Bayesian Approach for Spectrum Sensing in Cognitive Radio

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Abstract— with increasing demand of spectrum, it is necessary to increase the utilization of spectrum. Detection of primary signal in spectrum is one of the most challenging problems for proper communication. Cognitive radio is used for accurately detection of primary signal and increasing the utilization of spectrum. With previous data that the primary user (PU) is idle in spectrum and primary signals are digitally modulated, we tend to discussed Bayesian approach for detection of primary user and for maximum spectrum utilization. We discussed Optimal Bayesian detector structure for MPSK modulated primary signal. We additionally delineate its suboptimal detector in both low and high SNR regime. Through approximations, in low SNR regime, for MPSK signals, the suboptimal detector is that the energy detector as well as for BPSK signals, the suboptimal detector is that the energy detector on the real part. In high SNR regime, for BPSK signals, the test statistic is that the sum of signal magnitude, but uses the real part of the phase shift signals as the input. The performance analysis of the suboptimal detector is shown in terms of probabilities of detection and false alarm, secondary user throughput and spectrum utilization**.**

Index Terms — *Cognitive Radio, SNR, spectrum sensing, BPSK, MPSK, LRT Detection*

I. INTRODUCTION

Wireless communications and the utilization of the radio frequency spectrum have seen a tremendous growth during the past few decades. The crowd of different wireless devices, technologies and growth in the number of wireless subscribers, the continuous demand for higher data rates, which are all reasons for the radio frequency spectrum becoming more and more crowded. The radio frequency spectrum is divided to frequency bands which are allocated to different systems. The allocations are decided by the regulatory authorities in each country.

Most of the spectrum is already allotted to completely different system. Whenever a new wireless system is introduced a frequency band has to be made available for it, which can need worldwide collaboration. Hence, though this frequency allocation policy guarantees low interference as a result of every system operates in a very completely different band, it's additional terribly rigid and inflexible, Which realizes as heavy congestion in certain frequency band. However, many of frequency band which have been allocated to systems that are rarely used or to systems whose degree of frequency utilization varies from time to time and location to location. Hence there is many spectrum is available.

Cognitive radio (CR) is used for effectively utilizing available spectrum band. CR automatically detects available channels in wireless spectrum and instantly get into vacant channel whereas avoiding occupied channel.CR is a system which detects available channels in wireless spectrum then consequently changes its parameters to allow effective wireless communication in a given spectrum band. Using CR, the secondary users (SU) are allowed to use spectrum which is originally allocated to primary user (PU) as long as PU is idle. To avoid interference to the primary users, the secondary users have to perform spectrum sensing before transmit over the spectrum. On the basis of PU is idle, the SU can make use of the spectrum for transmission and overall utilization efficiency of the spectrum is increased. Nowadays spectrum sensing is one of the most challenging problems in cognitive radio systems. Many detection methods are used for spectrum sensing, for an example, like as, energy detector method, covariance based detector method, matched filter based detector and wavelet based sensing method etc. In this paper, we consider the MPSK primary signals. We discussed a Bayesian detector (BD) for digitally modulated primary signal to increase spectrum utilization.

With known order over additive white Gaussian noise (AWGN) channels. Generally, in low SNR regime, Bayesian detector is approximated to energy detector for BPSK and MPSK signal. In high SNR regime and for BPSK signals, Bayesian detector is approximated to a detector that sum of the total received signal amplitudes to detect the primary signal. We have to consider the fact that spectrum utilization of allocated spectrum is very low and determine the detection threshold based on unequal probabilities of the two assumptions. This detector is a likelihood ratio test (LRT) detector which might be approximated by its corresponding suboptimal structure within the low and high SNR regimes. We develop the analysis to calculate detection and false alarm probabilities and provide the expression for the detection threshold for sensing.

II.LITERATURE SURVEY

A. Challenges

Before moving into the details of spectrum sensing techniques, challenges related to the spectrum sensing for cognitive radio are:

1. Hardware requirement

Spectrum sensing for psychological feature radio applications wants high rate, high resolution analog to digital converters (ADCs) with giant dynamic vary, and high speed signal processors. However, in psychological feature radio, terminals area unit required to method transmission over a way wider band for utilizing any likelihood.

Hence, psychological feature radio ought to be able to capture and analyse a relatively larger band for characteristic spectrum opportunities. The large operative bandwidths impose extra desires on the radio frequencies (RF) components like antennas and power amplifiers in addition. These components should be ready to operate over a range of wide operating frequencies.

2. Detecting spread spectrum primary user

Primary users that use spread spectrum communication are tough to observe because the power of the primary user is distributed over a large frequency range even though the actual data bandwidth is much narrower. This problem is often partially avoided if the hopping pattern is known and ideal synchronization to the signal can be achieved as mentioned.

3. Sensing duration and frequency

Primary users will claim their frequency bands anytime while cognitive radio is working on their bands. In order prevent interference to and from primary license owners, cognitive radio should be able to identify the presence of primary users as quickly as possible and will vacate the band immediately. Hence, sensing strategies should be ready to identify the presence of primary users within a particular duration. This requirement poses a limit on the performance of sensing algorithm and creates a challenge for cognitive radio design.

Sensing frequency, i.e. however typically cognitive radio should perform spectrum sensing, is a design parameter that must be chosen carefully. The optimum value depends on the capabilities of cognitive radio itself and also the temporal characteristics of primary users within the environment Sensing time will be reduced by sensing only changing elements of the spectrum rather than the complete target spectrum. A sensing technique is developed in that adapts the sweeping parameters according to the estimated model of channel occupancy. This way, a far better sensing efficiency is obtained and sensing period is reduced over non-adaptive sensing strategies

B. Spectrum sensing method for Cognitive Radio

A number of various methods are proposed for characteristic of the presence of signal transmissions. In some approaches, characteristics of the identified transmission are detected for deciding the signal transmission likewise asidentifying the signal type. During this section, a number of the most common spectrum sensing techniques within the cognitive radio literature are explained.

1. Covariance based detector

Y.H. Zeng and Y.-C. Liang [1] [2], “Spectrum-sensing algorithms for cognitive radio based on statistical covariance,” Primary user detection in spectrum is basic problem in cognitive radio. The statistical covariance of received signal and noise are normally different. They can be used to separate the case where the primary user signal present from the case where there is only noise. In this paper, spectrum sensing algorithm is proposed, which is based on sample covariance matrix. It is calculated from received signal sample which is limited in number. Then, two test statistics are extracted from matrix. A decision of primary signal present in signal is made by comparing the two test statistics. The method needn't bother with any information about the signal, channel, and noise power from the earlier. In addition, no synchronization is needed between them.

2. Wavelet-based sensing method

Z. Tian and G. B. Giannakis [3], “A wavelet approach to wideband spectrum sensing for cognitive radios,” This paper explain a wavelet approach to efficient spectrum sensing of wideband channels. The signal range over a wide frequency band is deteriorated into basic building pieces of sub bands that are well characterized by local abnormalities in frequency. The wavelet transform is utilized to identify and evaluate the local spectral irregular structure, which carries important data on the frequency locations and power spectral densities of sub bands. By using local maxima of the wavelet transform modulus and the multi scale wavelet product, wideband spectrum sensing techniques are developed. It’s an effective radio sensing architecture of proposed sensing techniques to identify and locate spectrum holes in the signal spectrum. Without previous knowledge on the number of sub bands within the frequency range of interest, the proposed scheme is able to scan over a wide bandwidth to simultaneously identify all piecewise smooth sub bands. To characterize the entire wide bandwidth require high sampling rates. It has advantage in terms of implementation cost and flexibility in terms of adapting PSD structure.

3. Matched filter based detection

R. Tandra and A. Sahai [4], "Fundamental limits on detection in low SNR under noise uncertainty," When the transmitted signal is known then matched filter based detection is one of the optimum method. Main advantage of this method is in short time achieve certain probability of false alarm and false alarm. In the matched filter based detection cognitive radio demodulate received signal therefore it require complete knowledge of primary user signalling feature like bandwidth, operating frequency, modulation type, pulse shaping and frame format. Implementation complexity of sensing unit is large because receive all signal type by cognitive radio. It require various receiver algorithm therefore power consumption is large.

4. Energy detector

F. Digham, M.-S. Alouini, and M. K. Simon, "On the energy detection of unknown signals over fading channels[4],"Energy detector based method is most common method of spectrum sensing because it required low computational and implementation complexities. It is very normal method as compare to other because as receiver do not require any knowledge on primary user signal. The signal is detected by comparing output of energy detector with a threshold value. This threshold value is depending on noise floor. The threshold used in energy detector based sensing algorithm depends on the noise variance. When energy detector used for sensing primary user some challenge have to face, which include selection of threshold for detecting primary user, unable to differentiate interference from primary user and noise and under low signal to noise ratio(SNR) have poor performance. Efficiency of energy detector for detecting spread spectrum signal is low.

III.BAYESIAN DETECTOR FOR MPSK MODULATE PRIMARY SIGNALS

In this paper we have referred the mathematical model of Shoukang Zheng [5].while considering spectrum sensing there are two hypothesis H_0 and H_1. Hypothesis $H_0$for that PU is absent and H_1 hypothesis for that PU is present. There are two important design parameters for spectrum sensing. First is probability of detection P_D and other is probability of false alarmP_F. Probability of detection is the probability that SU accurately detects the occurrence of active primary signal. Probability of false alarm is the probability that SU falsely detect primary signal when PU is absent. We can define spectrum utilization as

$$(H_0)(1-P_F) + P(H_1)P_D \qquad (1)$$

Probability of detection is P_D the probability that the test correctly chooses H_1 when it is H_1:

$$P_D = (T_D > \varepsilon|H_1) \qquad (2)$$

Probability of detection is P_F the probability that the test correctly chooses H_1 when it is H_0:

$$P_F = (T_D > \varepsilon|H_0) \qquad (3)$$

3.1 Channel Model and Detection Statistic

We consider time slotted primary signal where N primary signal samples are used to detect the presence of primary user signals. The PU symbol duration is T which is known to the SU and the received signal ($\boldsymbol{t}$) is sampled at a rate of 1/T at the secondary receiver. For MPSK modulated primary signal, the received signal of k-th symbol at the CR detector is [1]:

$$r(k) = f(x) = \begin{cases} n(k), & H_0 \\ he^{j\emptyset n} + (k) & H_1 \end{cases} \qquad (4)$$

Where $n(k) = n_c(k) + jn_s(k)$ is a complex AWGN signal with variance N_0, $n_c(k)$ and $n_s(k)$ are real and imaginary part of $n(k)$, $\emptyset\text{n}(\text{k}) = \frac{2\text{n}}{M}$, n= 0,1, … $M-$ 1 with equi-probability, h is propagation channel that is assumed to be constant within sensing period.

The detection statistics of energy detector(ED) [8] can be well-defined as the average energy of observed samples as

$$T_{ED} = \frac{1}{N}\sum_{k=1}^{N} |r(k)|^2 (5)$$

Although energy detector does not require the complete knowledge of the symbol rate, we assume that the sample rate is matching to the symbol rate. It is well-known that the best detector for binary hypothesis testing based on Bayesian rule is to calculate the likelihood ratio test (LRT). LRT sort its decision by comparing the ratio with threshold. The likelihood ratio test of the hypothesis H_1 and H_0 defined as

$$T_{LRT}(r) = \frac{p(r|H_1)}{p(r|H_0)} \qquad (6)$$

It is convenient to derive the optimal detector

$$T_{LRT}(r) \underset{H_0}{\overset{H_1}{\gtrless}} \varepsilon (7)$$

Where, $\varepsilon = \frac{p(H_0)}{p(H_1)}$

3.2 Optimal Detector Structure

Probability density function (PDF) of received signal over N symbol duration for hypothesis is defined as [1]:

$$p(r|H_0) = \prod_{k=0}^{N-1} \frac{e^{-|r(k)|^2/N_0}}{\pi N_0} \quad (8)$$

For the hypothesis H_1, the PDF of received signal is denoted as $p(r|H_1)$:

Hence, the log-likelihood ratio (LLR), in $T_{LRT}(r)$, is

$$T_{LRT}(r) = \left(ln\left(\sum_{n=0}^{M-1} e^{\frac{2}{N_0}\Re[r(k)h^* e^{-j\phi_n(k)}]}\right) - \gamma - \ln M\right) (10)$$

Where γ is the SNR of signal i.e. $\gamma = \frac{|h|^2}{N_0}$

Let,

It is easy to define the structure of the optimal detector (BD) for MPSK signal as [1]

$$T_{BD} = \frac{1}{N}\sum_{k=0}^{N-1} ln\left(\sum_{n=0}^{\frac{M}{2}-1} \cosh(V_n(k))\right) > \gamma + ln\frac{M}{2} + \frac{\ln \epsilon}{N} (11)$$

Although the detector is optimal but it is too complicated to use in practice so we will simplify the SNR is very low or very high.

IV. Suboptimal Detector and Theoretical Analysis

If N is appropriately large, according to central limit theorem (CLT), sum of all the independent identical distributed random variables can be approximated by a Gaussian distribution theorem. Therefore, based on the optimal detector (BD), we can derive approximate in the low and high regimes. We also give the theoretical analysis i.e. detection performance and threshold.

4.1 Approximation in Low SNR regimes

We study the approximation of BD detector for MPSK modulated primary signals in the low SNR regime [1]. When $x \to 0, cosh(x) \approx 1 + \frac{x^2}{2}$ and $ln(1+x) \approx x$. We can obtain:

$$\frac{1}{N}\sum_{k=0}^{N-1} \quad \sum_{n=0}^{\frac{M}{2}-1}\left(\Re\left[r(k)h^* e^{-j\phi_n(k)}\right]\right) \underset{H_0}{\overset{H_1}{\gtrless}} \frac{MN_0^2}{4}\left(\gamma + \frac{\ln \varepsilon}{N}\right) \quad (12)$$

4.2 Approximation in High SNR Regimes

Through approximation in high SNR regime, the detector structure (H-ABD) becomes [1]

Detection Performance

We give the detection performance in terms of P_D and P_F for L-ABD-1. As we have discussed above, thedetector for complex MPSK signals (M >2) is the energydetection [1].

For Complex MPSK Signals we defined,

The detection probability is:

$$P_D = Q\left(\frac{\ln \epsilon - N\gamma^2}{\gamma\sqrt{N(1+2\gamma)}}\right)$$

Where, $Q(t) = \frac{1}{\sqrt{2\pi}}\int_t^{\infty} e^{-u^2/2}\, du$

The false alarm probability is:

$$P_F = Q\left(\frac{\ln \varepsilon}{\gamma\sqrt{N}}\right)$$

4.3 Detection Algorithm

After starting the program it initially sense the spectrum in wireless network which will sense that whether the primary user are present in network or not, if so then it will proceed to next step and if they are present then it will hold and wait until the next sensing is completed. If a primary user is absent in spectrum then secondary user transmit signal on spectrum without interfering to primary user. The spectrum sensing techniques are better elaborated in next topic. This will give brief idea about the system implementation using MATLAB. This shows that cognitive radio network can be implemented using the primary and secondary user designing in the network, so that virtual network can be designed.

V.RESULT

Fig.1. Primary User Signal

Fig.2. PU-SU status

The fig. 1 shows that the idea about primary user spectrum generated with random signal generator. Primary users are operating at different channels and SU tries to wait for vacant channel and access them opportunistically so this can be achieved by sensing the spectrum.

The Fig. 2 show that if primary user vacant channel is found then secondary user transmit data on that channel without creating interference to primary user.

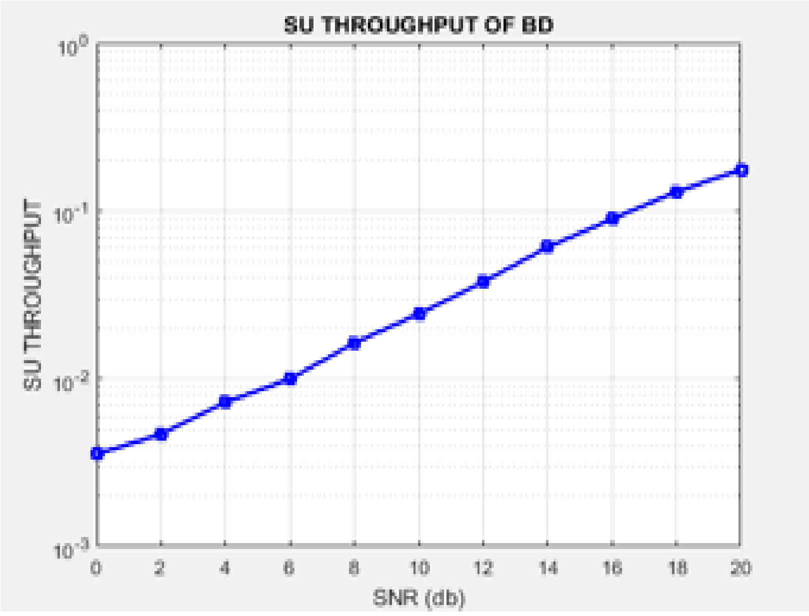

Fig.3. SU throughput

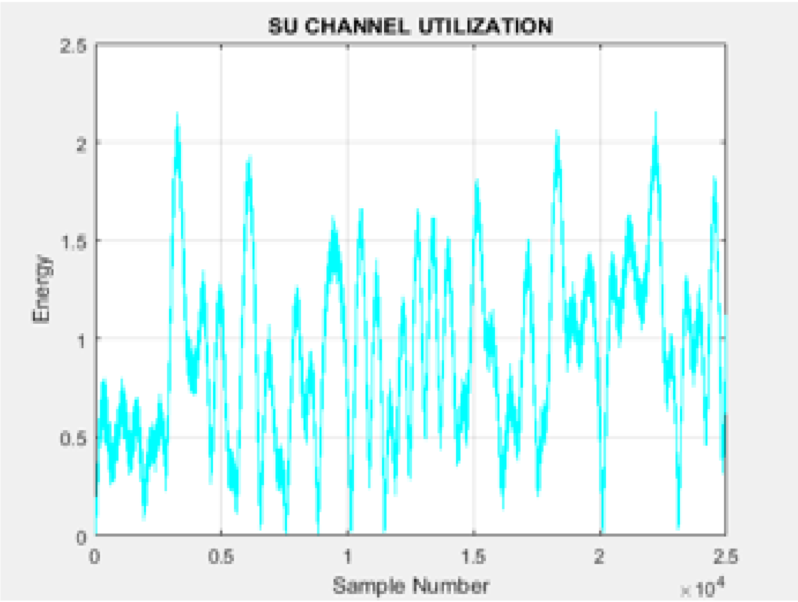

Fig.4. Channel utilization

Fig. 5 shows that detection probability of Bayesian detector,which indicate that BD accurately detect primary user in spectrum when actually primary user is present in spectrum. Bayesian detector accurately detects PU in spectrum at low and high SNR. Its accuracy is increased with increasing SNR value.

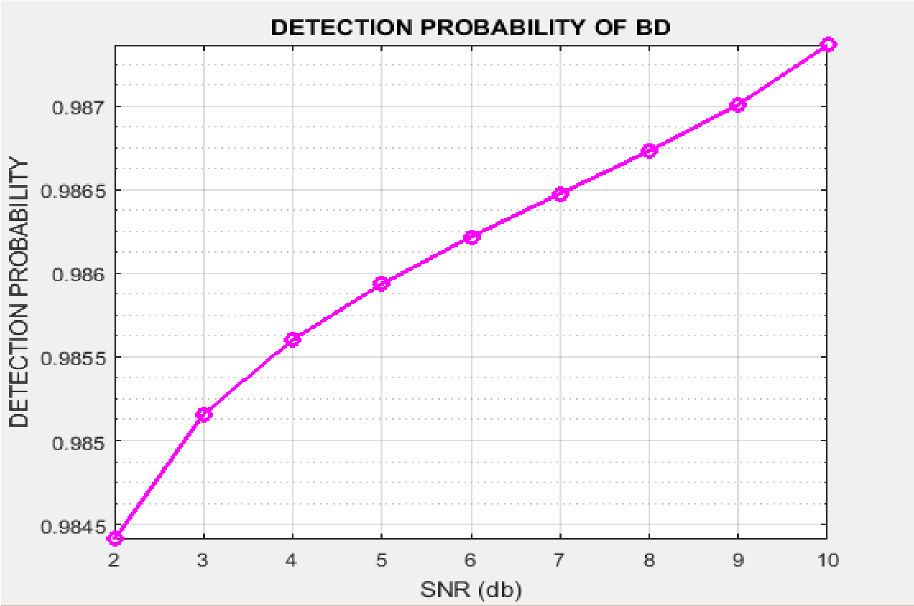

Fig.5. Detection Probability of BD

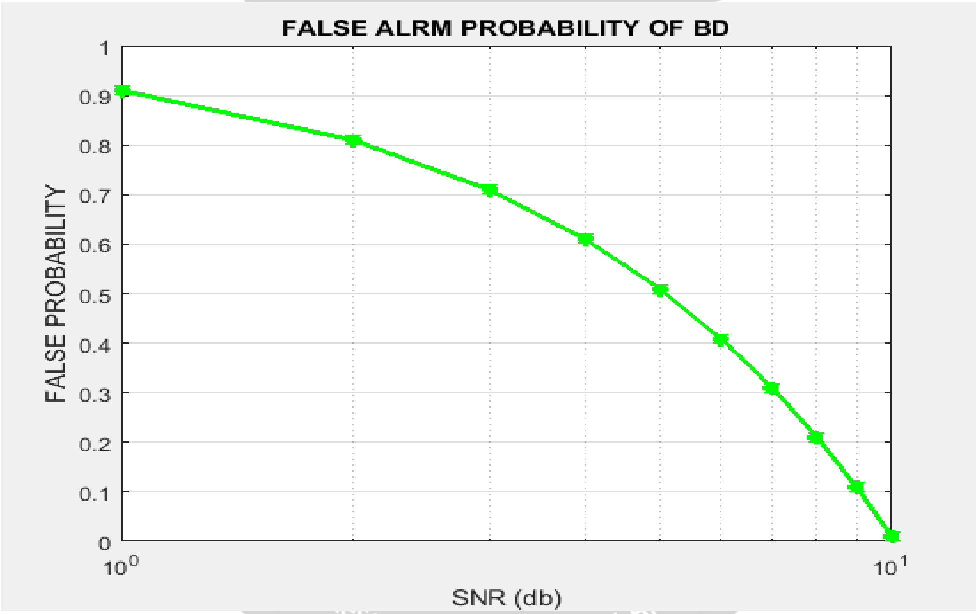

Fig.6. False Alarm Probability of BD

Fig. 6 shows that false Alarm probability of Bayesian detector, which indicate that BD detect primary user in spectrum when actually primary user is absent in spectrum. As the SNR value is increased then Bayesian detector minimizes false alarm probability.

VI.CONCLUSION

In this paper, we discuss Bayesian detector structure to detect the known order MPSK modulated primary signals over AWGN channels which is based on Bayesian decision rule. We provide the performance analyses of the suboptimal detector for complex MPSK signals, in terms of probabilities of detection and false alarm, secondary throughput and secondary user utilization. Although Bayesian detector structure is that the same as or similar to that of energy detector after approximation, because of the difference in detection threshold, Bayesian detector has the advantage over both energy detector and Neyman-Pearson detector that maximize the detection probability for a given false alarm probability, in terms of overall spectrum utilization and secondary users throughput, when primary users underutilize the spectrum.

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