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Study on Spectrum Sensing Techniques under Low SNR

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Abstract- Detection of spectrum hole is one of the essential criteria of cognitive radio networks which enable cognitive radio users to coexist with licensed users without harmful interference. The radio frequency spectrum is not efficiently allocated among licensed users, which leads to scarcity and dependence of spectrum resource in the modern era. One of the ways to improve the efficiency and utilization of an available frequency spectrum is to share the same spectrum resource among the licensed and unlicensed users. The cognitive radio systems aim to overcome the problem of limited radio frequency spectrum by helping to achieve improved spectral management, utilization, and efficiency. One of the most necessary requirements before performing spectrum sharing is spectrum sensing. There are many spectrum sensing algorithms available for cognitive radio technology. This paper has examined the most suitable detection method under low signal to noise ratio. Hence, a comparative study has been done on the Covariance-based and Cyclostationary feature based detection method in a dense urban area.

Keywords- Spectrum Sensing; Covariance-Based Detection; Cyclostationary Feature Detection; Probability of Detection.

I. INTRODUCTION

The radio frequency (RF) spectrum popularly known as the electromagnetic spectrum is the natural resource for wireless communication and is divided into multiple bands based on some characteristics. The radio frequency band has been regulated by the federal communication commission (FCC) for different licensed users. As the entire spectrum based is already allocated to different services, a fundamental problem of spectrum scarcity arises during high demand for spectrum resource. However, the real situation with these allocated bands is that often these are underutilized with large spectrum holes at the different geographic location over a certain period of time [1]. Cognitive radio (CR) is a new way to overcome the spectrum shortage problem. It will allow smart and dynamic spectrum management in future wireless communication networks [2]. It is a radio or system which can sense its operational electromagnetic environment and, in turn, can dynamically or automatically adjust its operating parameters to improve system performance. Among the various Spectrum sensing in the transmitter spectrum sensing technique, SUs detect those signals that are transmitted from transmitters. In transmitter base sensing SUs detect the primary users (PUs) with or without prior signaling information of PUs.

Covariance-based spectrum sensing has been examined in [3]. In a cognitive radio network, Covariance-based spectrum sensing detects the presence of PUs, without any prior signaling information. However, Covariance-based sensing can be able to detect the PUs only at high SNR [4].In case of the low value of SNR, the Covariance method is inefficient [5-6]. For efficient detection, Covariance-based detection depends on the predefined system threshold value [7]. The selection of a predefined system threshold depends on the theoretical model.

Hence, the Covariance-based technique is not suitable for urban areas where SNR of the received signal is generally lower than the predefined system threshold due to the dense network traffic. At the low SNR, the performance of spectrum sensing can be enhanced by considering the Cyclostationary

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feature detection technique [8-10] as a spectrum sensing technique. In this paper, we have performed a comparative study of Covariance-based detection technique and Cyclostationary feature detection in an urban area. The fundamental objective of our work has focused on to maximize the probability of detection.

II. PROPOSED SCHEME

To improve the spectrum sensing performance in urban areas, we have considered Cyclostationary based feature detection technique. To justify, our selection in this paper, we have performed a comparative study on Cyclosttionary feature detection and Covariance-based detection in dense traffic condition. With the help of MATLAB Simulation, we have analyzed the performance of Cyclostationary feature detection and Covariance-based detection in the emulated urban scenario.

The performance of the detectors are characterized by the probability of detection (P_d) and the probability of false alarm (P_{fa}), sensing time and number of received signal samples.

For Covariance-based detection adaptive system threshold ($\gamma_{S/M}$) can be calculated as-

$$\gamma_{S/M} = \frac{1+(L-1)\sqrt{\frac{2}{N*\Pi}}}{1-Q^{-1}(P_{fa})*\sqrt{\frac{2}{N}}} \qquad (1)$$

In equation (1), L represents Number of level and samples respectively. N represents Number of sample respectively.

γ_L is level of threshold. γ_L can be calculated as-

$$\gamma_L \rangle (1+(L-\frac{1}{4.54})) \qquad (2)$$

Probability of detection (P_d) can be calculated as-

$$P_d = 1-Q\left(\frac{\frac{1}{\gamma_{S/M}}+\frac{\gamma_L+SNR}{\gamma_{S/M}\times(SNR+1)}-1}{\sqrt{\frac{2}{N}}}\right) \qquad (3)$$

In equation (3) Q represents Generalized Marcum Q-function.

For Cyclostationary feature detection the expression for the false alarm probability $\left(\mathbf{P_{fa}}\right)$ can be calculated as-

$$P_{fa} = e^{-\frac{((2N+1)\gamma_{S/N}^2)}{(2*\delta^4)}} \qquad (4)$$

In equation (4), N represents Number of samples respectively.6

$\delta^2 represents\ Noise\ variance. \delta^2 value\ is$ 1. For Adaptive Gaussian noise environment.

$\gamma_{S/N}$, represents adaptive system threshold.

Probability of detection(P_d) can be calculated as-

$$P_d = Q(\frac{\sqrt{2*\gamma_{S/N}}}{\delta},\frac{\lambda\sqrt{2N+1}}{\delta}) \qquad (5)$$

In equation (5) γ represents Signal to Noise Ratio respectively.

Q represents Generalized Marcum Q-function

Sensing time:

$$\tau_s \geq \frac{2}{\gamma^2 f_s}(Q^{-1}(p_F)-Q^{-1}(p_d))^2 \qquad (6)$$

f_s , refers sampling frequency.

III. SYSTEM MODEL

In CR network the major task of the SU as quickly as possible detect the present of PU signal in a quite frequency band and in licensed band .This technique is known as spectrum sensing [11-12].

$$y(n) = \begin{cases} w(n) : H_0\ pu\ is\ absent \\ h*x(n)+w(n)\ : H_1\ pu\ is\ present \end{cases}$$

Where n=denotes the number of sample. n varies 1….N. $y(n)$ is the secondary user received

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signal ,$x(n)$is the PU signal ,h denotes amplitude gain and $w(n)$ denotes additive white Gaussian noise(AWGN) with zero mean and variance δ^2.The detector output is test statistic .The detector output is then compare to threshold according to make decision the PU signal is present.

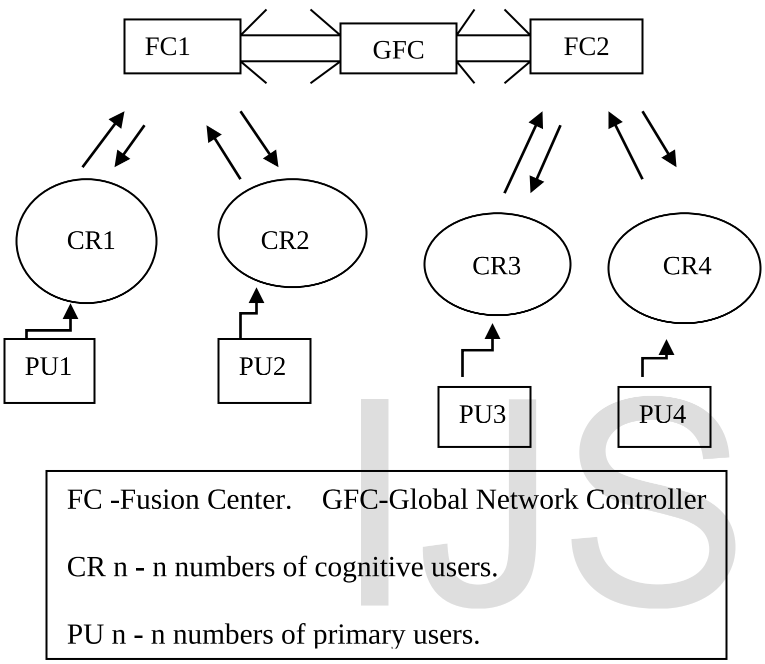
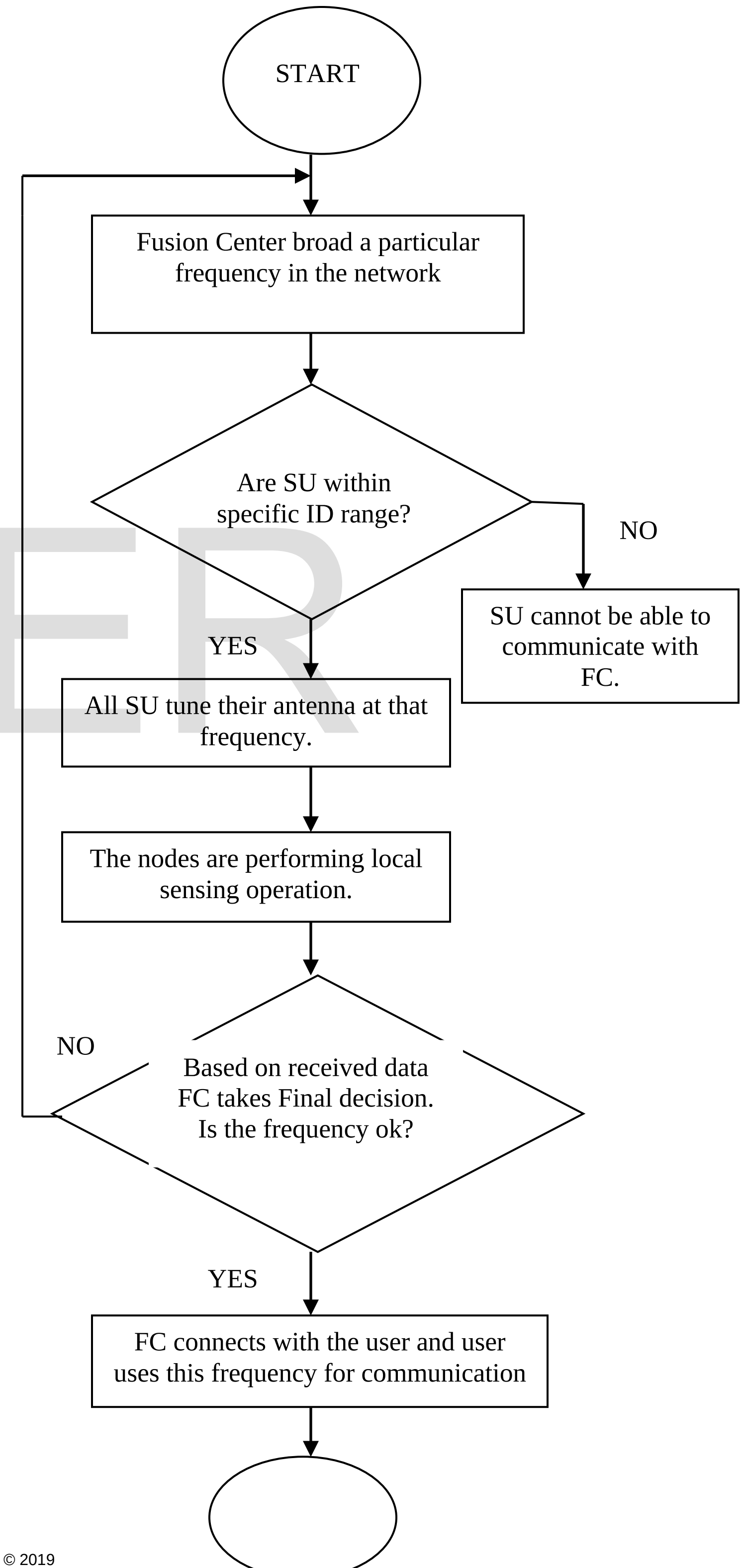


Figure 1: Communication between Fusion Center and cognitive radio user

We have designed a network, where a Global network controller (GFC) can be used as interconnect entity adjacent (Fusion Center) FCs to support the cognitive user roaming and resource sharing. The registered SUs can make request to the network controller or FC.FC continuously broadcast the available frequency information within a network. Only registered SUs are allowed to access the available broadcasted frequency. Any SU are allowed to access the available broadcasted frequency. All SUs perform the local sensing operation and result send to the FC. Based on the data FC takes the decision and decides which user is suitable for communication for that frequency.



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STOP

Figure 2: Communication Steps between Fusion Center and cognitive user.

IV. SIMULATION

With the help of MATLAB Simulation, we have analyzed the performance of Cyclostationary feature detection and Covariance-based detection in the emulated urban scenario. For optimization, we have set the parameter value of Cyclostationary feature detection and Covariance-based detection as shown in table 1 and table 2 respectively.

Table 4.1: Input Parameter for Cyclostationary feature detection

Operating frequency	20 Khz
Channel model	AWGN
Probability of false Alarm	0.1:0.1:1
Number of sample	0:100:500

Table 4.2: Input Parameter for Covariance-based detection

Operating frequency	20Khz
Channel model	AWGN
Probability of false alarm	0.1:0.1:1
Number of sample	0:100:500
Number of level	10

4.1 **Probability of Primary Detection function of SNR**

Fig.3 depicts the "Probability of detection" as a function of SNR for the two cases: (i) Covariance-based detection, (ii) Cyclostationary feature detection. Under Low SNR, Covariance method is inefficient to detect the signal. To overcome this problem Clostationary feature detection technique is used.

Under first test scenario impact of varying signal to noise ratio (SNR) on probability of detection (P_d) has been evaluated. As given in figure-3 SNR values are varied in range of 0dB to 25dB and

it is observed that with increasing signal power P_d also increases. First, We choose P_{fa}(Probability of Alarm) = 0.1 and N (Number of Sample) = 100 for both Sensing technique. In covariance based we consider the number of level (L) is 10. As (Level of threshold) $\gamma_L \geq (1 + (L - \frac{1}{4.54}))$ so $\gamma_L \geq 11$. So we consider 11. We then obtain the system thresholds ($\gamma_{S/M}$) based on P_f, and N for Cyclostationnary Based technique. For Covariance detection technique we get fix $\gamma_{S/M}$ based on P_{fa}, L and N. Second, we fix the $\gamma_{S/M}$ on P_{fa} and simulate the P_d for different SNR values.

It is observed that P_d is better for Cyclostationary feature detection than covariance based detection. At Low value of SNR, P_d is less for covariance based detection compare to Cyclostationary based detection. For SNR = 6 dB P_d is 0. **B**ut this problem is overcome by Cyclostationary feature detection. For SNR equals to 6 dB probability of detection for Cyclostationary feature detection is 0.12. Covariance-based detection obtained 100% P_d for SNR equals to 16 dB. To achieve 100% P_d for Cyclostationary detection we need 14dB SNR value.

Fig.3 graph is based on P_{fa}. In this graph P_{fa} fixed so $\gamma_{S/M}$ also fixed because $\gamma_{S/M}$ is calculated based on P_{fa}. In general When P_{fa} are vary $\gamma_{S/M}$ also change so the performance of

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detection also change. We moved to next test Scenario where P_{fa} vary.

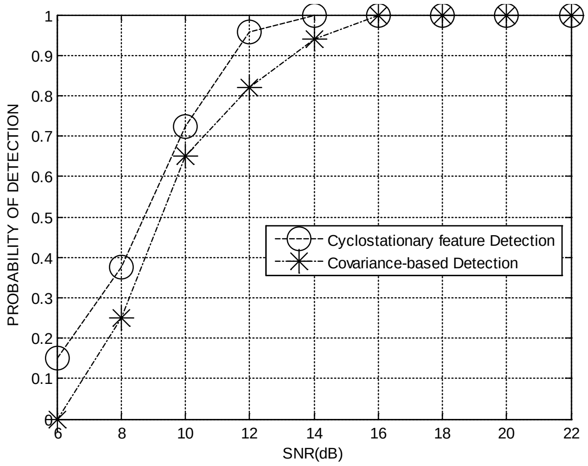

Figure 3: Comparative Study on Probability of Detection

4.2 Probability of primary Detection function of false alarm

Fig.4 illustrates the “Probability of detection” for two spectrum sensing techniques probability of detection versus probability of false alarm.

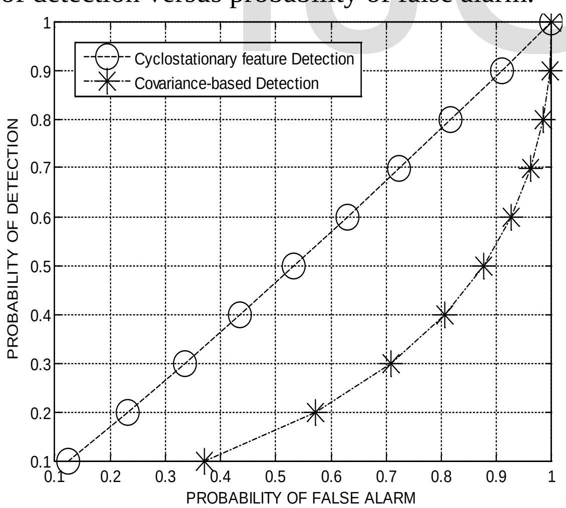

Figure 4: Probability of Detection under fixed number of samples (100) and SNR (16 dB).

This graph is totally based SNR. In this graph P_{fa} is varied and according to the system threshold $(\gamma_{S/M})$ also change so the performance of P_d are-changed. We moved to next test Scenario where P_{fa} vary.

4.3 Probability of Primary Detection function of Number of Sample

Figure-5 depicts the “Probability of detection” as a function of Number of sample for the two cases: (i) Covariance-based detection, (ii) Cyclostationary feature detection.

In this test scenario impact of number of sample on probability of detection (P_d) has been evaluated. As given in fig.5 where number of sample (N) vary from 10 to 100 and it has observed that with increasing value of N signal P_d also increases. First, we choose (P_{fa}) (Probability of false Alarm) = 0.1 and SNR = 16dB (16 dB is good for communication) for both Sensing technique. In Covariance-based we consider the number of level (L) is 10. As (Level of threshold) $\gamma_L \geq (1 + (L - \frac{1}{4.54}))$ so $\gamma_L \geq 11$. So We consider 11 .We then obtain the system thresholds based $(\gamma_{S/M})$ on P_{fa}, and N for Cyclostationary feature detection technique. For Covariance-based detection technique we get Fix $\gamma_{S/M}$ based on P_{fa}, L and N. Second, we fix the $\gamma_{S/M}$ based on P_{fa} and simulate P_d for different N.

Performance of P_d is better for Cyclostationary than Covariance-based detection. Cyclostationary feature detection is improved version of Covariance-based detection, where Cyclostationary feature are associated with modulation type, carrier frequency and data rate.

It is observed that for Cyclostationary feature detection, less number of N is required than Covariance-based detection to obtain a 100% P_d. With increase N detection performance of Cyclostationary feature detection technique is better than Covariance-based detection. For Covariance-based detection about 70 sample is needed for achieve 100% P_d.

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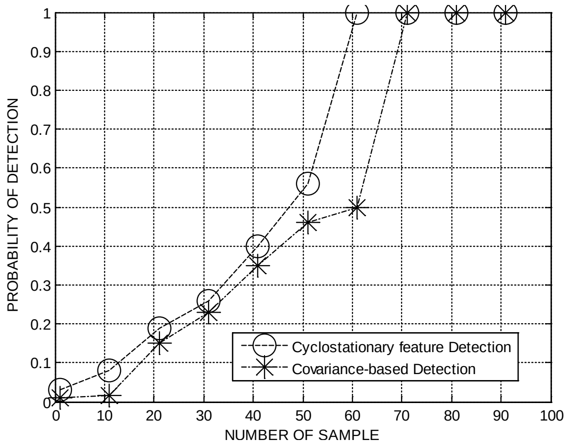

Figure 5: Variation in Probability in Detection with Variable Number of Received Signal Samples

This graph is totally based on P_{fa} and SNR because threshold is calculated base on P_{fa}.When P_{fa} are vary threshold values change also so the performance of detection also change. Finally we moved to next test Scenario where $\gamma_{S/M}$ are varied.

4.4 Probability of Primary Detection Function for Variable System Threshold

Fig.6 depicts the "Probability of detection" as a function of different threshold for the two cases: (i) Covariance-based detection, (ii) Cyclostationary feature detection.

In this test scenario impact of varying signal to noise ratio on probability of detection(P_d) has been evaluated. As given in figure-6 SNR values are varied in range of 0dB to 30dB and it is observed that with increasing signal power P_d also increases. N (Number of Sample) = 100 for both Sensing techniques. In Covariance-based we consider the number of level (L) is 10. As (Level of Threshold) $\gamma_L \geq (1 + (L - \frac{1}{4.54}))$ so $\gamma_L \geq 11$. So we consider 11. Previous case We then obtain the system thresholds based ($\gamma_{S/M}$) on P_{fa}, and N for Cyclostationary feature detection technique. For Covariance-based detection technique We get fix $\gamma_{S/M}$ based on P_{fa}, L and N. But in this technique $\gamma_{S/M}$ is independent of P_{fa}. Here $\gamma_{S/M}$ value is varied from 800 mV to 1400mV.

In Covariance-based detection selection of threshold is very important. P_d depends on the $\gamma_{S/M}$.But In the Cyclostationary feature detection technique threshold selection is not difficult.

In a dense urban area the interference caused by Secondary Transmitters (STs) to the Primary Receivers (PRs). This interference is controlled by the threshold value. The STs utilizing the shared band must ensure that their transmissions added to the existing interference must not exceed the interference threshold at the PR.

It is observed that for SNR equals to 10 dB to obtain 100% P_d Covariance detection technique we need 800mV $\gamma_{S/M}$ values. If SNR value increases $\gamma_{S/M}$ also increases to obtain 100% P_d . For SNR equals to 16 dB $\gamma_{S/M}$ value is 1400 mV but In case of Cyclostationary feature detection technique to obtain 100 % P_d we need 26dB SNR and $\gamma_{S/M}$ value 1400 mV, if $\gamma_{S/M}$ decreases SNR also decrease to obtain the highest P_d. For SNR 20dB P_d occurs at 800mV.After certain $\gamma_{S/M}$ value, if $\gamma_{S/M}$ value increases interference generates between the secondary transmitter (ST) and primary receiver (PR). As a result communication is not possible under underlay technique. Communication between 15dB to 20 dB Cyclostationary feature detection requires 800mV but Covariance-based detection requires 1400 mV $\gamma_{S/M}$, results interference possible in case of Covariance-based detection technique.

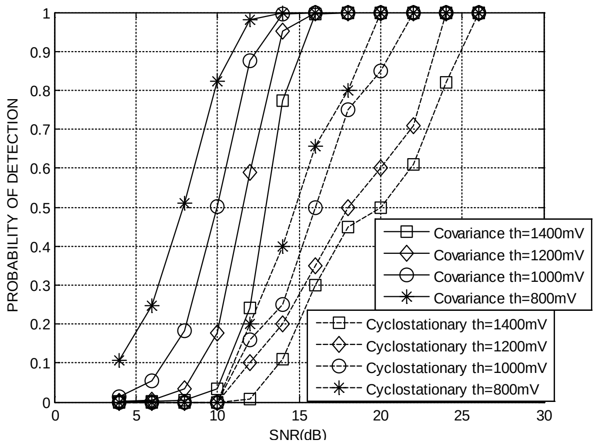

Figure 6: Probability of Detection under Variable Threshold (th) Selection

4.5 Number of Sample versus Sensing Time

Fig.7 depicts the "Sensing time" as a function of Number of sample for the two cases: (i) Covariance-based detection, (ii) Cyclostationary feature detection.

In this test scenario impact sensing time on number of sample has been evaluated. As given in figure-7 where number of samples is varies from 10 to 100. First, we have selected P_{fa} (Probability of Alarm) = 0.1 and SNR=16dB (16 dB is good for communication) for both the Sensing techniques. In Covariance-based we consider the number of level (L) is 10. As level of threshold $(\gamma_L) \geq (1 + (L - \frac{1}{4.54}))$ so $\gamma_L \geq 11$. Therefore, we have considered 11. Then we have obtained the system threshold ($\gamma_{S/M}$) based onP_{fa}, and N for Cyclostationary feature detection technique. For Covariance-based detection technique We get fix $\gamma_{S/M}$ based on P_{fa}, L and N. Second, we fix the $\gamma_{S/M}$ based on P_{fa} and simulate the P_d for different sample value. And then corresponding detect the sampling time. Where sampling frequency is fix to 200 KHz.

In case of Covariance-based detection technique cognitive radio devices do not need any information of primary user(PU) signal. But Cyclostationary feature detection Cognitive radio (CR) devices need sufficient information about these unique characteristics of primary user signal. Cyclostationary feature detection technique is more complex compare to Covariance-based detection .So Cyclostationary feature detection is more sensing time needed compare to Covariance-based detection.

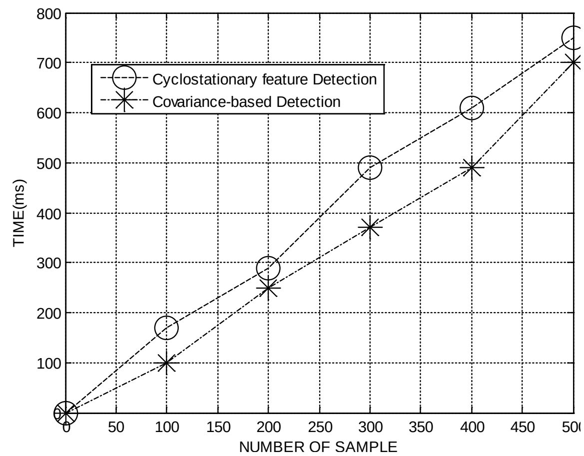

Fig.7: Sensing Time Variation under predefined $\mathbf{P_{fa}}$ (0.1) and SNR (16dB)

It has been observed that in both the cases when N value increases sensing time also increases. For Cyclostationary feature detection requires more sensing time compare to Covariance-based detection. At 300 sample Covariance-based sensing time is 380 ms but Cyclostationary feature detection sensing time is 500 ms.

V. CONCLUSION

In this paper the performance of Covariance-based sensing and Cyclostationary feature detection techniques have been tested for different SNR, Probability of false alarm, the number of samples and the variable threshold value. The Covariance-based spectrum sensing has low computational and implementation complexities and does not require any prior knowledge about the primary signal. However, its accuracy depends on the SNR and number of received signal samples which affect the sensing performance. Therefore to enhance the sensing performance of the Covariance-based detection method requires to define the sample number and optimum SNR value (about 16 dB). On the other hand, the Cyclostationary feature detection can perform efficiently only with the known primary signal. It has high detection accuracy with the optimum value of SNR and less number of received signal samples. But the implementation complexity of this technique is very high with respect to the Covariance-based sensing technique. Sensing time for both techniques are more or less the same. But sensing time for Cyclostationary feature detection has been observed more due to the implementation complexity. Cyclostationary feature detection can operate with the variable system threshold value. Due to the flexibility in the system threshold, the interference probability with the primary user is also minimum for Cyclostationary feature detection than covariance based detection. Hence Cyclostationary feature detection is best possible sensing technique to achieve optimum performance in the cognitive radio network.

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