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Cooperative Spectrum Sensing in Cognitive Radio Networks

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***Abstract*— The entire operation of cognitive radio depends on the spectrum sensing technology. The main function of cognitive radio is to detect unused spectrum and sharing it to other user without causing harmful interference to the primary user induced by reporting phase. Basically it requires two phases: detection phase and reporting phase. In detection phase cognitive users detects the presence of primary users (Licensed user). In reporting phase cognitive user forward their detection report to fusion center. In this, we analyze the effect of ROC (Receiver Operating Characteristics) with and without dedicated reporting channel by jointly considering the signal detection and reporting phases**

***Keywords*— Cognitive radio, cooperative spectrum sensing, receiver operating characteristics, fusion center**

I. Introduction

Cognitive radio detects the unused spectrum and shares it with the other users. The use of cognitive radio improves the efficiency of wireless spectrum resources [1], [2]. Energy detection [3] , matched filter [4] detection and feature detection [5]: these three are the main categories of signal processing. In order to reduce the fading effect in wireless system, a cooperative spectrum sensing technique is used. In this technique the detection results from various cognitive users are obtained and then combined it at the fusion center together by using various logic rule such as AND fusion rule and OR fusion rule. The cooperative spectrum sensing process needs two phase: detection phase and reporting phase. For the spectrum sensing process one cannot be designed and optimized these two phases in isolation as they are not independent to each other. In detection phase cognitive users detects the presence of primary users (Licensed user) and cognitive user forward their detection report to the fusion center in reporting phase. At the fusion center the results are combined by the logic rule [6]. But there is a need to take care of time duration of both the phases as both the phases could affect each other. If the time duration of any phase is more then it will degrade the performance of overall spectrum sensing at the fusion cente

II. PROPOSED COOPERATIVE SPECTRUM SENSING IN COGNITIVE RADIO NETWORKS

A. *System Description*

Time duration for detection phase and reporting phases are α and 1-α fractions respectively of one time slots. It is to be assumed that α is same for all cognitive users. CUs forwards their detection report to fusion center (FC) over the orthogonal sub-channel. Sub-channels are equally divided in reporting phase, resulting in multiple time slots. These all CUs will interfere primary user (PU) potentially in the reporting phase so in order to reduce this interference as much as possible we use a concept of selective relay based cooperative sensing scheme where all cognitive users sends their detection report to the fusion center in a selective fashion depending on the presence or absence of primary user. If CU detects that PU is absent in that case it will transmit an indicator signal with encoded cyclic redundancy code (CRC) to the FC else no signal is transmitted. At the fusion center the signal is decoded and if it is successfully decoded then it means CU detection report says that PU is absent else primary user is present. So the possibility of causing interference is reduced and controlled also as CU will interfere the PU only when it fails to detect the presence of PU

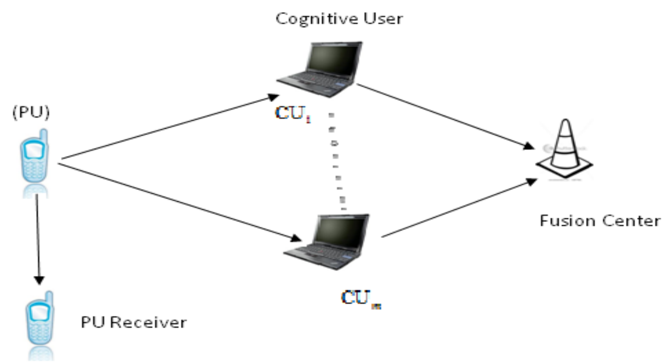

Figure 1. System model of cooperative spectrum sensing

B. *Signal Model*

In this model we use a Rayleigh fading and it is constant during one whole time slot. N_0 is the power spectral density of the additive white Gaussian noise (AWGN) that is same for the entire receiver. Assume that P_p and P_s are the transmit power of PU and CU. Let $H_p=H_1$ denotes the presence of primary user and $H_p=H_0$ represents absence of it. In the detection phase, the signal received at CU_i for the k time slots, can be written as,

$$y_i(1) = \sqrt{P_p} h_{pi}\theta(1) + n_i(1), \quad i = 1,2,3.....,M \qquad \text{(i)}$$

Where index(1) shows the 1^{st} phase of k time slots, and M is number of CUs. h_{pi} is fading coefficient from PU to CU_i.

$$\theta(1) = \begin{cases} 0 \quad , & H_p=H_0 \\ x_p(1), & H_p=H_1 \end{cases} \qquad \text{(ii)}$$

Where $x_p(1)$ is a complex symmetric Gaussian distribution and this is the transmit signal of PU in the 1^{st} phase of time slots k. And $|y_i^{(n)}(1)|^2$ is the n-th sample energy of signal received at i-th CU. Therefore the output statistic of energy detector of CU_i is given by the formula,

$$T\left[y_i(1)\right] = \frac{1}{N}\sum_{n=1}^{N}\left|y_i^{(n)}(1)\right|^2 \qquad (iii)$$

Where $N=\alpha Tf_s$ is number of samples where f_s is sampling frequency and T is time slot length.

Using an energy detection approach, the detection results $\hat{H}_i(1)$ is given by,

$$\hat{H}_i(1) = \begin{cases} H_0, & T[y_i(1)] < \lambda_i \\ H_1, & T[y_i(1)] < \lambda_i \end{cases} \qquad \text{(iv)}$$

Each CU sends a βi to fusion center over orthogonal sub-channel. x_i is an indicator signal with encoded CRC. β_i and θ(2) is defined as,

$$\beta_i = \begin{cases} x_i, & \hat{H}_i(1)=H_0 \\ 0, & \hat{H}_i(1)=H_1 \end{cases} \qquad \text{(v)}$$

$$\theta(2) = \begin{cases} 0 \quad , & H_p=H_0 \\ x_p(2), & H_p=H_1 \end{cases} \qquad \text{(vi)}$$

Where $x_p(2)$ is a complex symmetric Gaussian distribution and this is the transmit signal of PU in the 2^{nd} phase of time Slot k.

Signal received at fusion center is given as,

$$y_c^i(2) = \sqrt{P_s} h_{ic}\beta_i + \sqrt{P_p} h_{pc}\theta(2) + n_c(2) \qquad \text{(vii)}$$

Where index 2 denotes the second phase.Now fusion center will decode the β_i and do the CRC operation and if CRC checking fails means no signal is transmitted and PU is present otherwise PU is absent, and finally result is stored in $\hat{H}_i(2)$. And the $\hat{H}_i(2)$ can be written as,

$$\hat{H}_i(2) = \begin{cases} H_1, & \Theta_{ic}(2)=1 \\ H_0, & \Theta_{ic}(2)=0 \end{cases} \qquad \text{(viii)}$$

Where $\theta_{ic}(2)$ is an outage event that occur when a channel capacity is below a required data rate. Therefore $\theta_{ic}(2)$ is defined as,

$$\Theta_{ic}(2) = 1 : \frac{(1-\alpha)}{M}\log_2\left(1 + \frac{|h_{ic}|^2 \gamma_s |\beta_i|^2}{|h_{pc}|^2 \gamma_p |\theta(2)|^2 + 1}\right) < \frac{1}{BT} \qquad \text{(ix)}$$

$$\gamma_s = P_s / N_o, \gamma_p = P_p / N_o$$

Where B is the frequency bandwidth.Over each time slot spectrum sensing is performed which gives data rate of initial detection results as 1/(BT). However it is completed during the whole reporting phase time i.e (1-α), so the reporting phase capacity is scaled by (1-α). An outage event occur under two condition one is $\beta_i = 0$ when $\hat{H}_i(1) = H_1$ and other one is small value of $|h_{ic}|^2$ which gives channel capacity below a required data rate 1/(BT). Now by using fusion rule FC combine all $\hat{H}_i(2)$.So the final result obtained

By using AND fusion rule,

$$\hat{H}_c = \bigotimes_{i=1}^{M} \hat{H}_i(2) \qquad \text{(x)}$$

By using OR fusion rule,

$$\hat{H}_c = \bigoplus_{i=1}^{M} \hat{H}_i(2) \qquad \text{(xi)}$$

III. PERFORMANCE ANALYSIS OF SPECTRUM SENSING SCHEME

In this section we have to analyze ROC by the traditional method as well as proposed scheme over Rayleigh fading channels.

a). ROC Analysis:

We check the performance of Receiver operating characteristic (ROC) with and without dedicated channel

b). Traditional cooperative sensing with a dedicated channel:

In this the results of initial detection of CU that is encoded with CRC are forwarded to FC through a dedicated channel. At FC signal will be decoded and successfully decoded outcomes only will be combined. These successfully decoded outcomes after combined constitute a set C. Sample space of all possible set such that {C € 0 U C_m} where m = 1,2,3…..,2^M-1. C_m is sub collection of non empty subset of M CUs.

Case C=0: decoded operation fails at FC therefore

$$\log_2(1+\left|h_{ic}\right|^2\gamma_s^T)<\frac{1}{B_dT_d}\quad,\quad i=1,2,.......,M \qquad \text{(xii)}$$

Where B_dT_d is bandwidth time product of dedicated channel. Therefore at C=0 no fusion is done at FC and degrade the performance of spectrum sensing.

$$\overset{\Lambda}{H}_c\left(C=\varnothing\right)=H_1 \qquad \text{(xiii)}$$

Case $C=C_m$ decoded operation successfully happens so fusion is happened at FC either by AND fusion rule or OR fusion rule,

$$\log_2(1+|h_{ic}|^2\gamma_s^T>1/B_dT_d,\quad i\in C_m \qquad \text{(xiv)}$$

$$\log_2(1+\left|h_{jc}\right|^2\gamma_s^T)<\frac{1}{B_dT_d},\quad j\in\overline{C}_m \qquad \text{(xv)}$$

where $\overline{C}_m=R-C_m$

AND Fusion Rule $\overset{\Lambda}{H}_c(C=C_m)=\underset{i\in C_m}{\otimes}\overset{\Lambda}{H}_i(1)$ (xvi)

OR Fusion Rule $\overset{\Lambda}{H}_c(C=C_m)=\underset{i\in C_m}{\oplus}\overset{\Lambda}{H}_i(1)$ (xvii)

$Pd_{AND}^{traditional}$ can be referred as probability of overall detection of PU presence at FC for the AND based rule,

$$Pd_{AND}^{traditional}=\Pr\{\overset{\Lambda}{H}_c=H_1\left|H_p=H_1\right\}$$

$$=\Pr\{\overset{\Lambda}{H}_c=H_1\left|H_p=H_1,C=\phi\right\}\Pr\{C=\phi\left|H_p=H_1\right\}$$

$$+\sum_{m=1}^{2^M-1}\Pr\{\overset{\Lambda}{H}_c=H_1\left|H_p=H_1,C=C_m\right\}pr\{C=C_m\left|H_p=H_1\right\}$$

$$Pd_{AND}^{traditional}=\Pr\{C=\phi\}+\sum_{m=1}^{2^M-1}\Pr\{C=C_m\}\prod_{i\in C_m}Pd_{i,1} \qquad \text{(xviii)}$$

$$Pf_{AND}^{traditional}=\Pr\{\overset{\Lambda}{H}_c=H_1\left|H_p=H_0,C=\phi\right\}\Pr\{C=\phi\left|H_p=H_0\right\}$$

$$+\sum_{m=1}^{2^M-1}\Pr\{\overset{\Lambda}{H}_c=H_1\left|H_p=H_0,C=C_m\right\}pr\{C=C_m\left|H_p=H_0\right\}$$

$$Pf_{AND}^{tradional}=\Pr\{C=\phi\}+\sum_{m=1}^{2^M-1}\Pr\{C=C_m\}\prod_{i\in C_m}Pd_{f,1} \qquad \text{(xix)}$$

The probability of individual false alarm is given by,

$$Pf_{i,1}=\begin{cases}Pd_{,1}\quad, & Pd_{i,1}=Q(-\sqrt{N})\\ Pd_{i,1}-Q(Q^{-1}(Pd_{i,1})+\frac{1}{\sigma_{pi}^2k_i})\exp(\epsilon_i)\,, & otherwise\end{cases} \qquad (xx)$$

$$k_i=\gamma_pQ^{-1}(Pd_{i,1})+\sqrt{N}\gamma_p\,,\varepsilon_i=\frac{Q^{-1}(Pd_{i,1})}{\sigma_{pi}^2k_i}+\frac{1}{2\sigma_{pi}^4k_i^2}\,,$$

$Pd_{OR}^{traditional}$ is probability of overall detection by OR based rule,

$$Pd_{OR}^{traditional}=\Pr\{C=\phi\}+\sum_{m=1}^{2^M-1}\Pr\{C=C_m\}[1-\prod_{i\in C_m}(1-Pd_{i,1})] \qquad (xxi)$$

$Pf_{OR}^{traditional}$ is probability of overall false alarm is ,

$$Pf_{OR}^{traditional}=\Pr\{C=\phi\}+\sum_{m=1}^{2^M-1}\Pr\{C=C_m\}[1-\prod_{i\in C_m}(1-Pf_{i,1})] \qquad (xxii)$$

Therefore the term $\Pr(C=\emptyset)$ are calculated as,

$$\Pr\{C=\phi\}=\prod_{i=1}^{M}\;[1-\exp(-\frac{\Delta}{\sigma_{ic}^2})] \qquad (xxiii)$$

Where, $\Delta=[2^{1/(B_dT_d)}-1]/\gamma_s^T$

Similarly $\Pr(C=Cm)$ is given by,

$$\Pr\{C=C_m\}=\prod_{i\in C_m}\exp(-\frac{\Delta}{\sigma_{ic}^2})\prod_{j\in\overline{C}m}[1-\exp(-\frac{\Delta}{\sigma_{jc}^2})] \qquad (xxiv)$$

c) *By Proposed scheme:*

The probability of overall detection at the FC of presence of PU is given by,

$$Pd_{AND}^{proposed}=\Pr\{\overset{\Lambda}{H}_c=H_1\left|H_p=H_1\right\} \qquad (xxv)$$

$$=\Pr\{\overset{M}{\underset{i=1}{\otimes}}H_i(2)=\overset{\Lambda}{H}_1\left|H_p=H_1\right\}$$

$$Pd_{AND}^{proposed}=\prod_{i=1}^{M}Pd_{c,i} \qquad (xxvi)$$

$$Pd_{c,i}=\Pr\{\overset{\Lambda}{H}i(2)=H_1\left|Hp=H_1\right\} \qquad (xxvii)$$

$$Pf_{c,i}=\Pr\{\overset{\Lambda}{H}_i(2)=H_1\left|H_p=H_0\right\} \qquad (xxviii)$$

Where $Pd_{c,i}$ and $Pf_{c,i}$ is the probability of individual cognitive detection and individual false alarm.

Now the probability of overall false alarm for the presence of PU is given as,

$$Pf_{AND}^{proposed}=\Pr\{\overset{\Lambda}{H}c=H_1\left|Hp=H_1\right\}$$

$$=\Pr\{\overset{M}{\underset{i=1}{\otimes}}\overset{\Lambda}{H}i,2(2)=H_1\left|Hp=H_0\right\}$$

$$Pf_{AND}^{proposed}=\prod_{i=1}^{M}Pf_{c,i} \qquad (xxix)$$

And now if we consider an OR logic rule, then

$$Pd_{OR}^{proposed}=1-\prod_{i=1}^{M}\;(1-Pd_{c,i}) \qquad (xxx)$$

$$Pf_{OR}^{proposed}=1-\prod_{i=1}^{M}(1-Pf_{c,i}) \qquad (xxxi)$$

From the signal model $Pd_{c,i}$ can be written as,

$$Pd_{c,i}=1-\Pr\{\overset{\Lambda}{H}_i(2)=H_0\left|H_p=H_1\right\} \qquad (xxxii)$$

By using indicator signal and outage event eq. it can be further written as,

$$Pd_{c,i} = 1-(1-Pd_{i,1})\times \Pr\{\frac{(1-\alpha)}{M}\log_2(1+\frac{|h_{ic}|^2\gamma_s}{|h_{pc}|^2\gamma_p+1}) > \frac{1}{BT}\} \quad (xxxiii)$$

On solving, it can be rewritten as,

$$Pd_{c,i} = 1-\frac{\sigma_{ic}^2(1-Pd_{i,1})}{\sigma_{pc}^2\gamma_p\Lambda+\sigma_{ic}^2}\exp(-\frac{\Lambda}{\sigma_{ic}^2}) \quad (xxxiv)$$

where $\Lambda = [2^{M/[(1-\alpha)BT]}-1]/\gamma_s$.

Now as $Pd_{c,i}$ The $Pf_{c,i}$ can also be written as follows,

$$Pf_{c,i} = 1-\Pr\{\hat{H}_i(2) = H_0 | H_p = H_0\}$$

$$Pf_{c,i} = 1-\Pr\{\Theta_i(2) = 0 | H_p = H_0\}$$

$$= 1-(1-Pf_{i,1})\Pr\{\frac{(1-\alpha)}{M}\log_2(1+|h_{ic}|^2\gamma_s) > \frac{1}{BT}\}$$

$$Pf_{c,i} = 1-(1-Pf_{i,1})\exp(-\frac{\Lambda}{\sigma_{ic}^2}) \quad (xxxv)$$

Where $Pf_{i,1}$ is probability of individual false alarm at CU_i of presence of PU.

IV. RESULT AND ANALYSIS

In this section, we are showing the results of receiver operating characteristic (ROC) by using the traditional method and proposed scheme. The figure 2 explains the overall detection probability versus the overall false alarm probability for the traditional method, where the ROC obtained by AND has better result than OR based rule.

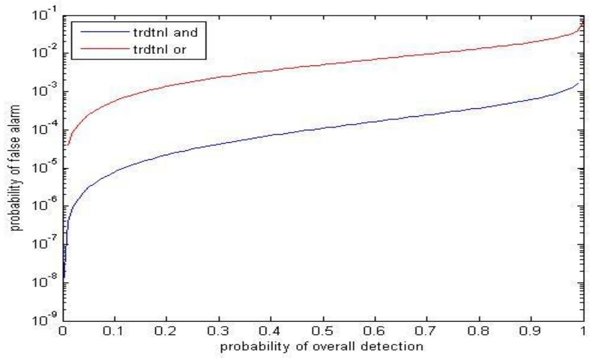

Figure 2 ROC by traditional method

In figure 3 we show the overall probability detection versus overall false alarm probability by the proposed scheme by the AND and OR fusion rule, In this figure also we are getting the better result for AND based method.

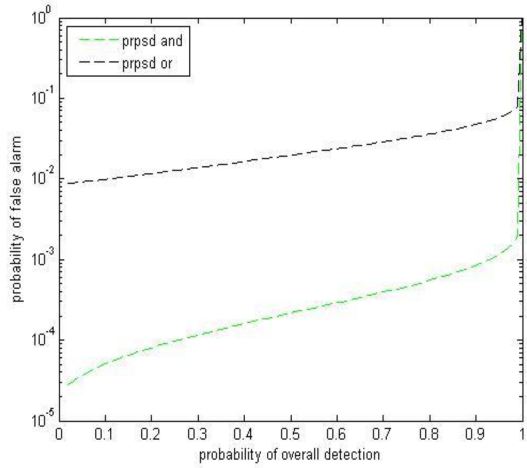

Figure 3. ROC by proposed method

And finally the figure 4 illustrates the combined result of ROC obtained by both traditional method as well as proposed method. In this paper the parameter that we used to get the results are:

γ_p =5dB, γ_s^T =10 dB, $\gamma_s = -5$ dB, α =0.2, $\sigma_{pc}^2 = \sigma_{id}^2$ =0.2, $\sigma_{pi}^2 = \sigma_{pd}^2 = \sigma_{ic}^2$ =1, M=2, R_p = 1bits/Hz, T=25ms, B=50 kHz, f_s= 100kHz, B_dT_d=1000, $Pout_{thr}$ = 0.01.

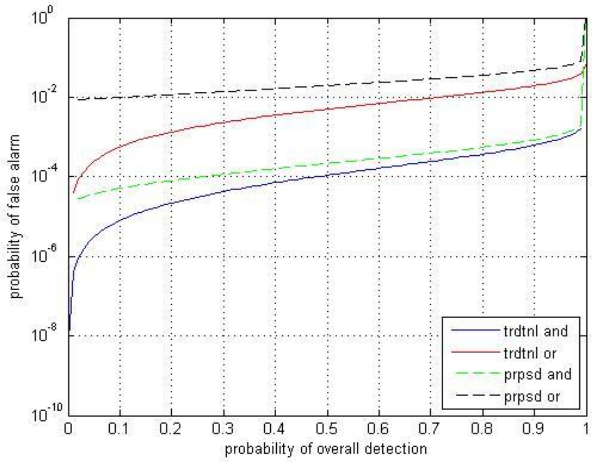

Figure 4 ROC by traditional method as well as proposed method

V. CONCLUSION

In this we used a concept of proposed selective relay based cooperative sensing scheme in cognitive radio network without dedicated reporting channel. We obtained the ROC from proposed method as well as from traditional method and on comparing we found that with this proposed scheme we can save the dedicated channel resources without reducing the ROC performance. But in Fig 4 we can see that in low probability detection region the overall false alarm probability obtained from proposed method are more than that of traditional method by any fusion rule that is the disadvantage of the proposed method and in higher detection region we can see that ROC obtained from both the scheme by any fusion rule is almost identical specially in AND fusion rule. So this proposed method is good when the overall probability detection region is more than 0.9.

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