A Comparative Analysis of the Filter Bank Spectrum Sensing Methods for Cognitive Radio a Brain Empowered Technology

Ankita Jain[1] Dr. Deepak Nagaria[2]
[1,2]Department of Digital Communication
[1,2]Bundelkhand Institute of Engineers and Technology Jhansi, India

Abstract— Cognitive radio, an innovative approach to explore natural assets effectively: radio electromagnetic spectrum. It has emerged as fascinating wireless technology that effectively makes use of under-utilized spectrum to change the future technologies. It is basically an evolution of software defined radio which provides intelligence, learns from the environment and adapts itself keeping two purposes in mind.

- Whenever and wherever required reliable communication is provided.
- Radio spectrum is effectively utilized.

For effective utilization of the spectrum cognitive radio looks for the vacant spectrum or the underutilized spectrum. Hence at every knob of the Cognitive radio, network is bolstered by a spectrum analyser. This paper includes a comparison of filter bank sensing methods, a contrivance in CR systems for spectrum sensing. Wherein, performance evaluation of Filter Bank Spectrum Estimation and period-gram spectrum estimation is been done. FBSE has been analysed to be done without any cost.

Key words: Brain Empowered Technology, Filter Bank Spectrum Sensing Methods

I. Introduction

In recent past wireless communication have become a newly emerging and fastest growing field in the communication industry. Day by day due to increase in number of subscribers the allocated frequency spectrum is getting limited [1]. This leads to spectrum shortage, means restricted spectrum which causes hurdles in implementation of new wireless services. The further research in this field showed that it is not the scarcity of the spectrum but the underutilization of the fixed spectrum allocation is the main problem. In order to have full utilization of the spectrum, if we allow the access of licensed spectrum to the unlicensed user such that there is no interference, a big problem of spectrum utilization can be solved. Thus the solution of this problem can be achieved by cognitive radio that enables unlicensed user to have right to use the certified spectrum devoid of dominant user with legal right to utilize that spectral range [2].

The main aim of the paper is to introduce the utilization of a particular type of filter arrays which senses the spectral range in cognitive radio. This method of spectral range recognition will be done without any cost; at the receiver or at the output of the demodulator the power of the signal at the output of the subcarrier channel is calculated. WOSA, [3] weighted overlapped segment averaging; the most widely used period-grams and related procedure can be used in filter bank estimation comparatively with simpler prototype filters. The basic period-gram approach works on window of rectangular form in time as a prototype filter possessing large side lobes giving high losses in frequency domain in terms of side lobe leakage. Results are improved by performing FFT action with window functions supresses the side lobes.

Though tapering effect improve the performance but results in the loss of information by minimizing the leakage in power from the neighbouring sub bands. This loss in information degrades the accuracy and reliability of sensing results. To increase the accurateness of the evaluation multiple prototype filter in power spectrum estimation is used [4].

II. Spectral analysis methods

The various methods of Spectrum Sensing has been discussed and compared on the basis of the basic parameters.

A. *Filter Bank Spectral Estimator*

In the past, three communication techniques have been proposed regarding different filter bank multicarrier communication. Revolutionary effort has been done on filter bank multicarrier communication techniques. It showed that in a multichannel QAM system, it is possible to achieve a baud-rate spacing between adjacent subcarrier channels and still recover the information symbols, free of inter symbol (ISI) and inter-carrier interference (ICI) by proper design of a transmit pulse-shape, and by introducing a half symbol space delay between the in-phase and quadrature components of QAM symbols. This leads to the maximum spectral efficiency. Further research showed [7] that in a poly-phase/DFT structure the transmitter and receiver part of this modulation method could be implemented efficiently. The technique was named orthogonally multiplexed QAM (OQAM) in [8]. OQAM has been mentioned as OFDM-OQAM, standing for offset QAM, replicating that the in-phase and quadrature of each QAM symbol are time-offset with respect to each other.

FBSE uses a filter bank for signal analysis in which the input process is passed through a bank of filters and output power of each filter is measured as an estimate of the spectral power over the associated sub-band.

When a filter bank multicarrier technique is exploited as the physical layer of a CR network the same filter bank can also be used for channel sensing. In such systems, channel sensing will be done virtually Filtered multi-tone (FMT) is another multicarrier modulation.

B. *Period-OGRAM Spectral Estimator*

The period-gram spectral estimator (PSE), it takes a process x(n) arbitrary in nature and on the basis of recognition on N samples of x(n) an evaluation of the spectrum S(f) is done as [3].

$$\hat{S}_{PSE}(fi) = \left|\sum_{k=0}^{N-1} hi(k)x(n-k)\right|^2 \qquad (2.1)$$

Equation (2.1) is {x (n-k), k=0,1…,N-1} is the collection of samples, hi(k)= w(k)$e^{j2\pi fik}$,and w(k) has characteristics of window, w(k) is the coefficient of a FIR low pass sieve, hi(k) a has fi as the frequency at the centre and is a sieve that allows only a particular range of frequency to pass through. Let us take fi=i/N, i=0, 1…N-1, proto-type sieve w (k) is defined by a group of sieve hi (k). In the simpler method,

$$w(k) = 1/\sqrt{N}, \text{ for } k= 0 , ...N-1 \quad (2.2)$$

The magnitude rejoinder of sinc task is exemplifies the window function. The sinc pulse obtained is band limited in a spectral dynamic range in order to avoid spectral leakage. Thus a prototype filter with minor lobes is obtained by smoothly decaying both the sides by the help of tapered function [5].

The approximation of (2.1) draws a distinctive consideration as each sample of the approximations of (2.1) is centred on the mock-up of the corresponding sieve output. The approximations of the (2.1) are very bristly which states that accuracy value is very low. So in order to improve the accurateness of the appraised values is done by averaging in time domain. The method to perform the average in time domain a method called WOSA is been defined [6].

III. METHODOLOGY

The method of obtaining a bank of filter is been discussed below.

A. *Stimulation System of Filter Bank Spectral Estimation*

For successful estimation of the power spectral density of a random process with a wide spectral dynamic range a prototype filter with good stop-band behavior should be used. Slepian sequence constitutes a pack of orthogonal vectors which enlarges the series in time domain as{x(n), x(n-1)…..x(n-M+1)} or, equivalent x(n) = [x(n) x(n1)…….x(n-M+1)]^T in the range of frequency limited from (fi-Δf/2,to fi+Δf/2). In mathematical form, this is written as:

$$x(n) = \sum_{k=0}^{K-1} k_k(f_i) D q_k \quad (3.1)$$

Where, in equation (3.1) $k_k(fi)$ are the coefficients of expansion,q_k, pack of orthogonal vectors ,also represents the slepian sequences, K< N, diagonal matrix is given by D whose diagonal elements are 1, $e^{j2\pi fi}$, … …., $e^{j2\pi(M-1)fi}$. The equation (3.1) shows similarity with Fourier series expansion,

$$k_k(f_i) = (Dq_k)^H x(n) \quad (3.2)$$

In equation (3.2), H denote hermitian. Signal energy is evaluated in the frequency band (f_i-Δf/2, f+Δf/2) and is given by:

$$\hat{S}_{MTSE}(f_i) = \frac{1}{K}\sum_{k=0}^{K-1} |k_k(f_i)|^2 \quad (3.3)$$

Where, in equation (3.3) $k_k(f_i)$ is the output of bank of band pass filter whose coefficient vectors are Dq_k. Where, q_k is a set of prototype filter which constructs a set of filter bank. The spectral estimate of x (n) is obtained by averaging the output energy of the same numbered sub bands. Let a random process x (n) whose power spectral density is gives as:

$$\text{Ø}(f)=\begin{cases}1 & -\frac{\Delta f}{2} \le f \le \frac{\Delta f}{2} \\ 0, & otherwise\end{cases} \quad (3.4)$$

1) Let us make matrix of x (n) of size M*M which is correlation in nature. This matrix resembles to a symmetric Toeplitz matrix. The elements of the first row of the matrix consist of correlation matrix of x (n.)

$$\text{Ø}(k) = \Delta f \text{sinc}(\Delta f k), \text{ for } k = 0, .. ,.. …….M-1 \quad (3.5)$$

2) The starting K Eigen vector obtained from equation (3.5) of R i.e. q_0, q_1……q_{k-1}, are the desired slepian sequence. We conclude that q_0 which begins its stop-band energy at $\frac{\Delta f}{2}$ is the coefficient vector of a low pass vector. Now, Q_0 (f) represents the frequency response of the specified filter of q_0. It monitors that

$$\Lambda_0 = \int_{-\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} |Q_0(f)|^2 \,\text{Ø}(f)$$
$$= \int_{-\Delta f/2}^{\Delta f/2} |Q_0(f)|^2 df$$
$$= 1 - \int_0^1 |Q_0(f)|^2 df \quad (3.6)$$

From the Parseval's identity equation (3.6) gives

$$q_0{}^T q_0 = \int_0^1 |Q_0(f)|^2 d f = 1. \quad (3.7)$$

Equation (3.7) results in a filter in which stop-band energy $\int_0^1 |Q_0(f)|^2 d f$ is minimized.

A pair of matched root-Nyquist filters is the finest transmitter and receiver filters. A pair of matched root-Nyquist filters should be there at the transmitter and receiver of the prototype filter to satisfy the conditions required for perfect separation of subcarrier streams [8, 9]. The root-Nyquist filter is premeditated such that at the intervals of samples, zero-crossing occur where N is the maximum number of subcarriers. Where H(z) and G(z) =H(z)H(z^{-1}) are called root-Nyquist (N). Hence, in the time domain, following constraints should satisfy:

$$.g(n) = \begin{cases}1, & n = 0 \\ 0, & n = mN, m = 0\end{cases} \quad (3.8)$$

H (z) is a root-Nyquist (2N) filter [2]. Power spectral density of the output calculated as:

$$S_{yiyi}(f_i) = S_{xx}(f+ f_i)\left|H(e^{j2\pi f_i})\right|^2 \quad (3.9)$$

If we assume that H(z) is a narrowband filter in (3.9), we obtain:

$$S_{yiyi}(f_i) = S_{xx}(f_i)\left|H(e^{j2\pi f_i})\right|^2 \quad (3.10)$$

Where, S_{xx} (f_i) is a constantin (3.10) and results are rewritten in the form of z-transform, we get:

$$\text{Ø}_{yiyi}(z) = S_{xx}(f_i)\, H(z)\, H(z^{-1}) \quad (3.11)$$

Ø_{yiyi} (z) in equation (3.11) is the inverse Z transform which gives the correlation coefficient of y_i(n).

When root nyquist(N) is represented by H(z) (2). g_N (n) is Nyquist (N) sequence are resembles as a autocorrelation coefficient Ø_{yiyi} (k). The correlation matrix of the observation vector y_i(n) = [y_i(n), y_i(n-L)……, y_i(n-(K-L))], where L is the sample spacing, is the toeplitz matrix obtained in equation 3.11

$$R_{yiyi} = S_{xx}(f_i)\, A \quad (3.12)$$

A is defined as a matrix consist the elements as:

$$\begin{bmatrix} gN(0) & gN(n) & \dots & gN((K-1)L) \\ gN(-L) & gN(n) & \dots & gN((K-2)L) \\ & & & \vdots \\ gN(-(K-1)L) & gN(-(K-2)L) & & gN(0)\end{bmatrix} \quad (3.13)$$

Thus by using the toeplitz matrix from equation (3.5) and correlation matrix R from equation (3.7) the prototype filters are designed using the steps used in design of multi-tapered methods from (3.5-3.7).

IV. SIMULATION MODEL

This paper presents the cognitive radio network using Matlab file in MATLAB R2011a. We have use filter array spectral sensors in cognitive radio. A filter bank is been designed on the basis of the model shown below.

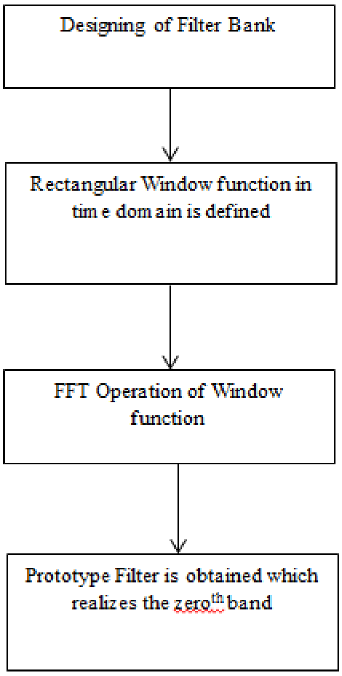

Fig. 2: Simulation Model of Prototype Filter

V. SIMULATION RESULTS AND ANALYSIS

Here the prototype filter by using period-gram spectral method has been obtained and various parameters like filter length (N), Number of samples (M), Signal to noise ratio (Gamma), roll off factor (alpha) has been varied and further analysis has been done Ideally alpha is 0.95 and gamma is 0.001 whereas variations has been shown by taking alpha as 0.5 and gamma 0.1.

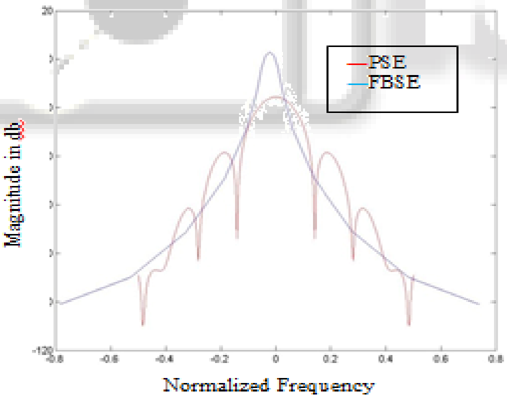

Fig. 3: Prototype Filter v/s Periodo-gram Filter

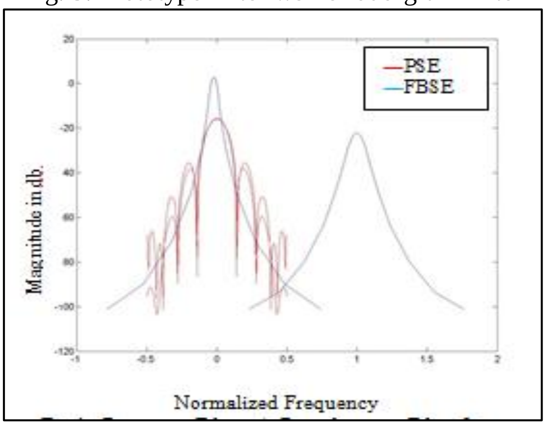

Fig. 4: Prototype Filter v/s Periodo-gram Filter for Gamma = 0.1

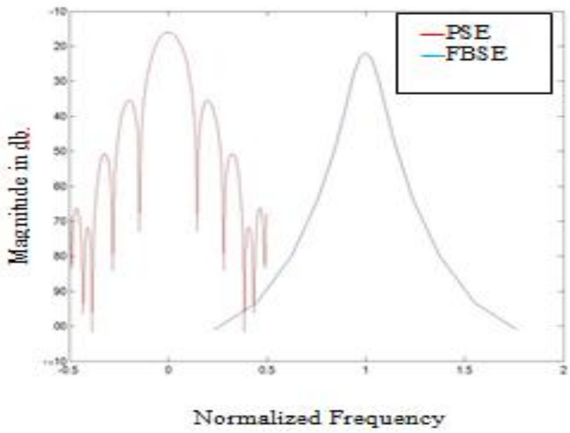

Fig. 5: Prototype Filter v/s Periodo-gram Filter for Alpha = 0.5

Fig.3 it shows the difference between the period-gram spectral estimator and filter bank spectral estimator where FBSE is shown to be better than period-gram spectral estimator.

Fig.4 PSE is more prone to noise due to increase in overlapping whereas FBSE is less prone to interference comparatively for gamma = 0.1.

Fig.5 PSE spectral peaks increases comparative to FBSE for alpha = 0.5.

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