Spectrum Sensing in Cognitive Radio using Mimo Technique

Suman Rathi, Rajeshwar Lal Dua, Parmender Singh

Abstract*— In this paper one of the most important cognitive radio task i.e. spectrum sensing is explained in detail. Cognitive radio is an intelligent wireless communication technology in order to increase the spectrum efficiency. Increasing efficiency of the spectrum usage is an urgent need as an intrinsic result of the increasing demand for higher data rates, better quality of services and higher capacity. There are several spectrum sensing techniques proposed in literature for cognitive radio based systems like Non cooperative and cooperative spectrum sensing. But there are some practical challenges and limitations in these techniques. So this paper provides the idea behind the MIMO concept in cognitive radio where multiple antennas can be placed both on primary user and secondary user and results evaluate the performance of its implementation. With the emergence of MIMO system, multipath were effectively converted into benefit for communication system. The probability of detection increases and the probability of false alarm decreases as given below in the simulation section.

Index terms: Cognitive Radio, Spectrum hole, Spectrum Sensing, MIMO, Cooperative

I. INTRODUCTION

Primary users are licensed users having higher priority on the usage of part of spectrum and secondary users are unlicensed users. Cognitive radio is a promising solution to this spectrum underutilization problem.

Federal Communication Commission (FCC) has issued a Notice of Proposed Rulemaking regarding cognitive radio that requires rethinking of the wireless communication architecture so that emerging radios can share spectrum with primary users without causing interference to them [1]. The term cognitive radio is coined by Dr Joseph Mitola in his doctoral thesis [2]. The word “Cognition” means the mental process of acquiring knowledge through thought, experience and the senses.

Cognitive radio enables the users to determine portion of the spectrum available and detect the presence of licensed users when a user operates in licensed bands. There are four main cognitive tasks: spectrum sensing, spectrum management, spectrum mobility and spectrum sharing. Spectrum sensing aims to determine spectrum availability and the presence of the licensed users. Spectrum management is to predict how long the spectrum holes are likely to remain available for use to the unlicensed users (also called cognitive radio users or secondary users). Spectrum sharing is to distribute the spectrum holes fairly among the secondary users bearing in mind usage cost. Spectrum mobility is to maintain seamless communication requirements during the transition to better spectrum. Spectrum sensing is key element in cognitive radio communication. It enables cognitive radio to adapt to its environment by detecting spectrum holes. A spectrum hole (also known as white space) is a band of frequencies licensed to a primary user but at a particular time and specific geographical location that particular band is not utilized by that user. Several spectrum sensing methods are proposed in literature among them we will focus on few like matched filtering, energy Detector, Periodogram, Welch’s, cooperative and multiple antenna spectrum sensing methods. In this paper we evaluate the results about spectrum sensing using MIMO technique in which multiple antennas are implemented at both transmitter and receiver side.

II. ARCHITECHTURE OF COGNITIVE RADIO TRANCEIVER

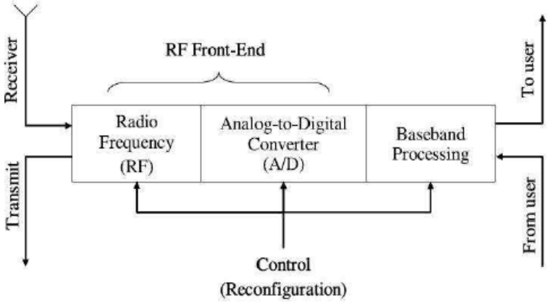

Fig. 1.1 Cognitive Radio Transceiver architecture

The wideband signals are received through the RF front end and then are sampled using the high speed analog-to-digital (A/D) converter and furthermore different measurements are done for detection of licensed user signal. But in real applications, RF antenna receives signal from various transmitters operating at different power levels, bandwidths and locations which makes it hard to detect weak signals in that kind of range. So there should be multi-GHz speed A/D converter with high resolution but it is practically infeasible to implement.. Another approach can be the usage of multiple antennas.

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The key challenge of the physical architecture of the cognitive radio is an accurate detection of weak signals of licensed users over a wide spectrum range. Hence, the implementations of RF wideband front-end and A/D converter are critical issues in xG networks.

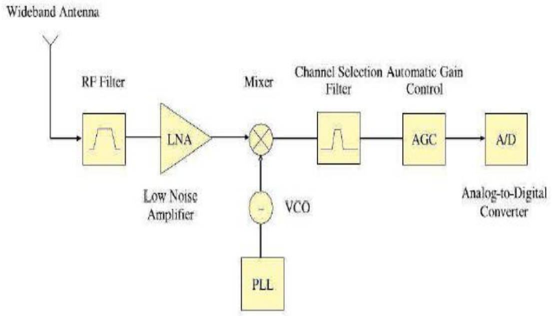

Fig.1.2 Cognitive Radio RF Front End

The components of a cognitive radio RF front-end are as follows [3]:

1. RF filter: The RF filter filters the received RF signal with a band-pass filter and selects the desired band.
2. Low noise amplifier (LNA): The LNA amplifies the desired signal while minimizing noise component at the same time.
3. Mixer: In the mixer, the received signal is mixed with locally generated RF frequency and converted to the baseband or the intermediate frequency (IF).
4. Voltage-controlled oscillator (VCO): The VCO generates a signal at a specific frequency for a given voltage to mix with the incoming signal. This procedure converts the incoming signal to baseband or an intermediate frequency.
5. Phase locked loop (PLL): The PLL ensures that a signal is locked on a specific frequency and can also be used to generate precise frequencies with fine resolution.
6. Channel selection filter: The channel selection filter is used to select the desired channel and to reject the adjacent channels. There are two types of channel selection filters. The direct conversion receiver uses a low-pass filter for the channel selection On the other hand, the super heterodyne receiver adopts a band pass filter.
7. Automatic gain control (AGC): The AGC maintains the gain or output power level of an amplifier constant over a wide range of input signal.

The wideband signals are received through the RF front end and then are sampled using the high speed analog-to-digital (A/D) converter and furthermore different measurements are done for detection of licensed user signal. But in real applications, RF antenna receives signal from various transmitters operating at different power levels, bandwidths and locations which makes it hard to detect weak signals in that kind of range. So there should be multi-GHz speed A/D converter with high resolution but it is practically infeasible to implement. Moreover this need of multi-GHz speed A/D converter requires the dynamic range of the signal to be reduced before A/D conversion. This reduction can be achieved by filtering strong signals which can be located anywhere in the wide spectrum range and using tunable notch filters. Another approach can be the usage of multiple antennas. The key challenge of the physical architecture of the cognitive radio is an accurate detection of weak signals of licensed users over a wide spectrum range. Hence, the implementations of RF wideband front-end and A/D converter are critical issues in xG networks.

III. VARIOUS SPECTRUM SENSING METHODS

Cognitive radio is an exciting technology that has potential of dealing with the stringent requirement and scarcity of the radio spectrum. Spectrum sensing refers to the action of monitoring the characteristics of received signals which may include RF energy levels if particular band is occupied. Ideal characteristics of Cognitive Radio are: intelligence, reliability, awareness, adaptability, efficiency and excellent quality of service.

To improve the detection probability, many signal detection techniques can be used in spectrum sensing. Signal processing is concerned with improving the quality of signal at the top of measurement systems and its main aim is to attenuate the noise in the signal that has not been eliminated by careful design of measurement system. With the advancement in signal processing, we are able to think about cognitive radio technology. In this section, we give an overview of some well-known spectrum sensing techniques.

3.1 Matched Filtering Method: If there is prior knowledge of the signal transmitted by primary transmitter, the matched filter followed by threshold detector can be used to detect the presence of primary user. The matched filter is an optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive white stochastic noise. This technique is possible if number of users is very small. A matched filter is obtained by correlating a known signal, with an unknown signal to detect the presence of the known signal in the unknown signal. This is equivalent to convolving the unknown signal with a time-reversed version of the signal. Convolution does essentially with two functions that it places one function over another function and outputs a single value suggesting a level of similarity, and then it moves the first function an infinitesimally small distance and finds another value [4]. The end result comes in the form of a graph which peaks at the point where the two images are most similar.

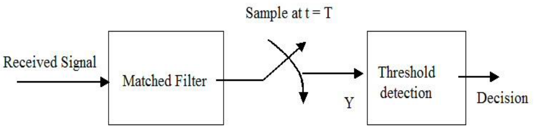

Fig. 1.3 Basic operation performed by matched filter.

Advantage of matched filter is that it needs less time to achieve high processing gain due to coherent detection. Disadvantage of matched filter is that it would require a dedicated sensing receiver for all primary user signal types and it requires the prior information of primary user signal which is very difficult to be available at the CRs.

3.2 Energy Detector Method: If the prior knowledge of the primary user signal is unknown, the energy detection method is optimal for detecting the presence of PU. In this approach, the radio frequency (RF) energy in the channel or the received signal strength indicator is measured to determine whether the channel is idle or not. The detection is based on some function of the received samples which is compared to a predetermined threshold level [5]. If the threshold is exceeded, it is decided that signal(s) is (are) present otherwise it is absent. However, this method is prone to false detections since it only measures the signal power. When the signal is heavily fluctuated, it becomes difficult to distinguish between the absence and the presence of the signal if prior knowledge of PU signal is unknown since the energy detection method is optimal for detecting any zero mean constellation signals.

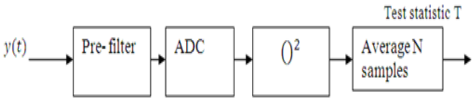

Fig. 1.4 Energy detection with pre-filter and square law device

First step is to filter the input signal with a band pass filter to select the bandwidth of interest and then output signal is squared and integrated over the observation interval. The output of the integrator is compared to a predetermined threshold to infer the presence of the PU signal [6].

However, the energy detection approach can be implemented without any prior knowledge of PU signal but still it has some disadvantages:-

(i) The first problem is that it has poor performance under low SNR and conditions. This is because the noise variance is not accurately known at the low SNR, and the noise uncertainty may explain the energy detection is useless.

(ii) The threshold used in energy detection depends on the noise variance and small noise power estimation errors can result in significant performance loss.

3.3 Periodogram Method: This is a non parametric method of spectral estimation in which the power spectral density is estimated directly from the signal itself. The power spectral density of the signal can be estimated by finding the fast Fourier transform of the samples & taking the magnitude square of the result [6]. In this method, we consider a finite length sequences. It is equivalent to multiplying the signal with a rectangular window is time domain. This abrupt change introduces the undesired side lobes in the frequency response, leading to a spectral leakage. The variance of estimated power spectral density does not decreases with increase in number of samples considered. The main disadvantage of periodogram is the spectral leakage. The formula for periodogram is given by:

$$P_N(e^{jw})=\frac{1}{N}\left|\sum_{n=0}^{N-1} X(n)e^{-jnw}\right|^2$$

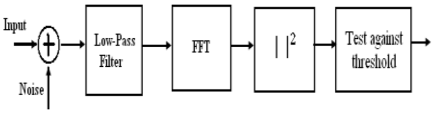

Fig.1.5 Block diagram of spectrum sensing using periodogram

The main disadvantage of periodogram is the spectral leakage. Hence the periodogram is a much poorer estimation of the Power spectral density.

3.4 Welch's Method: The method consists of dividing the time series data into overlapping segments, computing a modified periodogram of each segment, and then averaging the power spectral density estimates [6]. The result is Welch's Power Spectral Density (PSD) estimate. The length of the applied window controls the trade-off between bias and variance of the resulting power spectral density (PSD). Welch's method is implemented in the Signal Processing Toolbox by the pwelch function.

By default, the data is divided into eight segments with 50% overlap between them. A Hamming window is used to compute the modified periodogram of each segment. The averaging of modified periodograms tends to decrease the variance of the estimate relative to a single periodogram estimate of the entire data record. Although overlap between segments tends to introduce redundant information, this effect is diminished by the use of a nonrectangular window, which reduces the importance or weight given to the end samples of segments (the samples that overlap).

However, as mentioned above, the combined use of short data records and nonrectangular windows results in reduced resolution of the estimator. In summary, there is a tradeoff between variance reduction and resolution. One can manipulate the parameters in Welch's method to obtain improved estimates relative to the periodogram, especially when the SNR is low.

3.5 Cooperative Spectrum Sensing: Cognitive radio cooperative spectrum sensing occurs when a group or network of cognitive radios share the sense information they obtain with each other. This provides a better scenario of the spectrum usage over the area where the cognitive radios are located. There are broadly two approaches to cooperative spectrum sensing [7]:

(i) Centralized approach: In this approach of cognitive radio cooperative spectrum sensing, there is a central node within the network that collects the sensing information from all the sense nodes or radios within the network. It then process and analysis the information and determines the frequencies that can and cannot be used. The cognitive radio central node or controller can also organize the various cognitive radio users to undertake different measurements at different times.

(ii) Distributed approach: Using the distributed approach for cognitive radio cooperative spectrum sensing there is no any central node i.e. no one node takes control. Instead communication exists between the different nodes and they are able to share sense information. However this approach requires for the individual radios to have a much higher level of autonomy and setting themselves up as an ad-hoc network.

The problem which makes spectrum sensing more critical to implement is Hidden Terminal Problem. This problem exists due to environmental conditions and creates the problems like multipath fading, shadowing. Due to these factors there may be loss of information and wrong interpretation can be taken by the secondary user. So to remove these problems Cooperative spectrum sensing is used.

Cooperative spectrum sensing will go through two successive channels:(i) Sensing channel (from the PU to CRs) and (ii) Reporting channel (from the CRs to the common receiver).

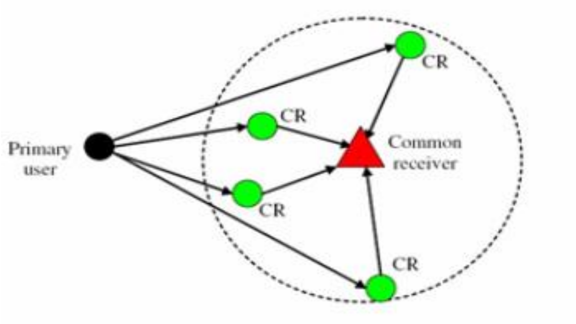

Fig. 1.6 Cooperative spectrum sensing

Advantages of cooperative spectrum sensing: It has many advantages as follows:(i) Hidden node problem is significantly reduced: By using a cooperative sensing system, it is possible to reduce the possibility of reducing hidden node problem because a greater number of receivers will be able to build up a more accurate scenario of the transmissions in the area.(ii) Increase in agility: An increase in the number of spectrum sensing nodes by cooperation enables the sensing to be more accurate and better options for channel moves to be processed, thereby providing an increase in agility. (iii) Reduced false alarms: By having multiple nodes performing the spectrum sensing, channel signal detection is more accurate and this reduces the number of false alarms.

Disadvantage of Cooperative Spectrum Sensing: Significant disadvantage of cooperative spectrum sensing are:- (i) Control channel: In order for the different elements within the cognitive radio cooperative spectrum sensing network to communicate, a control channel is required. This will take up a proportion of the overall system bandwidth. (ii) System synchronization: It is normally necessary to provide synchronization between all the nodes within the cognitive radio cooperative spectrum sensing network. Accurate spectrum sensing requires a longer period of time than a rough sense to see if a strong signal has returned. By adapting the sense periods, channel throughput can be maximized, but there is a greater need to maintain synchronization under these circumstances. (iii) Suitable geographical spread of cooperating nodes: In order to gain the optimum sensing from the cooperating nodes within the cognitive network, it is necessary to obtain the best geographical spread. In this way the hidden node syndrome can be minimized, and the most accurate spectrum sensing can be gained.

3.6 Multiple Antenna Spectrum Sensing: In multiple antenna spectrum sensing we use single antenna at primary user and multiple antennas at secondary user. Multiple antenna techniques currently are used in communications and their effectiveness has been shown in different aspects [8]. The efficiency of multiple antenna spectrum sensing is shown in terms of required sensing time and hardware by using a two stage sensing method [8].

The ED has been proposed for spectrum sensing by using multiple antennas. A GLR detector is proposed which do not have any primal information about the parameters like; channel gains, noise variance, and primary user signal variance [8]. It is supposed that the SU has M receiving antennas and each antenna receives L samples. It is also assumed that the PU signal samples are independent zero-mean random variables with complex Gaussian distribution.

The Fig. 1.1 from [8] provides the scenario of multiple antenna spectrum sensing techniques

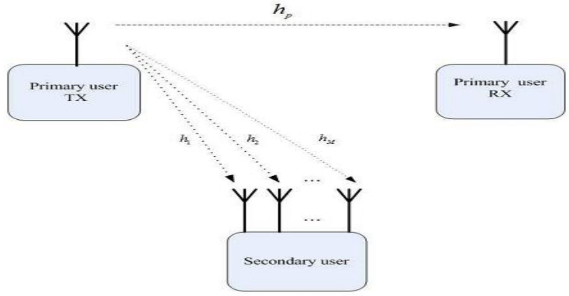

Fig. 1.7 Multiple Antenna Spectrum sensing

It is assumed that the channel gain vector, i.e., h, is a constant parameter at each The optimal detector needs to know the values of channel gains, noise and PU variances. Detection methods for signals with correlation between the received symbols in noise and interference are of special importance in the implementation of a communication system.

This new idea of multiple antenna spectrum sensing is provided in [9]. It is assumed that there is no any primal knowledge of primary user signal, the channels between the primary user and cognitive user is available to the system. A new approach that is known as generalized likelihood ratio test (GLRT) is developed to detect the presence/absence of the primary user in [9]. It is considered that multiple receiver antennas are used, and there is only one primary signal to be detected. In this case, the signal covariance matrix can be modeled as a rank 1 matrix that is an outer product of the channel vector. By exploiting this inherent signal structure, a new GLRT detector is developed.

The proposed detector requires no primal knowledge of the transmitted signal, the wireless channel from the primary transmitter to the CR receiver, and the noise variance. The test statistic of the proposed detector admits a simple form that is given by the ratio of the largest eigenvalue to the sum of eigenvalues of the sample covariance matrix of the received signal. By fully exploiting the signal structure, this detector is able to achieve better performance than other existing methods when the noise variance is unknown.

Another approach with GLRT detector is also used with multiple antenna based spectrum sensing in [9].

Let consider the same case of hypothesis :

H_0: x (n) = w (n), n = 0,……. N-1

H_1 : x (n) = s (n) + w (n), n = 0,…….., N-1

Where x (n) is the receiver signal, s (n) is the primary user signal and w (n) is the white additive Gaussian noise signal. Additive noise is considered as identically, independent and distributed circularly symmetric complex Gaussian (CSCG) vector with zero mean and the covariance matrix $\sigma^2 I$, with I denoting an identity matrix. $s(n)$ is assumed to be an i.i.d. CSCG random vector with zero mean. Results show that GLRT approach provides high value of probability of detection within low SNR realm.

IV. MIMO METHOD

MIMO is a communication technique in which the multiple properties of the channel are utilized to support greater data through put. In a MIMO system the transmitter transmits multiple channel of data traffic through multiple antennas, the receiver learns the channel behaviour between the transmitters multiple antennas and the receivers multiple antennas, and uses signal processing technique to compute what waveform was transmitted by each antenna and the corresponding data stream.

By using MIMO the same frequency is reused in the same geographic region to deliver great amount of data traffic than could be expected from SISO. MIMO techniques deliver significant performance enhancement in terms of data transmission rate and interference reduction. By using multiple antennas at Receiver and Transmitter in a wireless system the rich scattering channel can be exploited to create a multiplicity of parallel links over the same radio band and thereby to either increase rate of data transmission through multiplexing or to improve the system reliability through the increased antenna diversity.

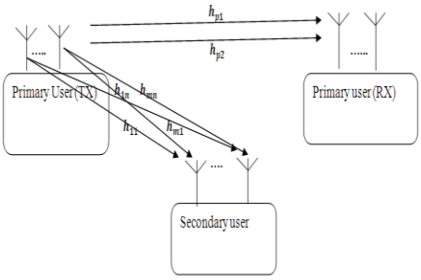

Fig. 1.8 Spectrum sensing using MIMO

To evaluate the performance of MIMO, optimal detector is used. Assumption is that optimal detector needs to know the noise and PU signal variances and channel gains. To reduce the complexity of the system here only 2 antenna system is consider for implementation. Two antennas at transmitter and two at receiver are mounted.

Mathematically, it can be given as:-

$$Y = HS + N$$

Here, H is channel matrix and its elements are assumed to be independent, S is the signal and N is the noise. Let's assumed that the signals received to the secondary user from the primary user after sensing its surrounding environment is (x_1, x_2). After applying hypothesis at these two symbols i.e.

$$\begin{cases} H_0: \mathit{Primary\ user\ is\ absent;} \\ H_1: \mathit{Primary\ user\ is\ present} \end{cases}$$

For this it's necessary to find out its probability density function. It is assumed that the signals are Gaussian distributed with zero mean and channel is independent in this case.

The PDF of a Gaussian distribution function is given as:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (1)$$

where μ is the mean and σ^2 is variance of the signal.

Let $S = [x_1, x_2, \dots \dots \dots . x_L] \in C^{M \times L}$ is a complex matrix containing the observed signals at M antennas. L is the number of samples which each antenna receives and σ_n^2 and σ_s^2 are the noise variance and signal variance respectively.

$$\begin{cases} H_0: X \sim N(0, \sigma_n^2 I) \\ H_1: X \sim N(0, \sigma_s^2 + \sigma_n^2 I) \end{cases} \qquad (2)$$

In this case it is assumed that, the Secondary Users knows the channel gains, noise and primary user signal variances. So under H_0 the PDF of matrix X, can be given as:-

$$f(X : H_0, \sigma_n^2) = \prod_{l=1}^{L} \frac{1}{\sqrt{2\pi\sigma_n^2}} \exp\left\{\frac{-(x_l)^2}{2\sigma_n^2}\right\} \qquad (3)$$

$$f(X : H_0, \sigma_n^2) = \frac{1}{(2\pi\sigma_n^2)^{L/2}} \sum_{l=1}^{L} \exp\left\{\frac{-(x_l)^2}{2\sigma_n^2}\right\} \qquad (4)$$

$$f(X ; H_0, \sigma_n^2) = \frac{1}{(2\pi\sigma_n^2)^{L/2}} \exp\left\{\frac{-tr(X)^2}{2\sigma_n^2}\right\} \qquad (5)$$

Where tr (.) is the trace of the matrix.

By taking logarithm of PDF of observation matrix H:

$$L_0(X) = \frac{-tr(X)^2}{2\sigma_n^2} - L \ln\pi - \frac{L}{2} \ln\sigma_n^2 \qquad (6)$$

For H_1 the PDF of matrix X, can be given as:-

$$f(X ; H_1, \sigma_n^2, \sigma_s^2) = \prod_{l=1}^{L} \frac{1}{\sqrt{2\pi(\sigma_n^2 + \sigma_s^2)}} \exp\left\{\frac{-(x_l)^2}{2(\sigma_n^2 + \sigma_s^2)}\right\} \qquad (7)$$

$$f(X ; H_1, \sigma_n^2, \sigma_s^2) \frac{1}{(2\pi(\sigma_n^2 + \sigma_s^2))^{L/2}} \sum_{l=1}^{L} \exp\left\{\frac{-(x_l)^2}{2(\sigma_n^2 + \sigma_s^2)}\right\} \qquad (8)$$

$$f(X ; H_1, \sigma_n^2, \sigma_s^2) = \frac{1}{(2\pi(\sigma_n^2 + \sigma_s^2))^{L/2}} \exp\left\{\frac{-tr(X)^2}{2(\sigma_n^2 + \sigma_s^2)}\right\}$$

(9)

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By taking logarithm of PDF of observation matrix H:

$$L_1(X) = \frac{-tr(x)^2}{2(\sigma_n^2+\sigma_s^2)} - L \ln\pi - \frac{L}{2}\ln(\sigma_n^2 + \sigma_s^2) \qquad (10)$$

Let’s calculate the likelihood ratio function:

$$LLR = \ln\frac{f(x;H_1,\sigma_n^2,\sigma_s^2)}{f(x;H_0,\sigma_n^2)}$$

$$= L_1(X) - L_0(X) = \frac{tr(x)^2}{2\sigma_n^2}\left(\frac{1}{1+\frac{\sigma_n^2}{\sigma_s^2}}\right) - \frac{L}{2}\ln\sigma_s^2$$

(11)

Comparing the LLR function with a threshold results as:-

$$\frac{tr(x)^2}{2\sigma_n^2}\left(\frac{1}{1+\frac{\sigma_n^2}{\sigma_s^2}}\right) - \frac{L}{2}\ln\sigma_s^2 \gtreqless \eta \qquad (12)$$

Where η is the decision threshold and $\frac{\sigma_n^2}{\sigma_s^2}$ is the SNR of the signal

$$\eta = \frac{\eta_1 + L\ln\left(\frac{\sigma_s^2}{\sigma_n^2}||h||^2+1\right)}{\left(\frac{\sigma_n^2}{\sigma_s^2}+||h||^2\right)\sigma_n^2} \qquad (13)$$

For independent channel in MIMO case; P_f and P_d expressions can be written as:-

$$P_{fa} = \frac{\Gamma\left(L,\frac{\eta}{||h||^2\sigma_n^2}\right)}{\Gamma(L)} \qquad (14)$$

Where $\Gamma\left(L,\frac{\eta}{||h||^2\sigma_n^2}\right)$ is upper incomplete and $\Gamma(L)$ is complete gamma functions

$$P_d = \frac{\Gamma\left(L,\frac{\eta}{||h||^2\left(||h||^2\sigma_s^2+\sigma_n^2\right)}\right)}{\Gamma(L)} \qquad (15)$$

In terms of SNR:

$$P_d = \frac{\Gamma\left(L,\frac{\eta}{||h||^2\sigma_n^2(1+\gamma)}\right)}{\Gamma(L)} \qquad (16)$$

Where γ is SNR of received signal and given by:-

$$\gamma = \frac{||h||^2\sigma_s^2}{\sigma_n^2} \qquad (17)$$

The gains achievable by a MIMO system in comparison to a SISO one can be described stringently by information theory. A lot of research in the area of MIMO systems and Space Time Coding is based on this mathematical proof given by Shannon [10].

The Shannon’s Theorem for SISO is given by

$$C = B\log_2\left(1+\frac{S}{N}\right) \qquad (18)$$

Theoretically, the capacity C increases linearly with the number of antennas M in case of MIMO.

$$C = MB\log_2\left(1+\frac{S}{N}\right) \qquad (19)$$

The channel capacity can be increased by using higher order modulation schemes, but these require a better signal to noise ratio than the lower order modulation schemes. So some criteria exist between the data rate and the allowable error rate, signal to noise ratio and power that can be transmitted. While some improvements can be made in terms of optimizing the modulation scheme and improving the signal to noise ratio, these improvements are not always easy or cheap and they are invariably has to compromise and balance the various factors involved. Therefore, it is necessary to keep in mind other ways of improving the data throughput for individual channels. MIMO is one way in which wireless communications can be improved and as a result it is receiving a considerable degree of improvement.

V. SIMULATION RESULTS

The implementation of MIMO spectrum sensing results in the following graphs for probability of false alarm (Pfa) and probability of detection (Pd).

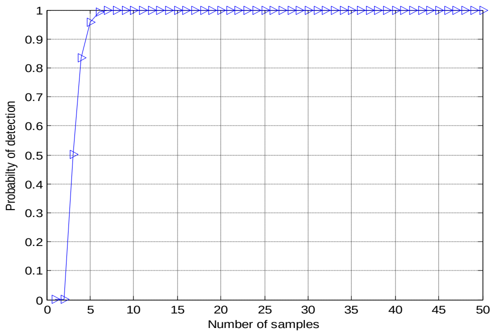

Fig. 1.9 Pd vs. Number of samples M=6 and L=50

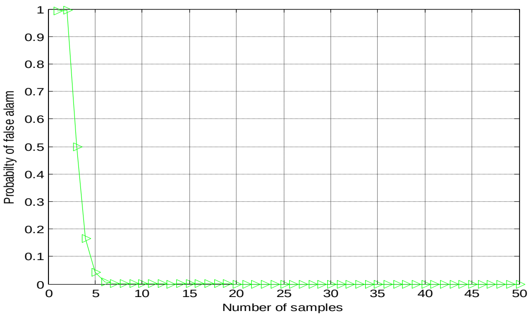

Fig. 1.10 Pfa vs. Number of samples M=6 and L=50

Advantages of MIMO spectrum sensing are:

(i) Higher capacity
(ii) Better transmission quality
(iii) Increased coverage
(iv) Improved user position estimation

VI. CONCLUSION

Radio frequency spectrum is a very valuable resource in wireless communication systems and it has been a major research topic from last several decades. Cognitive radio is a promising solution which enables spectrum sensing for opportunistic spectrum usage by providing a means for the use of spectrum holes. As described in this paper, the development of the cognitive radio network requires the involvement and interaction of many advanced techniques,

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including matched filter, energy detection, cyclostationary, periodogram, Welch, cooperative, multiple antenna and MIMO spectrum sensing. In this paper, spectrum sensing using MIMO is described in detail with mathematical calculations. The capacity increases and data rates are higher using MIMO technique. By using MIMO technique in spectrum sensing the probability of detection increases and the probability of false alarm decreases more rapidly than using other techniques.

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