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Primary user signal detection over fading channel in the presence of weakly correlated noise

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Abstract: The rapid deployment of new wireless devices and application leads to increase in demands for wireless radio spectrum. But the fixed spectrum assignment policy becomes a bottleneck for more efficient spectrum utilization, under which a greater portion of licensed spectrum is severely underutilized. However in cognitive radio networks reliable spectrum sensing is necessary to avoid interference to secondary users from the primary users. The cognitive radio networks are networks that have reconfigurable properties and the capability to detect the unoccupied spectrum holes and change frequency for end to end communication. Spectrum sensing methods independent of noise samples will not provide optimum performance. To address this issue a locally optimum detection method is adopted. The performance of LO detection mainly depends on false alarm and detection probability. Numerical and simulation results demonstrate the superiority of the proposed method over the known detection method with comparable complexities. Furthermore the estimated correlation different from the real correlation is considered for detailed study in this paper.

Keywords: Cognitive radio(CR), spectrum sensing, signal detection, fading channels, energy detection, optimum detection

I. INTRODUCTION

In recent years the word cognitive has become an emerging technology that is applied to many different networking and communication system. The opportunistic use of the wireless communication community in recent years due to intense competition for the use of spectrum at frequencies below 3GHz. Cognitive networks has cognitive process that has capability to change its transmission and reception parameters according to network conditions.

A cognitive network consists of number of wireless service subscribers and they are called as cognitive users. The primary users in the networks are the traditional wireless services subscribers that have legacy priority access to spectrum. Secondary users are the cognitive users in this system those who are allowed to access the spectrum only if the communication does not create significant interference to the licensed primary users.

The cognitive radio (CR) concept is a new wireless communication paradigm that improves spectrum usage efficiently by exploiting the existence of spectrum holes. Cognitive radio is the key enabling technology that enables next generation communication networks also known as dynamic spectrum access (DSA) networks to utilize the spectrum more efficiently without interfering the primary users. Cognitive users will have both cognitive capability and reconfigurability [4].

Spectrum sensing is one method for detecting the presence or absence of a primary license holder [4]. This is a challenging task because primary user signal is usually very weak due to fading, shadowing, etc. Spectrum sensing methods includes matched filtering, energy detection, cyclostationary based detection and eigenvalue based detection.

Cyclostationary detection [2] performs better in low SNR region but with increased complexity compared to energy detection. A signal is said to be cyclostationary (wide sense) if its autocorrelation is a periodic function of time with some period. Here maximal ratio combining(MRC) based cyclostationary detector to detect a primary user. The performance of this method is worse when noise is stationary.

Energy detection [1] is another simplest method to detect the licensed user signal. Here prior knowledge of primary or licensed user signal is not required. If noise power is known then energy detector is the good choice. However this method requires longer sensing time to achieve good results. Also it is unable to distinguish between sources of received energy.

Locally optimum detector is the most simplest method for detecting licensed user signal. For performance comparison another detector namely energy detector is considered. In order to validate theoretical results. We perform simulation over a large number of channel gains and obtain averages.

Also performance of proposed LO detector is better than simple energy detection.

II. SYSTEM MODEL

Locally optimum detection (LO) technique is proposed for efficient and reliable spectrum sensing. LO detection is non-cooperative spectrum sensing method. Here prior knowledge of primary signal is not considered. By detecting presence of primary license holder the secondary user uses spectrum holes which are known as unused frequency bands for data transmission. Block diagram of system model is shown in figure below. In presence of primary user the secondary user will receive primary user signal otherwise only noise is

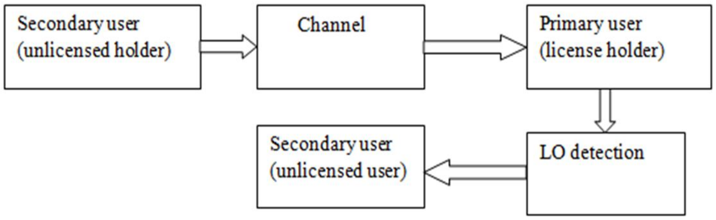

Fig.1. Block diagram of system model

Two hypotheses are assumed as H_0 when primary user is absent and H_1 when primary user is present. At secondary user (n=1,2,3.......,N) signal samples are received, the two hypotheses may be modelled in equivalent complex baseband representation as:

$$H_0: x_n = w_n$$
$$H_1: x_n = hs_n + w_n$$

Where x_n denotes the received signal, h the Rayleigh fading channel gain, w_n denotes the noise samples, s_n is the primary user signal. Since slow fading channels are considered the
channel gain h is assumed to be constant with zero mean and the variance of σ_h^2 . PU signal is assumed to have zero mean and the variance of σ_s^2 and its real and imaginary parts are statistically independent with variance of $\sigma_s^2/2$. The noise is assumed to have zero mean and variance σ_n^2. The PU samples are assumed to be temporally independent, identically distributed (i.i.d). First order bilateral and unilateral moving averages (MA's) of an i.i.d. random process are used to model the weakly correlated noise [1]. This moving averages are simple and good approximation to the weakly correlated noise. We assume that noise samples, the fading gains and PU signals are mutually independent.
Here we assuming that e_i, i=1,2,.......,N are independent, identically distributed(i.i.d) random variables with probability density function (pdf) fe(.) the noise samples $w_1, w_2, \ldots, w_n$ can be modelled as,

$$w_1 = e_1$$
$$w_n = e_n + \rho e_{n-1},\ n=1,2,\ldots,N$$

ρ denotes noise correlation and $|\rho|<1$.
For deriving test statistics between two hypothesis globally optimal(GO) decision statistics can be expressed as

$$\Lambda = \frac{p(X|H_1)}{p(X|H_0)} \quad (1)$$

III. PERFORMANCE ANALYSIS

False alarm and detection probabilities are used to calculate the performance of proposed detector
For hypothesis H0, we have

$$\Lambda_{|H_0} = \sum_{i=1}^{N}\sum_{k=0}^{i-1}\rho^{2k}\left|\sum_{k=0}^{i-1}(-\rho)^k w_{i-k}\right|^2 \quad (2)$$

For hypothesis H1, we have

$$\Lambda_{|H_1} = \sum_{i=1}^{N}\kappa_i\left|\sum_{k=0}^{i-1}(-\rho)^k hs_{i-k} + w_{i-k}\right|^2 \quad (3)$$

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The Gaussian parameters of each hypothesis, the false alarm probability as well as the detection probability are given as,

$$P_f = Pr(\Lambda > \tau | H_0) = Q\left(\frac{\tau - \mu_0}{\sigma_0}\right) \quad (4)$$

$$P_d = Pr(\Lambda > \tau | H_1) = Q\left(\frac{\tau - \mu_1}{\sigma_1}\right) \quad (5)$$

τ is the threshold

We can calculate mean and variance of each hypothesis. For H_0 the calculation is straight forward

$$\mu_0 = \sigma_n^2 \sum_{i=1}^{N} \kappa_i$$
$$\sigma_0^2 = \sigma_n^4 \sum_{i=1}^{N} \kappa_i^2 \quad (6)$$

For hypothesis H_1,

$$\mu_1 = \sigma_n^2 \sum_{i=1}^{N} \kappa_i \left(1 + \frac{\sigma_s^2 |h|^2}{\sigma_n^2} \kappa_i\right) \quad (7)$$

$$\sigma_1^2 = E[\Lambda_{|H_1}^2] - \mu_1^2 \quad (8)$$

Both μ_1 and σ_1^2 depends on the channel gain h. Therefore the average detection probability can be written as,

$$\hat{P}_d = E_h\left[Q\left(\frac{\tau - \mu_1}{\sigma_1}\right)\right] \quad (9)$$

IV. ENERGY DETECTOR UNDER CORRELATED NOISE CONDITIONS

The performance of LO detector is compared with performance of energy detector (ED) in the presence of correlated noise samples. The test statics of energy detector can be expressed as follows,

$$\Lambda = \sum_{i=1}^{N} |x_i|^2 \quad (10)$$

Therefore,

$$\Lambda_{|H_0} = \sum_{i=1}^{N} |w_i|^2 \quad (11)$$

$$\Lambda_{|H_1} = \sum_{i=1}^{N} |hs_i + w_i|^2 \quad (12)$$

V. NUMERICAL RESULT AND DISCUSSION

At secondary user a fading channel with weakly correlated noise with N=500 samples have been collected. Here detection probability is fixed to 0.95 and false alarm probability has to be estimated at different SNR.

False alarm probabilities and detection probabilities for proposed LO detector and ED detector is shown in fig 1 and fig 2. At low SNR we can see that we have higher false alarm probability and lower detection probability. Increase in SNR increases detection probability and decreases false alarm probability, so proposed LO detector has better performance.

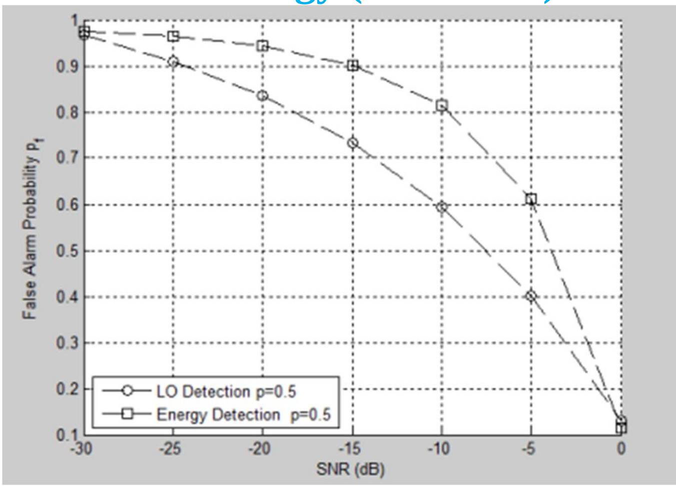

Fig.2.The average false alarm probability for correlation coefficient ρ = 0.5.

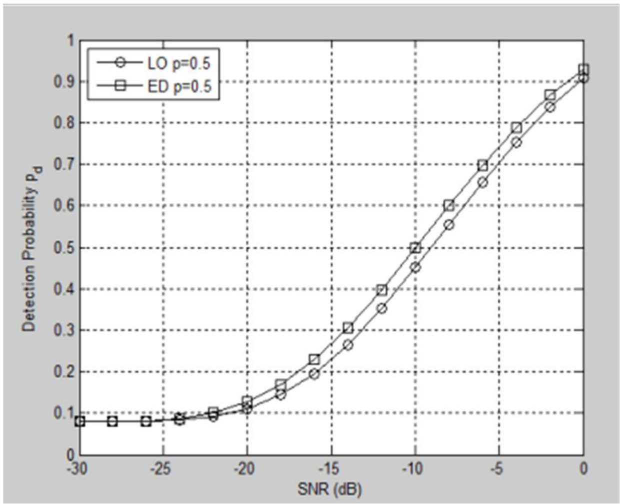

Fig.3.Average detection probability at different SNR's at ρ = 0.5

Average false alarm and detection probability with respect to number of samples is shown in fig 3 and fig 4. With small number of samples false alarm probability is higher and detection probability is lower. Increase in number of samples increases detection probability and decreases false alarm probability

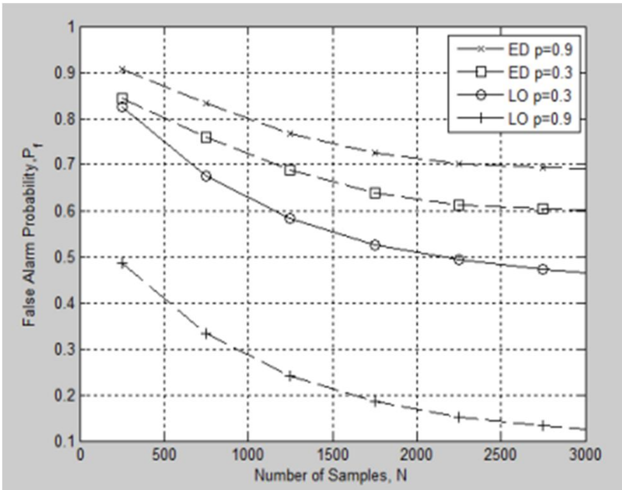

Fig.4.Average false alarm probability versus number of samples

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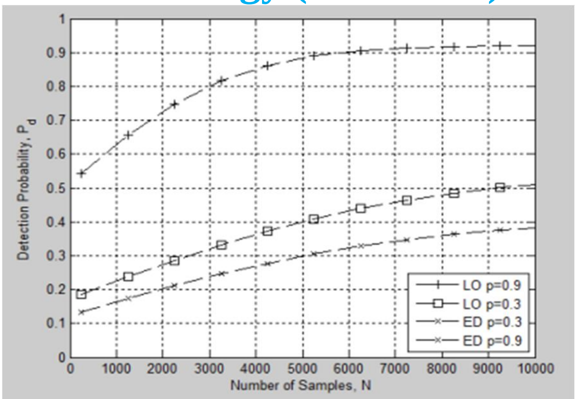

Fig.5.Average detection probability versus number of samples

Fig 6 and 7 shows different correlation ρ are taken and average probabilities of false alarm and detection probability. The gain of proposed detector becomes high with increase in correlation coefficient.

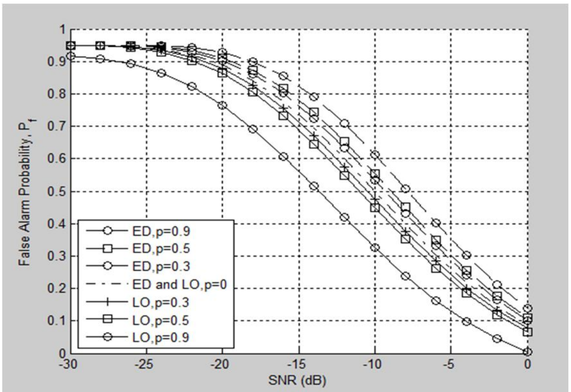

Fig.6.Average false alarm probabilities at different SNRs for detection probability of 0.95 and different correlation coefficients.

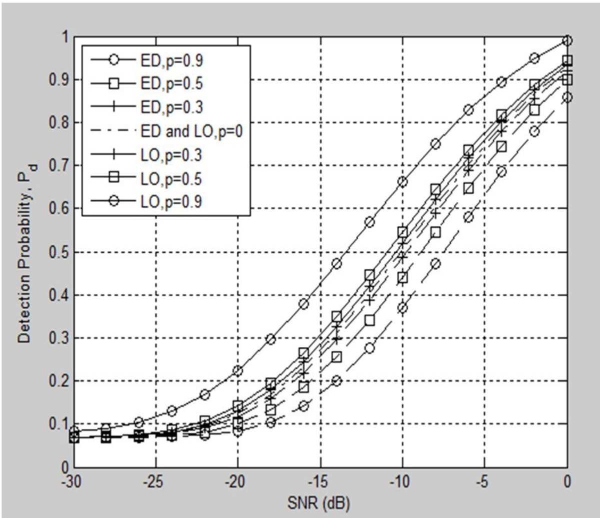

Fig.7.Average detection probabilities at different SNRs for false alarm probability of 0.05 and different correlation coefficients.

Fig 8 and 9 shows the false alarm and detection probabilities with estimated correlation is 0.5 and then the actual correlation is [0.1:0.2:0.9]. Fig 8 shows that detection probabilities decreases with increase in difference between actual and estimated correlation.

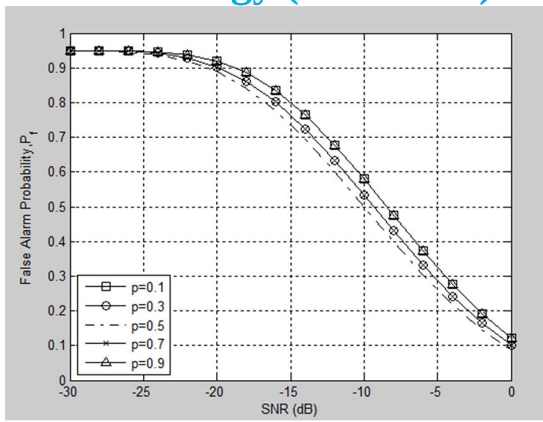

Fig.8.False alarm probability at different SNRs for estimated correlation of 0.5 and actual correlation of [0.1:0.2:0.9]

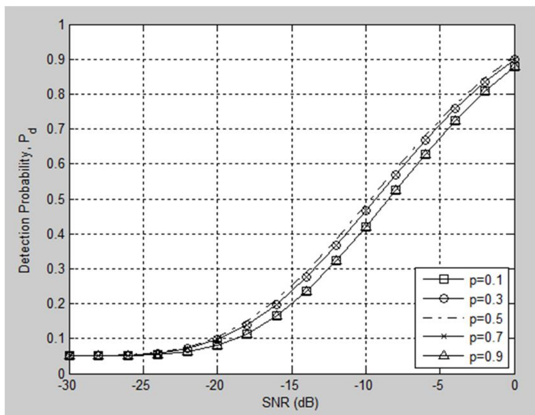

Fig.9.Detection probability at different SNRs for estimated correlation of 0.5 and actual correlation of [0.1:0.2:0.9]

VI. CONCLUSION AND FUTURE ENHANCEMENT

The proposed LO detector is has better performance of false alarm and detection probability compared to energy detection technique. The false alarm and detection probabilities with correlation coefficient 0.5 and with number of samples fixed to 10000 are estimated in this paper. Further the average false alarm and detection probability with different correlation coefficients has to be estimated.

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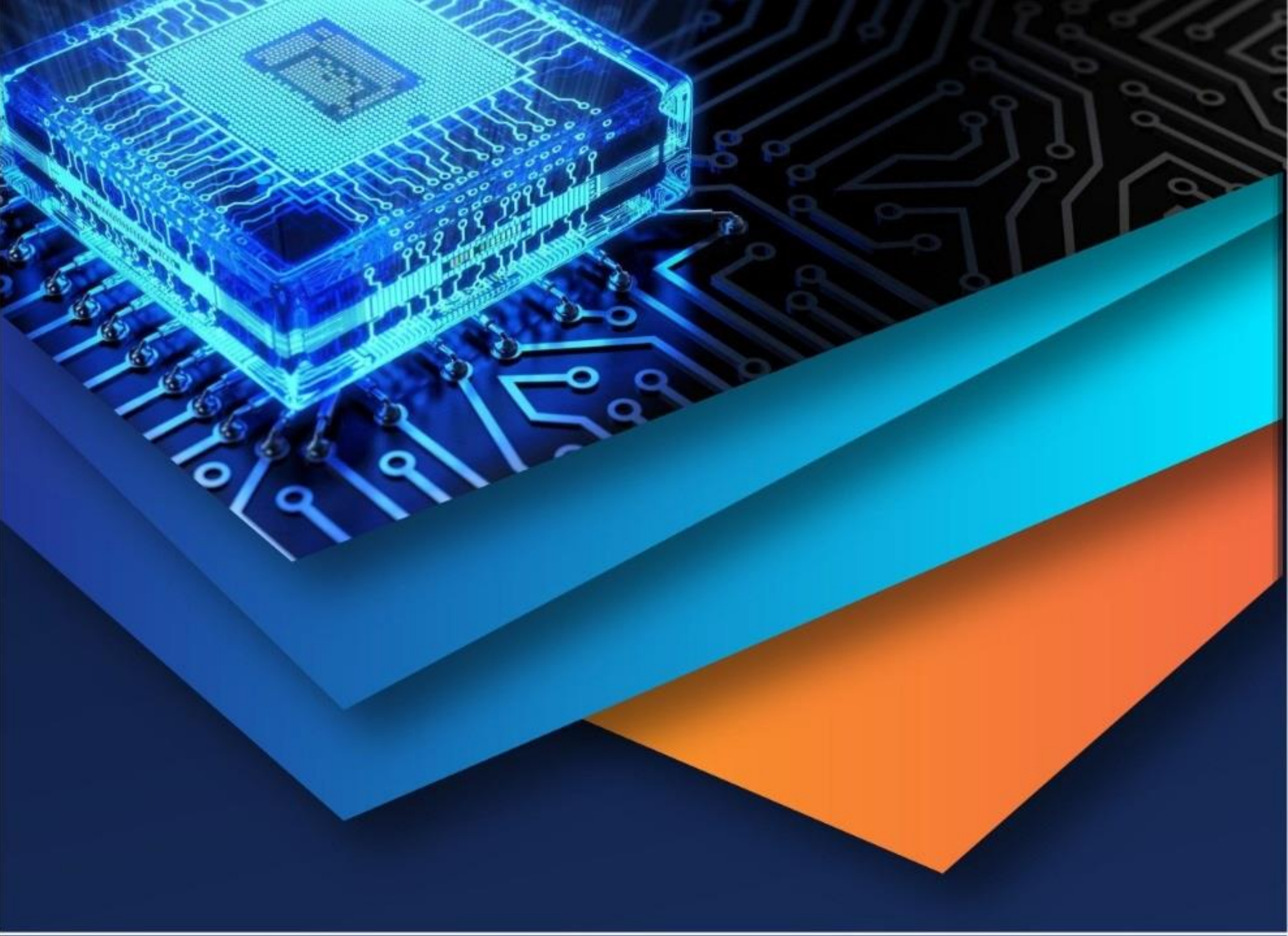

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