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Performance Analysis of Maximal Ratio Combining for Cyclostationary Feature Detection in Cognitive Radio Networks

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ABSTRACT

With some recent developments in the field of wireless communication, users are getting a number of applications which require the precious bandwidth to work on. As the bandwidth is limited, the available spectrum is being congested day by day. Cognitive Radio System plays an important role in such scenario. It adapts the parameters and protocols dynamically to provide unused spaces in the total usable spectra. There are a number of ways to detect the unused spectrum, Cyclostationary feature detection has been used in the given work. Spectrum sensing can be significantly improved by allowing different users to share their local sensing observations and to cooperatively decide on the licensed spectrum occupancy. From a number of combining schemes available, maximal ratio combining is incorporated as it is the most optimum of all. The main advantage of this detection technique is that it is robust to random noise and interference from other modulated signals, no synchronization is required and it gives optimal detection performance at very low SNR values. On the other hand, it has some limitations such as high computational complexity and increased sensing time.

Keywords-- ognitive radio, cyclostationary feature detection, cyclic spectral density, cooperative spectrum sensing, maximal ratio combining.

I. INTRODUCTION

The efficient use of available spectrum is a key requirement for wireless system design, since spectrum is a finite resource. The transceiver in cognitive radio (CR) communication has the power to observe communication channels that don't seem to be in use, and instantly get in empty channels whereas avoiding occupied ones. For further discussion, it is useful to distinguish between the two different definitions of cognitive radio:

- All the transmission parameters, i.e., modulation format, multiple-access method, coding, as well as center frequency, bandwidth, transmission times, and so on are adopted by a fully cognitive radio. A fully cognitive radio currently seems too complicated for practical purposes.
- A "spectrum-sensing cognitive radio," only adapts the transmission frequency, bandwidth, and time according to the environment. Such cognitive radio is also called Dynamic Spectrum Access (DSA).

There are three kinds of models for DSA:

- Dynamic exclusive model.
- Open sharing model
- Hierarchical access model

In Dynamic exclusive model, a frequency band is still reserved for the exclusive use of a particular service, but different providers can share the spectrum. In Open sharing model, all users can access the spectrum equally, subject to certain constraints on the characteristics of the transmit signal. The key principle of hierarchical cognitive radio is that the secondary users do not disturb the primary users. Such non disturbance can be achieved by three fundamental approaches: interweaving, overlay, and underlay. In the interweaving approach, the radio first identifies those parts of the spectrum that are not being used at a certain time, and transmits in those; thus, such a radio is a spectrum-sensing radio. In an overlay approach, the cognitive radio detects the actually transmitted signal of the primary user, and adjusts its own signal in such a way that it does not disturb the primary receiver even though it transmits in the same band. In the underlay approach, the secondary user actually does not adapt to the current environment, but always keeps its transmit Power Spectral Density (PSD) so low that its interference to primary users is insignificant. [13]

II. PRINCIPLES OF INTERWEAVING

- **Spectrum sensing**: The cognitive radio has to identify which parts of the time–frequency plane are not used by primary users. The sensing has to be done in the presence of noise, so that the sensing cannot be completely reliable. [13]

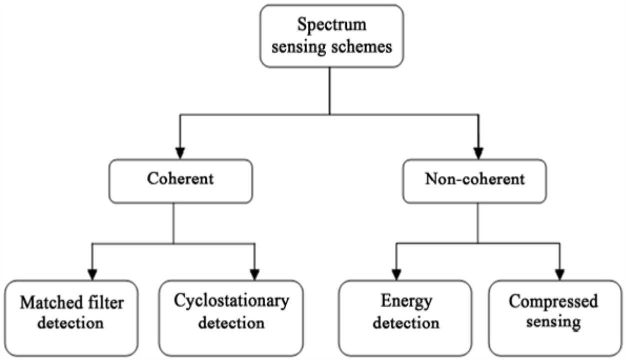

Figure.1: Types of Spectrum Sensing

- **Spectrum management**: The secondary system decides when, and in which part of the spectrum, to transmit. This decision is difficult for several reasons:

(1) The secondary system has only causal knowledge of the spectrum occupation, i.e., it knows only which parts of the spectrum were free in the past and the present, but it has to make assumptions (that are not necessarily correct) about how the primary system will work in the future, i.e., at the time when the secondary system will actually transmit.

(2) The sensing information on which the decisions of the secondary system is based are not perfect.

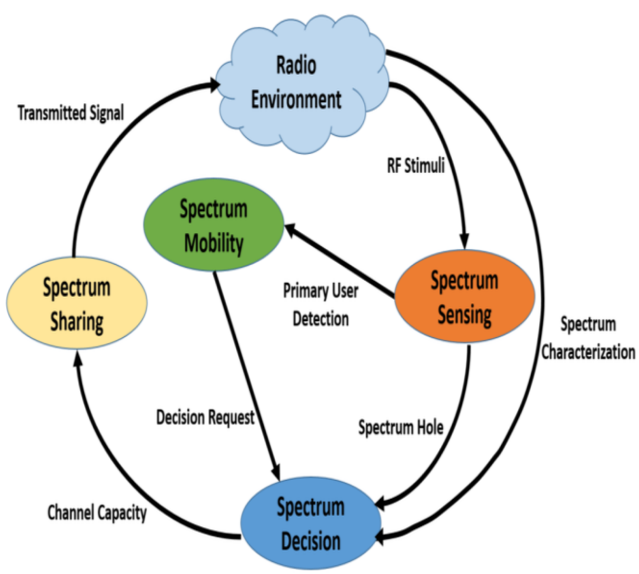

Figure.2: Principles of interweaving

- **Spectrum mobility:** A secondary user using primary user's band has to stop transmitting and find another spectrum hole to transmit, whenever the primary user returns to use its band.
- **Spectrum sharing**: A decision on how to divide up the free spectrum that the secondary system uses. Spectrum might be usable for a particular secondary transmitter (TX), but not for another.

III. CYCLOSTATIONARY FEATURE DETECTION

Cyclostationary feature detection is also known as non-blind sensing technique because it requires certain information of PU signal. In order to segregate PU signal and CR signal, this technique analyzes signals periodicity. Based on the periodicity, this detection method can easily isolate the noise from the PU signal. PU signals are joined with sine wave carrier signals, repeating spreading code sequences, or cyclic prefixes, all of which have a built-inperiodicity, their autocorrelation and mean show periodicity which is characterized as being cyclostationary. Noise is a wide sense stationary signal having no correlation. Basic flow diagram of CFD is shown below:

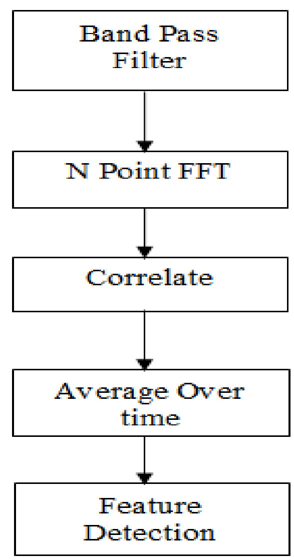

Figure.3: Block Diagram of CFD

The Cyclic Autocorrelation Function (CAF) and α denotes the cyclic frequency. Cyclic frequency is presumed to be a known parameter to the receiver. CAF is calculated as:

$$R_x^{\alpha}(\tau) = \frac{1}{T}\int_{\frac{-1}{T}}^{\frac{1}{T}} R_X(t+\frac{\tau}{2}, t-\tau/2)e^{-j2\pi\alpha t}dt$$

With the help of spectral correlation function, it is possible to distinguish noise signal energy from PU signal energy and thus sense if PU is present. [12]Spectral correlation function is obtained as:

$$S_x^{\alpha}(f) = \int_{-\alpha}^{\alpha} R_x^{\alpha}(\tau)e^{-j2\pi f\tau}d\tau$$

When the Cyclic spectral density or spectral correlation function for such signals is calculated taking Fourier transform of the correlated signal results in the peak at frequencies which are specific to a signal.

IV. IMPLEMENTATION OF DETECTOR

In order to implement the cyclostationary feature detector, the following steps are followed:

- Determine the cyclic frequencies for the signal, carrier frequency, window size, overlap number and FFT size as:

n = message length
nv = overlap number
nw = window size
$nfft$ = fft size

$$nv = \frac{2}{5}n$$

$$nw = \frac{3}{2}n$$

- The signal of interest say 'x(t)' is shifted in time domain by '$-\alpha/2$' and '$\alpha/2$' as:

$$x_1(t) = x(t).e^{-j2\pi(\alpha/2)t} \qquad x_2(t) = x(t).e^{j2\pi(\alpha/2)t}$$

- Now both the shifted signals are multiplied by a sliding window. The window used in this case is hanning window

$$Window = hanning(nw)$$

$$x_{i1}(t) = x_1(t).window$$

$$x_{i2}(t) = x_2(t).window$$

- Now Fourier transform of these windowed signals is done as

$$X_{i1}(f) = fft(x_{i1}(t), nfft) \qquad X_{i2}(f) = fft(x_{i2}(t), nfft)$$

- Spectral correlation function for each frame is found out and then it is normalized by its mean.
- Now maximum amount of the spectral correlation function is found. This is compared to a threshold to find the presence of a primary user

$$\mathrm{C} = \max(S_X^{\alpha})$$

Now 'C' is compared with a threshold 'λ'.

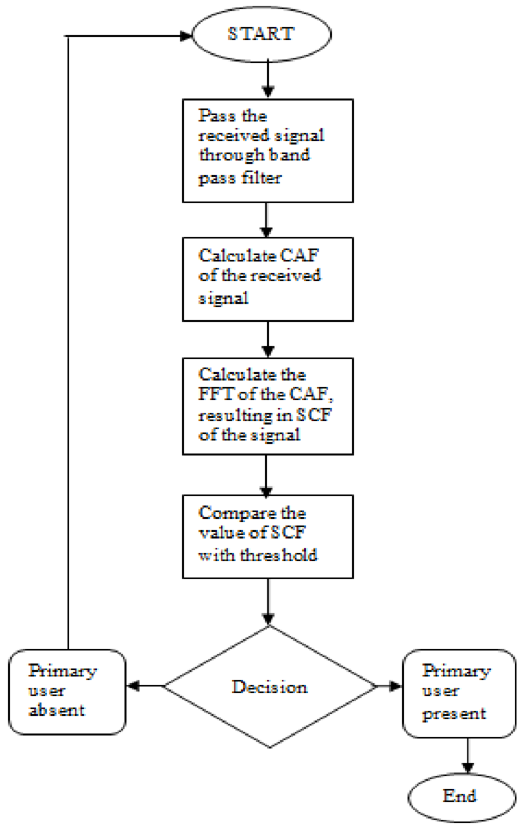

Figure.4: Flow chart of CFD

- The probability of false alarm for the cyclostationary detector is given as:

$$P_f = \exp\left[-\frac{(2N+1)\lambda^2}{2\delta^4}\right]$$

- From the above equation the threshold can be calculated as:

$$\lambda = \sqrt{(\frac{2\delta^4}{(2N+1)}\ln(P_f))}$$

- This value of threshold can be used to calculate the probability of detection as

$$P_d = Q\left[\sqrt{\frac{2\gamma_{cp}}{\delta^2}}, \frac{\lambda}{\delta_B}\right]$$

$$where,\ \delta_B = \frac{(2\gamma_{cp}+1)\delta^4}{2N+1}$$

'δ' is the variance of the received signal, 'N' is the number of samples values of the signal and 'γ_{cp}' is the SNR.

V. SIMULATION AND RESULTS

A 100 MHz test signal is taken which is QAM modulated. Which is then transmitted through AWGN channel, this signal is received by secondary users. The cyclic power spectrum obtained for the signal is shown in figure 4. The peaks can be observed at f=100 MHz (alpha=0) and alpha=200 MHz when (f=0).

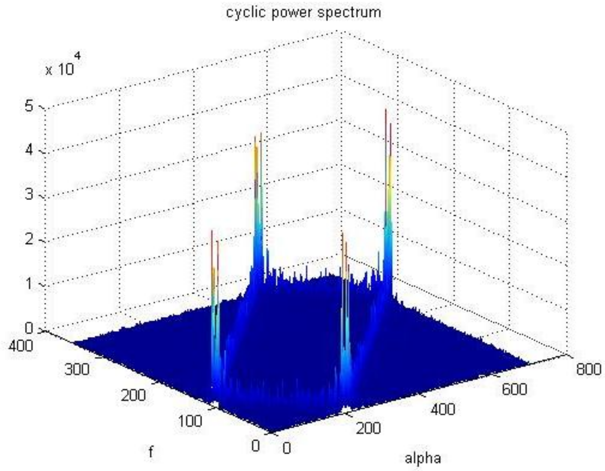

Figure.5: Cyclic power spectrum for f=100MHz

The obtained curve for probability of detection, probability of false alarm versus SNR is shown in figure 5.

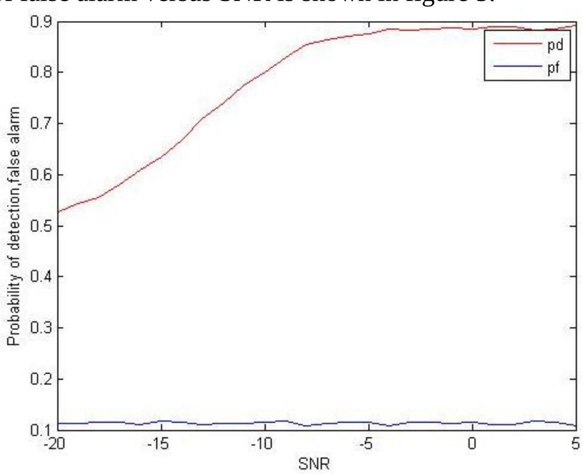

Figure.6: ROC curve for SNR vs probability of detection, false alarm.

The result obtained shows that cyclostationary feature detection is a highly reliable detection scheme even at low SNR values like -20dB. The probability of false alarm obtained is also very low in this scheme as the noise in the signal doesn't get correlated during the CAF calculation and is removed. So only the signal is detected, if present, keeping false alarm always low.

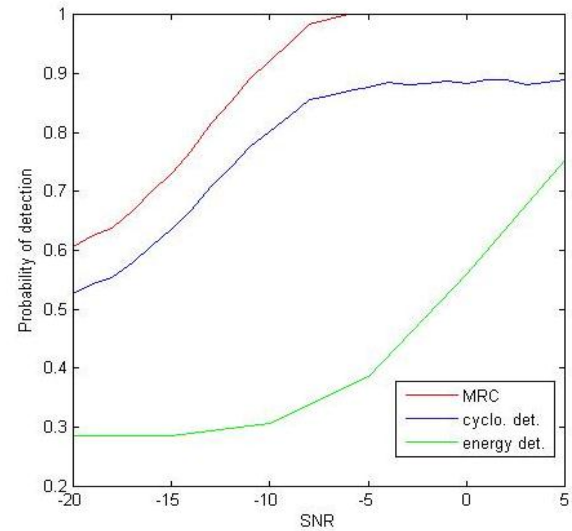

Figure.7: ROC curve for SNR vs Probability of detection

The result obtained in Figure 6 shows that cooperative sensing gives better results than single user sensing. Also, the comparison between Cyclostationary feature detection and energy detection in the above graph proves that Cyclostationary feature detection is better detection scheme at any SNR value even below -20 dB.Table 1 contains the values of probability of detection at different SNR value, obtained on implementing Cyclostationary feature detection, CFD followed by MRC i.e. cooperative sensing with five secondary users and energy detection. It can be clearly seen that cooperative sensing is much better and reliable than single user sensing. It also overcomes all problems/challenges occurring in sensing like hidden node problem, shadowing, fading due to multipath components, etc.One can implement this detection scheme if the work demands operation at low SNR values at the cost of increased complexity.

Table1: Comparison table for Pd versus SNR

SNo.	SNR (dB)	Probability of detection		
		Energy Det.	CFD	CFD with MRC
1	-20	0.2854	0.53	0.61
2	-15	0.2855	0.64	0.73
3	-10	0.30	0.81	0.93
4	-5	0.38	0.87	1.00
5	0	0.55	0.88	1.00
6	5	0.75	0.90	1.00

VI. CONCLUSION

To efficiently utilize the wireless spectrum cognitive radios were introduced which utilize the holes present in the spectrum. The most essential aspect of a cognitive radio system is spectrum sensing and various sensing techniques which it uses to sense the spectrum. To increase the accuracy and reliability of sensing results co-operative spectrum sensing is performed, a number of secondary users perform local sensing and send their local sensed data to a common hub called fusion center. Maximal Ratio combining is studied and simulated in order to examine its performance. Also, as the false alarm probability increases the minimum number of users which are required for satisfactory performance decrease. Thus instead of keeping a fixed number of users for fusion schemes in co-operative spectrum sensing, the number can be varied in accordance with the false alarm probability.

Comparison of the implemented work with other detection scheme i.e. energy detection is also done. Results show that cyclostationary feature detection method is much better than energy detection at any SNR value. In future, a hardware implementation of the Cyclostationary detector can be done so that it can be put to real time sensing. It becomes difficult to go beyond the physical layer in MATLAB for optimization so use of Network Simulator opens up more opportunities by allowing cross layer techniques.

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