IEEE Personal Communications. 1999; 6(4):13–18.
4. Haykin S. Cognitive dynamic systems. Proceedings of IEEE. 2006 Nov; 94(11):1910–11.
5. Tkachenko A, Cabric AD, Brodersen RW. Cyclostationary feature detector experiments using reconfigurable BEE2. Proceedings of the DySPAN Chicago; 2007.p. 216–19.
6. BlossomE. GNU radio: tools for exploring the radio frequency spectrum. Linux Journal. 2004 Jun:112.
7. Lee W, Cho DH. Sensing optimization considering sensing capability of cognitive terminal in cognitive radio system. 3rd International Conference on Cognitive Radio Oriented Wireless Networks& Communications, CrownCom; 2008. p.1–6.
8. Yucek T, Arslan H. A survey of spectrum sensing algorithms for cognitive radio applications. Communications Surveys Tutorials. IEEE. 2009; 11(1):116–30.
9. Atapattu S, Tellambura C, Jiang H. Energy detection based cooperative spectrum sensing in cognitive radio networks. IEEE Transactions on Wireless Communications. 2001; 10(4):1232–41.
10. Vardhan SC, Ratnam DV, Nitin SA, Durga S. Spectrum sensing for cognitive radio using Hilbert-Huang transform average ratio detector. Indian Journal of Science and Technology. 2015 Dec; 8(34):1–5.doi: 10.17485/ijst/2015/v8i34/70785.
11. Chen J, Gibson A, Zafara J. Cyclostationary spectrum detection in cognitive radios. IET Seminar on Cognitive Radio and Software Defined Radio; 2008 Sep. p. 1–5.
12. Fehske A, Gaeddert AD, Reed JH. A new approach to signal classification using spectral correlation and neural networks. Proceedings IEEE DySPAN; 2005 Nov. p. 114–50.
13. Cordeiro C, Challapali K, Birru D. IEEE 802.22: An introduction to the first wireless standard based on cognitive radios. Journal of Communications. 2006; 1(1):38–47.

14. Yin L, Yin S, HongW, Li SF. Spectrum behavior learning in cognitive radio based on artificial neural network. Military Communication Conference MILCOM; 2001 Nov 7–10. p. 25–30.
15. Tumuluru VK, Wang P,Niyato D. A neural network based spectrum prediction scheme for cognitive radio. IEEE International Conference ICC; 2010 May 23–27. p. 1–5.
16. Po K, Takada J. Signal detection based on cyclic spectrum estimation for cognitive radio. IEEE 802.22 WRAN System, IEICE Technical Reports. 2007 Mar; 106(558):15–19.