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Detection of White Spaces for Cognitive Radio

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Abstract - In this paper we shall discuss about cognitive radio, spectrum hole in cognitive radio, spectrum utilisation in cognitive radio, IEEE 802.22 standard, spectrum sensing techniques, spectrum sensor, multitaper method, space time processing, time frequency analysis, step wise description of developed programme for matlab and results.

I. INTRODUCTION

As Per References (2),(6),(7),(8)

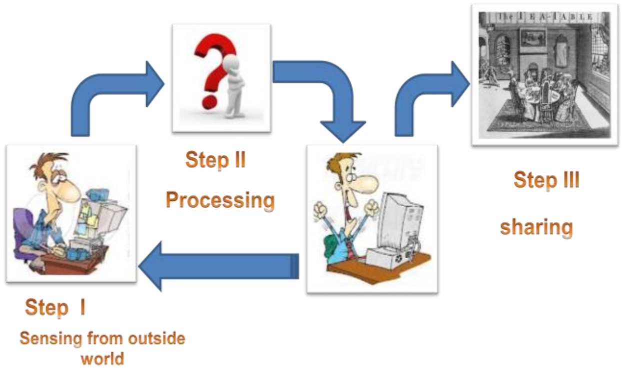

Figure 1 Cognitive radio definition

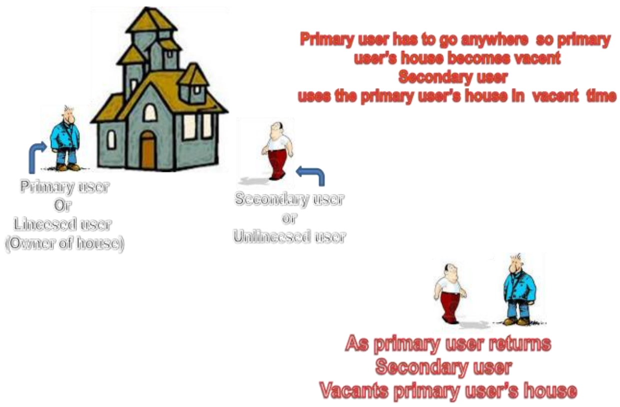

Figure 2 Spectrum hole in cognitive radio

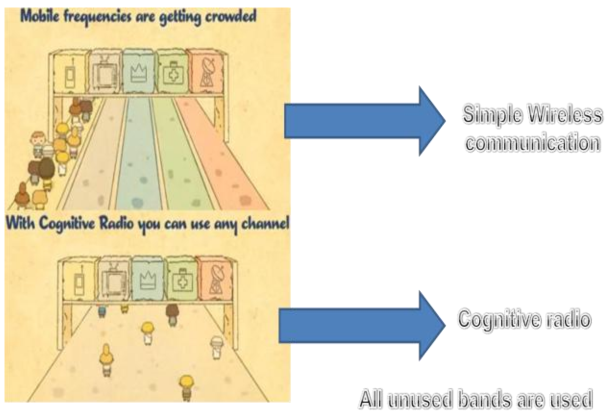

Figure 3 Spectrum utilization in cognitive radio

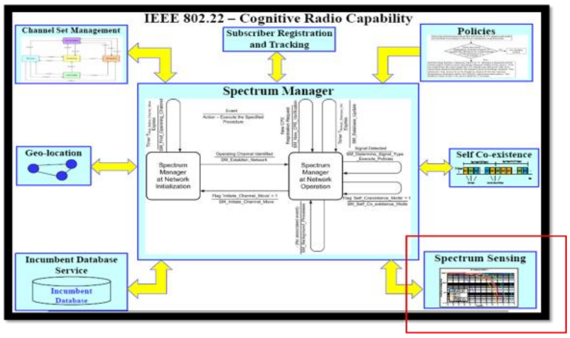

Figure 4 IEEE 802.22 for cognitive radio

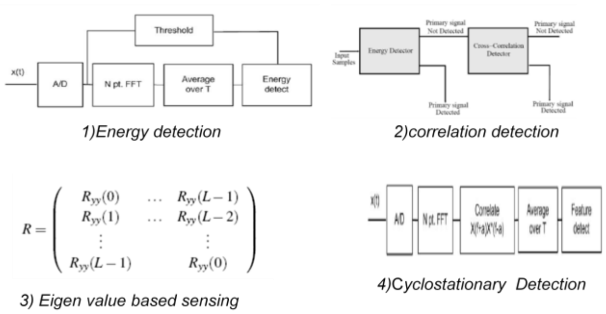

Figure 5 Sensing techniques techniques

5. Multitaper method

1. Spectrum sensor

(As per paper of Simon Haykin)

Three essential dimensions are required for sensing of radio enviornment

1. Time
2. Frequency
3. Space

A spectrum sensor consists of three parts

1. Multitaper method (Heart of system)
2. Singular value decomposition
3. Loeve transform

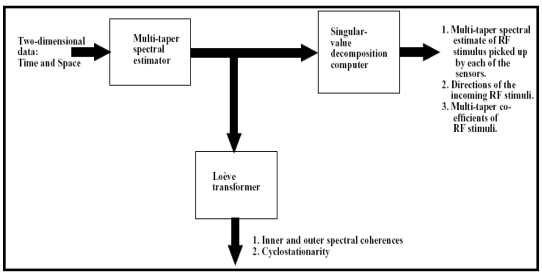

Figure 6 Block diagram for spectrum sensor

II. MULTITAPER METHOD

1. Older spectrum estimation methods suffered from bias variance dilemma.
2. To overcome this dilemma *MULTIPLE ORTHONORMAL TAPER* (WINDOW) are used.
3. Time series is linearly expanded from f-w to f+w. (where f is centre frequency) in a special family of sequence known as *SLEPIAN SEQUENCE*.
4. Fourier transform of Slepian sequence has maximum energy concentration in bandwidth 2W.
5. AN orthonormal sequence of slepian tapers, denoted by

$$\{v_t^{(k)}\}_{t=0}^{N-1};$$

1. Corresponding set of fourier transforms

$$X_k(f) = \sum_{t=0}^{N-1} x(t) v_t^{(k)} \exp(-j2\pi f t)$$

2. Time bandwidth $C_o = NW$ product bounds the numbers of tapers $K \leq \lfloor 2NW \rfloor$
3. Estimator for least sidelobe leakage, outside bandwidth 2w

$$\hat{S}(f) = \frac{\sum_{k=0}^{K-1} \lambda_k |X_k(f)|^2}{\sum_{k=0}^{K-1} \lambda_k}$$

4. It suffers from leakage as numbers of tapers increases so adaptive modification is done to multitaper specrum estimation, according it

$$\hat{S}(f) = \frac{\sum_{k=0}^{K-1} |d_k(f)|^2 \hat{S}_k(f)}{\sum_{k=0}^{K-1} |d_k(f)|^2}$$

Where

$$d_k(f) = \frac{\sqrt{\lambda_k} S(f)}{\lambda_k S(f) + \mathbf{E}[B_k(f)]}, \quad k = 0, 1, \ldots, K-1$$

4. Space time processing for sense of direction of incoming signals

1. Consider an array of M antenna and k slepian taper .
2. Then Spatiotemporal complex-valued matrix for m array of antenna and k slepian taper

$$\mathbf{A}(f) = \begin{bmatrix} a_0^{(0)} X_0^{(0)} & a_1^{(0)} X_1^{(0)} & \cdots & a_{K-1}^{(0)} X_{K-1}^{(0)} \\ a_0^{(1)} X_0^{(1)} & a_1^{(1)} X_1^{(1)} & \cdots & a_{K-1}^{(1)} X_{K-1}^{(1)} \\ \vdots & \vdots & & \\ a_0^{(M-1)} X_0^{(M-1)} & a_1^{(M-1)} X_1^{(M-1)} & \cdots & a_{K-1}^{(M-1)} X_{K-1}^{(M-1)} \end{bmatrix}$$

Where each row of matrix is produced by RF stimuli sensed at different grid point,each column is computed using different Slepian taper

3. There is signal +noise at the incoming R-F stimuli.
4. So SVD(SINGULAR VALUE DECOMPOSITION) is applied to matrix A(f) to compensate noise.

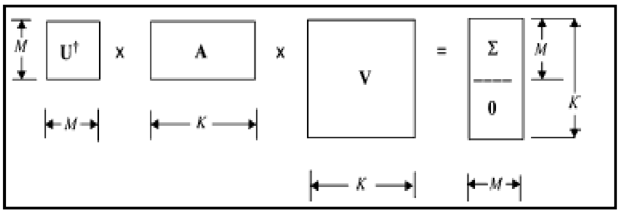

Figure 7 Diagrammatic representation of *SINGULAR VALUE DECOMPOSITION* applied to matrix A Where U is a m by m matrix , A is m by k matrix, v is k by k matrix

(Taken from Simon Haykin paper)

5. Time frequency analysis

1. LOEVE theory of time frequency analysis paves the way for finding cyclostationarity in a signal.
2. Estimate of loeve spectrum of first kind

$$\hat{\gamma}_{L,\text{outer}}(f_1, f_2) = \frac{1}{K} \sum_{k=0}^{K-1} X_k(f_1) X_k(f_2).$$

3. Estimate of loeve spectrum of second kind

$$\hat{\gamma}_{L,\text{inner}}(f_1, f_2) = \frac{1}{K} \sum_{k=0}^{K-1} X_k(f_1) X_k^*(f_2)$$

4. Loeve spectral coherence of first kind

$$C_{\text{inner}}(f_1, f_2) = \frac{\hat{\gamma}_{L,\text{inner}}(f_1, f_2)}{\left(\hat{S}(f_1)\hat{S}(f_2)\right)^{1/2}}$$

5. Loeve spectral coherence of second kind

$$C_{\text{outer}}(f_1, f_2) = \frac{\hat{\gamma}_{L,\text{outer}}(f_1, f_2)}{\left(\hat{S}(f_1)\hat{S}(f_2)\right)^{1/2}}.$$

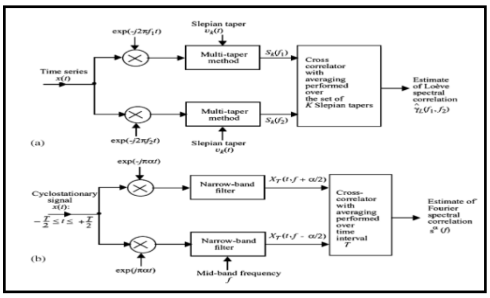

Figure 8 One to one correspondence between the *loeve* and *fourier theories* for *cyclostationary*

(a) The loeve spectral correlations of time series x(t)

(b) The fourier spectral correlations of cyclostationary signal x(t)

III. STEP WISE DESCRIPTION OF DEVELOPED PROGRAM

1. Waveform Generation

   a. Initializing parameters.

   b. Amplitude modulation for each carrier signal (Fc) and message

   Signal (x). [5-Carrier signals are assumed]

   c. Added all signals to form a waveform.

2. Assignment of primary user slots.
3. Assignment of empty slots to Secondary user
4. Adding user defined SNR value in dB.
5. Adding user defined %age of attenuation

IV. RESULTS

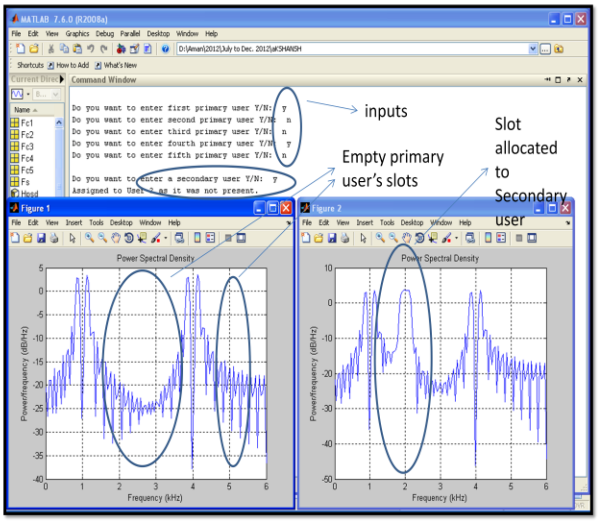

Figure 9

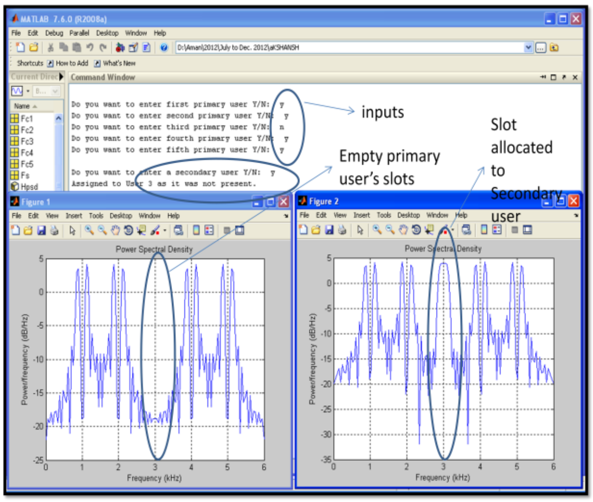

Figure 10

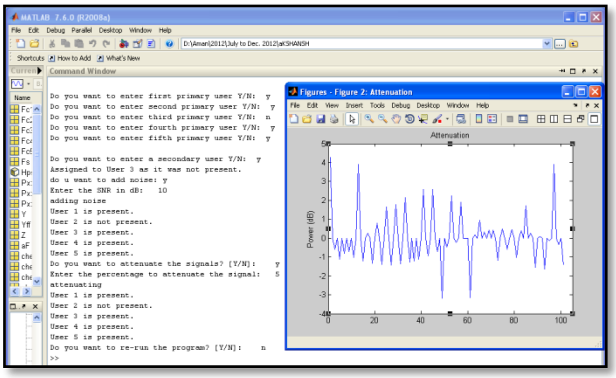

Figure 11

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