Improvement of Spectrum Estimation using Multi-Tapering Method (MTM) in Cognitive Radio

K. Sruthi and R. Vadivelu

Abstract--- *The radio spectrum is an indispensable natural resource which gets wasted because of the unused frequency spectrum by the Licensed Users or Primary Users. Hence it is the necessity of the Unlicensed Users or Secondary Users to find out the unused spectrum from the Primary Users in order to cope up with the increasing demand of radio frequency spectrum. The cyclostationary property of the signals that vary cyclically with time is used to analyze the spectrum availability. Time smoothed cyclic periodogram method, even though not efficient for computing estimates of the entire bi-frequency plane, the FFT Accumulation Method (FAM), a variation in time smoothed periodogram proves to be a better method in analyzing the entire spectrum. Multi-Tapering Method (MTM) which proves a better windowing technique than hamming windowing is used to analyze and to improve the spectral estimation in FAM. Comparative results are produced and analyzed using hamming window and multi tapering windowing technique.*

Keywords--- *FFT Accumulation Method (FAM), Cyclostationary Signals, Time Smoothing Periodogram, Multi-Tapering Technique*

I. INTRODUCTION

COGNITIVE Radio is the phenomenon which helps spectrum sensing and sharing. The simple idea behind cognitive radio is to sense the unused frequency bands from one user and make it available for the other hence to make the efficient utilization of the available radio frequency resource [1].

To sense the spectrum availability there are many techniques available like energy detection method, matched filtering method, cyclostationarity and some probabilistic approaches [2]. Out of which the cyclostationary detector method works well in noisy environment. In that, the existing method is modified by means of changing a windowing technique in the design algorithm and the improvement is compared with the existing method. The power spectral density estimates of the existing and the proposed technique are compared and results produced with the help of MATLAB R2010.

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This paper is organized as follows: The section II describes the proposed work. In section III we describe the cyclostationary property of communication signals. In section IV we deal with time smoothing algorithm and its modification. Section V illustrates the bias variance problem and its solution. Sections VI and VII ends with simulation results and conclusion.

II. PROPOSED WORK

Usually it is the hamming window used in the FFT accumulation method. Hamming window being the derivative of the cosine windows, has wider spectrum bandwidth than other methods like the rectangular windows. But due to the bias variance dilemma, the windowing technique advanced than the hamming window i.e. the Multi-Taper window is implemented in this paper as in Figure.1.

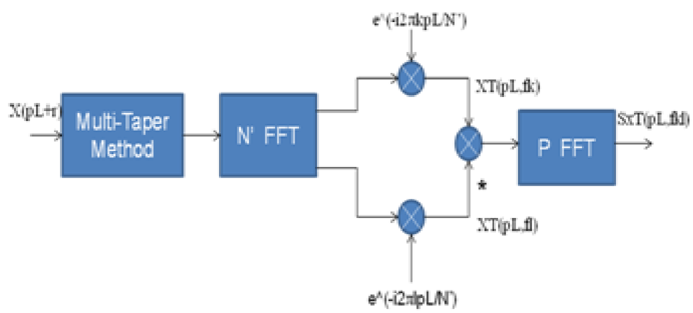

Figure 1: Proposed System Model

MTM overcomes the limitation of conventional Fourier Transform. It reduces the estimation bias by obtaining independent estimates from the same sample. This is because MTM concentrates on a single frame at a time.

III. CYCLOSTATIONARITY

A. Spectral Sensing Method

A Cyclostationary process can be viewed as a multiple interleaved stationary process. A Cyclostationary signal has statistical properties that vary cyclically with time. It is mathematically expressed as,

$$Rx\ (t, \tau) = Rx\ (t + T_0, \tau);\ \text{for all}\ [t, \tau]$$

Many signals used in the communication system exhibit periodicities of statistical parameters due to operations such as sampling, modulating, multiplexing. These cyclostationary properties which are named as spectral correlation features are used for spectrum sensing [3]. This method is used for signal detection and classification. The White space or noise is detected by a Radiometer, which is known for its energy detection capability or by using the method of Cyclostationarity. In both of these methods, the binary hypothesis testing problem is involved which refers to the testing of the presence of both the primary user signal and the noise [4]. But when both methods are compared the cyclostationary method proves to be a better option because of the two advantages of the method.

1. Ability to distinguish the co-channel interference.
2. Provide high Signal to Noise Ratio. (SNR)

The above said approaches are confined to white spaces only. If the area is to be extended to the gray spaces also (Signal with noise), then the spectrum can be estimated by two methods. Either the Parametric method or the Non-Parametric method is used [5]. There are different tools available for estimating the power spectrum in MATLAB.

B. Non Parametric Method

This is the method in which the PSD is estimated directly from the signal itself. The simplest such method is the periodogram. Other nonparametric techniques such as Welch's method, the Multi-Taper Method (MTM) reduce the variance of the periodogram.

IV. TIME SMOOTHING ALGORITHM

A basic time smoothing algorithm can be formed by evaluating the time smoothed cyclic periodogram at cycle frequency pairs (f_0, α_0) of interest. The time smoothed cyclic cross periodogram is given by,

$$S_{xy}^{\alpha 0}(n, f_0)_{\Delta t} = [X_T(n, f_0+\alpha_0/2)\ Y_T^{*}(n, f_0- \alpha_0/2)]_{\Delta t}$$

A small modification in the time smoothed cyclic periodogram leads to several computationally efficient algorithms [3].

1. The FFT Accumulation Method (FAM)
2. The Strip Spectral Correlation Algorithm (SSCA)

In this paper we deal with the FAM technique. Using an efficient Fourier Transform we obtain the time smoothed sequence and L-samples are skipped off to reduce the computational complexity

A. The FFT Accumulation Method

The FFT Accumulation Method (FAM) is a Fourier Transform of the correlation product between the spectral components smoothed over time shown in Figure.2. The cyclic spectral plane ranges in frequency from –fs/2 to +fs/2 and in cycle frequency from –fs to +fs where fs is the sampling frequency. The FAM cross spectral plane each cell is represented as (f,α). The FAM cross spectral estimate [2] is given by,

$$Sxy(pL,fkl)\Delta t= \sum XT(rL,fk)YT^*(rL,fl)\ gc(p-r)e^{\wedge}(j2\prod rq/P)$$

The FAM auto spectral estimate is given by,

$$Sxx(pL,fkl)\Delta t = \sum XT(rL,fk)XT^*(rL,fl)\ gc(p-r)e^{\wedge}(-j2\prod rq/P)$$

The FAM is implemented by forming an array from X (kT), where k=0 to N-1. A Hamming window is applied to each row which is then Fast Fourier Transformed and down converted to baseband to get a two dimensional array with columns representing constant frequencies.

The FAM technique is implemented by following steps. Input channelization, Windowing, FFT, Downconversion and Data Reduction. In the frequency array, the starting point of each succeeding row is offset from the previous rows star ting positions from L samples as shown in Figure.3.

The result at this point is a 2-dimensional frequency plane [7] with columns representing constant frequency as shown in Figure.3.

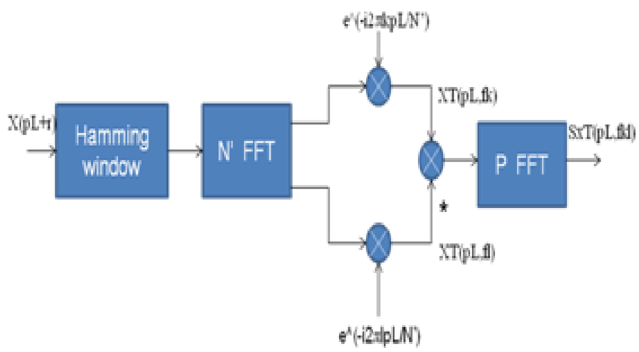

Figure 2: FFT Accumulation Method

Each column was point wise multiplied in turn with the conjugate of the columns resulting from the processing Y (kT).

- The input sample data is formed into a 2-D array with N=48, N’=16, L=4 and P=8.
- The array row length is equal to the number of input channels N’.
- For a given number of input sample points N, a row size of N’ and a chosen offset L, there are P= (N-N’)/L=N/L, number of rows are formed.
- The value of N’ must be chosen such that the time frequency resolution product must be greater than one.
- L value must always be less than N’/4.
- The completely filled array is with P rows and N’ columns.

The input signal is windowed and Fast Fourier Transformed, the result of which will appear from 0 to N’-1. Each row is downconverted to baseband signal by multiplying with the exponential term. The signal is then multiplied with its correlated value and then fast Fourier Transformed with L samples skipped to form the P point FFT. Data reduction is done to reduce the number large output data files due to FAM.

V. Bias Variance Problem

Smooth spectrums such as DFT and FFT have small variance because they produce similar spectra for different instance of the same random process. But at the same time over smoothing leads to increase the bias because of the reduction in the spectral resolution [8].

A good spectrum estimate therefore should have low variance to be robust against noise and other factors and at the same time it must retain low enough bias to be accurate enough for the achievement of the specified task.

When the hamming window is used it reduces the spectral leakage resulting from the convolution of the signal and the window function spectra.

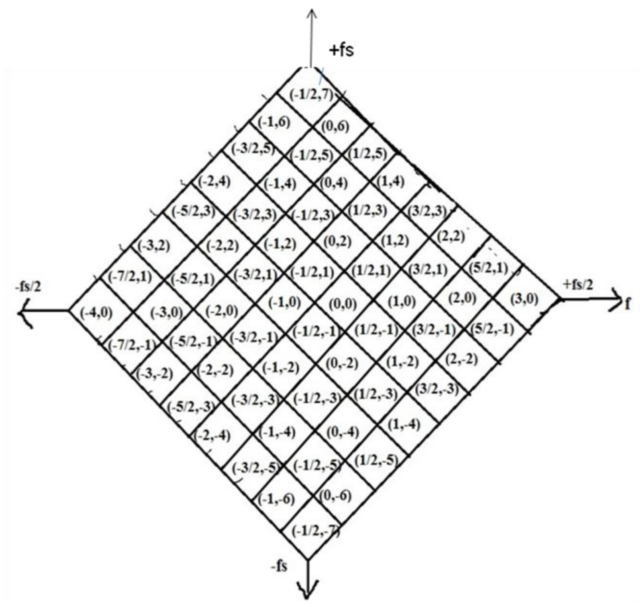

Figure 3: Frequency Plane

The windowing therefore reduces the bias. But unfortunately the variance remains high. Thus the variance needs to be reduced. One way to reduce it is to replace the hamming window spectrum estimate by a Multi-Taper spectrum estimate [10]. The Bias and Variance can intuitively be understood by considering the degree of smoothness in a spectrum estimate.

B. *Multi-Tapering Method*

The idea is to pass the analysis frame through two different window functions and form the final spectrum estimate as a weighted average of the individual sub-spectra. The window functions or the tapers are designed so that the estimation errors in the individual sub-spectra are approximately uncorrelated. Averaging these uncorrelated spectra gives a low-variance spectrum estimate. This Multi-Taper Method is similar to the well-known welch's method which forms a time averaged spectrum over multiple frames whereas MTM concentrates on only one frame at a time [12].

The output after the input is being presented into the window function and then to the FFT is given as the power spectrum density estimate with the help of MATLAB software. Using MTM, we obtain reduced spectral leakage than the hamming window, wider main lobe and robust spectrum estimate.

VI. Simulation Results

In order to improve the spectrum estimation we employ the MTM in place of Hamming window and the simulation results are obtained.

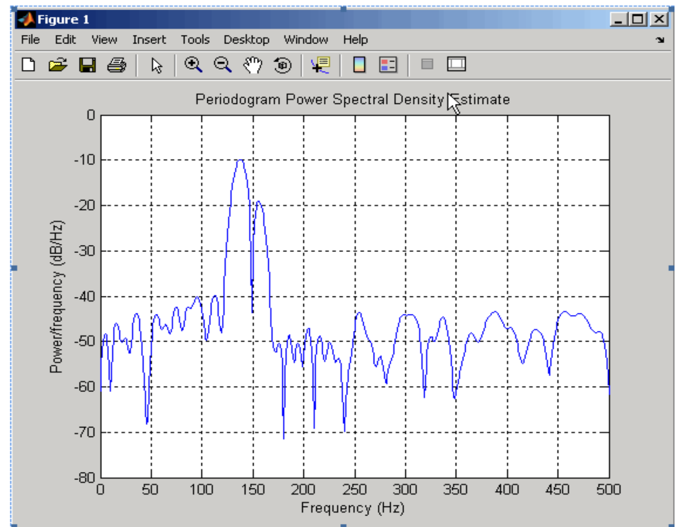

Figure 4: PSD Estimate of Hamming Window

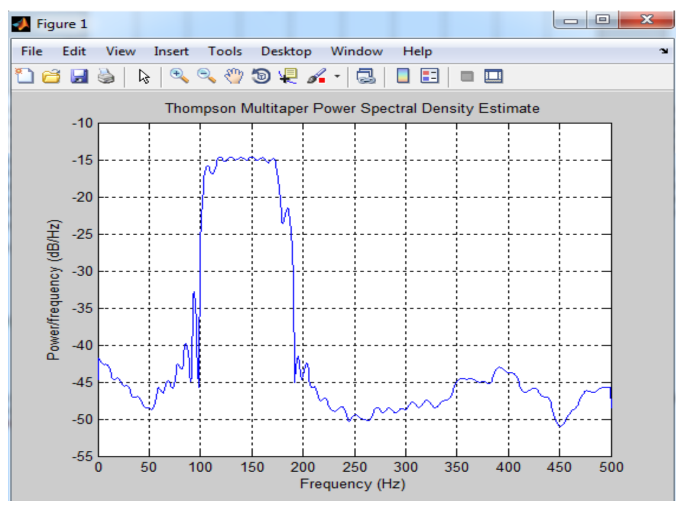

Figure 5: PSD Estimate of Mult-Ttaper Method

VII. Conclusion and Future Work

In order to provide the comparative results, the hamming window and the MTM are implemented only up to the N' point FFT block in the original FAM algorithm and the corresponding outputs are produced in terms of spectral estimates in the MATLAB tool as shown in Figure.4 and 5.

The width of the main lobe in hamming window is smaller than the Multi-Taper Method. Thus wider main lobe is obtained by using the Multi-Taper window.

The remaining work of finding the complex demodulates, correlating the signal and finding the power spectral estimates will be found in the future.

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