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The Presence of Weakly Correlated Noise over Fading Channels on Signal Detection

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Abstract: ***Cognitive radio is a technology which allows the secondary usage of spectrum allocated to primary users. The cognitive radio networks are networks that have cognitive and reconfigurable properties and the capability to detect the unoccupied spectrum holes and change frequency for end to end communication. In CRNs in order to avoid interference to the primary users efficient and reliable spectrum sensing is necessary. In the case where noise samples are correlated impairments due to independent noise samples must be considered. To address this issue, Locally Optimum (LO) detection technique is utilized. The performance of LO detector depends mainly on false alarm probability and detection probability. The probabilities of false alarm and detection at different SNRs are analyzed. The simulation results demonstrate the superiority of LO detector over known energy detection method. Furthermore, the scenario where estimated correlation is different from real correlation is considered for detailed study in this paper.***

Keywords: Cognitive Radio, spectrum sensing, fading channels, locally optimum detection, energy detection

1. Introduction

In recent years the word cognitive and smart has become buzzwords that are applied to many different networking and communication systems. The opportunistic use of the wireless communications community in recent years due to the intense competition for the use of spectrum at frequencies below 3 GHz. Cognitive network has a cognitive process that can perceive current network conditions, and then plan, decide and act on this conditions.

A cognitive network consists of a number of wireless service subscribers and they are called as cognitive users. The traditional wireless service subscribers have the legacy priority access to the spectrum and are usually called primary users in this network. Cognitive users in this system are called secondary users, 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 the spectrum usage efficiency by exploiting the existence of spectrum holes. The cognitive radio is a technology [2] [3] which helps to use the Radio Frequency (RF) spectrum more efficiently by allowing the secondary usage of spectrum allocated to the primary users. In order to avoid interference to the primary users the secondary users must perform spectrum sensing. Spectrum sensing is a method for detecting the presence or absence of license holder [4] [5].

In this paper, introducing a Locally Optimum (LO) detection of random signals over fading channels. The performance of LO detection is measured using false alarm probability and detection probability. For performance comparison another detector namely Energy detector is considered. While comparing LO detector has lower false alarm probability and higher detection probability than energy detector. Moreover the effect of correlation mismatch is considered. In order to validate theoretical results, we perform simulation over a large number of channel gains and obtain averages. Also show that simulation results are in good match with theoretical results.

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

2. Related Work

Radio Frequency (RF) spectrums is very expensive and have limited resource of wireless communication. Cognitive radio is a technology developed for opportunistic use of RF spectrum[1]. CR technology allows the secondary usage of spectrum allocated to primary users. In order to detect the presence of primary user signal spectrum sensing is a fundamental requirement to achieve the goal of cognitive radio[4] [5].

Cyclostationary detection [8] is the preferred technique to detect the primary users receiving data within the communication range of a CR user at very low SNR. The detection of the presence or absence of signal is performed based on scanning the cyclic frequencies of the cyclic spectrum or cyclic autocorrelation function. The performance of this method is worse when noise is stationary.

Energy detection[6] is another simplest method used to detect licensed user signal. It is a non-coherent detection method. It is a simplest method in which prior knowledge of primary or licensed user signal is not required. Energy detection is one of the popular and easiest techniques of non-cooperative sensing in cognitive radio networks. If noise power is known then energy detector is the good choice. However energy detector requires longer sensing time to achieve good results. Also it is unable to distinguish between sources of received energy.

Locally optimum detector[13] is the most simplest non-coherent method for detecting licensed user signal. The test statistic of the locally optimum detector is derived under a weakly dependent noise model. The performance characteristic of the locally optimum detector is analyzed and compared with that of the square-law detector in terms of asymptotic relative efficiency. While comparing Locally Optimum detector has better performance.

3. System Model

For efficient and reliable spectrum sensing the proposed system model uses Locally Optimum (LO) detection technique. LO detection is a non-cooperative spectrum sensing method. It doesn't depends on prior knowledge of the primary user signal. The performance of LO detection is based on false alarm and detection probabilities. False alarm probability is the probability that deciding hypothesis H0 when hypothesis H1 is true. The secondary user wants to check the presence of license holder. In order to check the presence of primary users secondary users uses cognitive radio technology. The secondary user first transmits a radio signal. Hence it act as the transmitter. This signal propagates through the channel. Due to noise and interference fading occurs in the channel. Now secondary user performs spectrum sensing based on locally optimum detection technique for checking the presence of license holder. If the primary user is present then the secondary user will receive primary user signal. By detecting the presence of license holder the secondary user uses unused frequency bands called spectrum holes or white space for data transmission. The block diagram of the system model is given in the figure 1. When the primary user is present the secondary user will receive primary user signal otherwise only noise is received. Hence in this scenario secondary user act as both transmitter andreceiver.

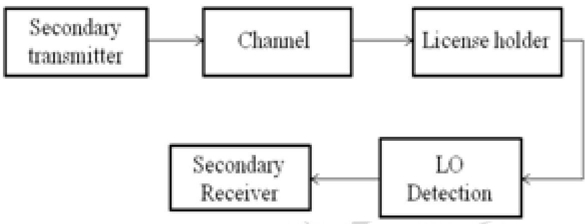

Figure1: Block diagram of system model

The system model is based on two hypothesis. Assuming there are two hypothesis, H0 when the primary user is absent and H1 when the primary user is absent. The secondary user for this two hypothesis may be modeled in equivalent complex baseband represented as,

H_0: $x_n = w_n$

H_1: $x_n = hs_n + w_n$

where x_n, h , and w_n denote the received signal , the Rayleigh fading channel gain and the noise samples at the secondary user and s_n is the primary user signal. Since in this paper we are considering slow fading channel the channel gain h is assumed to be constant. Assuming that noise samples are temporally dependent. In simple first order bilateral and unilateral moving averages (MAs) of an i.i.d random process are used to model weakly correlated noise.

In order to derive a test statistic to recognize between two hypothesis H_0 and H_1 the globally optimal (GO) decision statistic can be expressed as,

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

4. Performance Analysis

4.1 Energy Detector

In this paper a simple energy detector is used for detection in the presence of weakly correlated noise samples are analyzed for performance comparison. Also demonstrate the superiority of the proposed locally optimum detector in terms of performance compared to the conventional energy detection based on the analytical expressions. The test statistic can be expressed as,

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

Therefore,

$$\Lambda_{|H_0} = \sum_{i=1}^{N} |w_i|^2 \quad (3)$$

$$\Lambda_{|H_1} = \sum_{i=1}^{N} |hs_i + w_i|^2 \quad (4)$$

Average detection probability is,

$$\bar{P}_{d-e} = E_h[Q(\varepsilon_{d-e} - \alpha_e |h|^2)] \quad (5)$$

where $\varepsilon_{d-e} = \frac{\tau - \mu_{0-e}}{\sigma_{0-e}}$ and $\alpha_e = \frac{N\sigma_s^2}{\sigma_0}$ and average false alarm probability is,

$$\bar{P}_{f-e} = E_h[Q(\varepsilon_{f-e} + \eta |h|^2)] \quad (6)$$

where $\varepsilon_{f-e} = \frac{\tau + \mu_0}{\sigma_0}$ and $\eta = \frac{1}{2\sigma_{n-e}^2} \varepsilon_{f-e} + \alpha_e$

4.2 Correlation mismatch

Up to here all the results are based on assumption that there is a perfect knowledge of correlation coefficient between noise samples at different times. This is not valid for all cases because sometimes there is a difference between estimated value and real value of the correlation coefficient. In order to investigate the effect of correlation mismatch in our proposed detector, we denote the real correlation as ρ and estimated correlation as $\hat{\rho}$. In order to include this two quantities , start with test statistics,

$$\Lambda = \sum_{i=1}^{N} \frac{1-\hat{\rho}^{2i}}{1-\hat{\rho}^2}$$

For H_0 hypothesis

$$\hat{y}_i = \sum_{k=0}^{i-1} (-\hat{\rho})^k w_{i-k} = \sum_{k=0}^{i-1} (-\hat{\rho})^k (e_{i-k} + \rho e_{i-k-1})$$

$$= e_{i} + \left(1 - \frac{\rho}{\hat{\rho}}\right) \sum_{k=1}^{i-1} (-\hat{\rho})^k e_{i-k}$$

and therefore

$$\Lambda_0 = \sum_{i=1}^{N} \frac{1-\hat{\rho}^{2i}}{1-\hat{\rho}^2} \left| e_i + \left(1 - \frac{\rho}{\hat{\rho}}\right) \sum_{k=1}^{i-1} (-\hat{\rho})^k e_{i-k} \right| \quad (7)$$

where Λ_0 is a summation of dependent random variables. A similar approach can be followed for H_1 and the parameters can be used for computing false alarm and detection probabilities under mismatch conditions.

4.3 Locally Optimum Detector

This paper proposes an optimal locally detector for spectrum sensing to achieve higher spectrum utilization in cognitive radion networks. Here assume that the noise samples are temporally dependent. In order to derive a test statistic to recognize between two hypothesos H_0 and H_1, start with globally optimal decision statistic expressed as,

where f_w is the multivariate pdf of the noise samples and $X= x_1, x_2, \ldots\ldots x_N$, $S= s_1, s_2,\ldots\ldots s_N$. For the hypothesis H0,

$$\Lambda_{|H_0} = \sum_{i=1}^{N} k_i \, |e_i|^2 \qquad (9)$$

For hypothesis H_1,

$$\Lambda_{|H_1} = \sum_{i=1}^{N} k_i \left|\sum_{k=0}^{i-1} (-\rho)^k h s_{i-k} + w_{i-k}\right|^2 \qquad (10)$$

For LO detector average detection probability is,

$$\widehat{P_d} = E_h[Q(\varepsilon_d - \alpha|h|^2)] \qquad (11)$$

where $\varepsilon_d = \frac{\tau-\mu_0}{\sigma_0}$ and $\alpha = \frac{1}{\sigma_0}\sum_{i-1}^{N}\left(\frac{1-\rho^2}{1-\rho}\right)^2$ and average false alarm probability is,

$$\widehat{P_f} = E_h[Q(\varepsilon_f + \eta|h|^2)] \qquad (12)$$

where $\varepsilon_f = \frac{\tau+\mu_0}{\sigma_0}$ and $\eta = \frac{1}{2\sigma_0^2}\varepsilon_f + \alpha$

5. Numerical Results

In order to validate analytical results presented in the previous sections consider a fading channel with weakly correlated noise and N=500 samples have been collected at the secondary user. Assume a slow fading channel where the fading coefficient h is constant during the sampling period. Also fix the detection probability to 0.95 and find the average false alarm probabilities at different SNRs. Furthermore to verify theoretical results, also find the average false alarm probability over 100,000 independent realizations of the Rayleigh fading channel.

The average false alarm probabilities and detection probabilities at different SNRs for proposed LO detector and energy detector are shown in the figure 5(a) and 5(b).As we can seen in the figure at lower snr both detectors have higher false alarm probability and lower detection probability. As SNR increases false alarm probability decreases and detection probability increases. Hence proposed LO detector has better performance than energy detector.

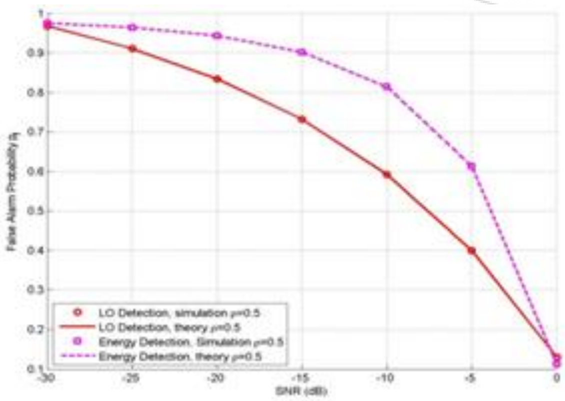

Figure 5(a): Average false alarm probabilities at different SNRs for $\rho = 0.5$

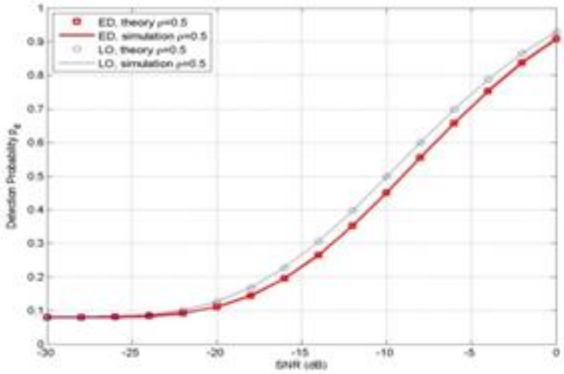

Figure 5(b): Average detection probabilities at different SNRs for $\rho = 0.5$

The average false alarm and detection probabilities with respect to number of samples is shown in the figure 5(c) and figure 5(d). For small number of samples false alarm probability is higher and detection probability is lower. But as number of samples increases false alarm probability gets lowered and detection probability increases.

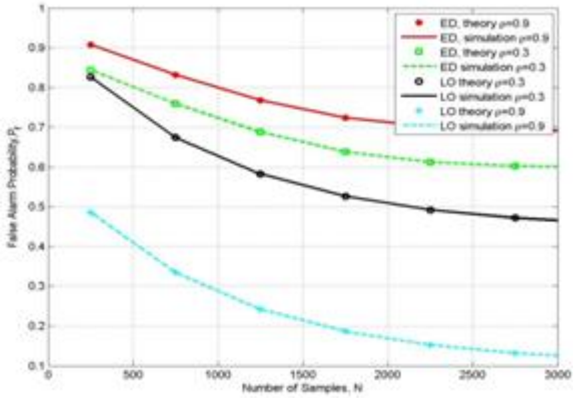

Figure 5(c): Average false alarm probabilities versus number of samples

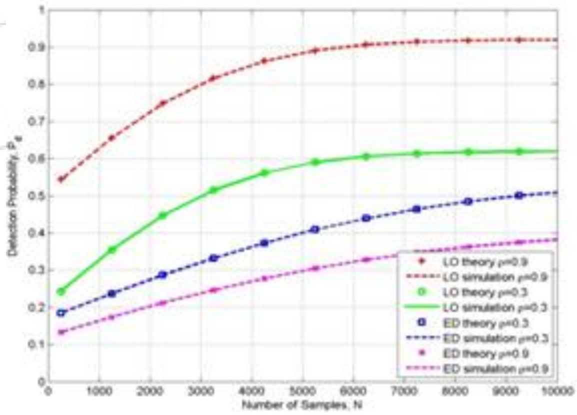

Figure 5(d): Average detection probabilities versus number of samples

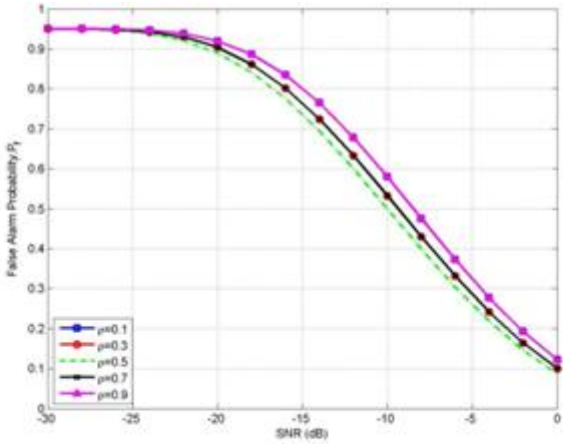

Figure 5(e): False alarm probability at different SNRs for estimated correlation of 0.5 and actual correlation of [0.1:0.2:0.9]

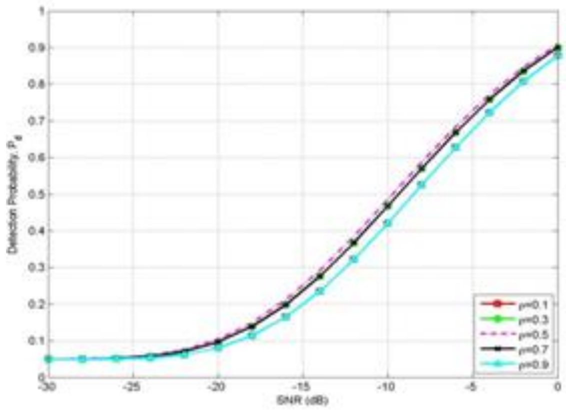

Figure 5(f): Detection probability at different SNRs for estimated correlation of 0.5 and actual correlation of [0.1:0.2:0.9]

All the figures so obtained is under the assumption that there is a perfect knowledge of the correlation coefficient. Now consider the correlation mismatch. For the cases where estimated correlation is 0.5 and the actual correlations of [0.1:0.2:0.9] is shown in figures 5(e) and 5(f). As seen in the figures higher correlation mismatch results in higher false alarm probability and lower detection probability. The perfect estimation case $\hat{\rho} = \rho$ results in the highest detection probability and lowest false alarm probability.

6. Conclusion

A locally optimum detector for detection of random signals under a weakly correlated noise over fading channels has been proposed in this paper. In order to consider the effect of correlation mismatch, we assume that estimated value and real correlation value is different. The proposed LO detector has better performance than Energy detector. That is, the proposed LO detector has lower false alarm probability and higher detection probability. Also, higher the correlation mismatch results in higher false alarm probability and lower detection probability and vice versa.

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