Abstract—This paper develops a cooperative scheme among cognitive radios (CRs) to improve the spectrum sensing performance. CRs adaptively transmit local binary decisions to a fusion center (FC), which in turn uses a simple maximum-likelihood detector to decide the presence of absence of the primary user (PU). The diversity order of the probability of false alarm and miss-detection is studied under both Neyman-Pearson and minimum-error-probability criteria. In particular, it is shown that under the Neyman-Pearson criterion, the probability of miss-detection can achieve diversity order up to the number of CRs for a bounded probability of false alarm. Under the minimum-error-probability criterion, both the probability of false alarm and miss-detection can achieve diversity order up to the number of cognitive radios. Compared to existing cooperative sensing approaches, this novel scheme is robust to fading effects in both PU-to-CR and CR-to-FC links. Simulated tests verify the analytical claims, showing considerable performance gains compared to non-cooperative and non-adaptive hard-decision schemes.

I. INTRODUCTION

Cognitive radio systems have been recently considered as a potential remedy to the wireless spectrum scarcity problem [3]. In these systems, cognitive radios (CRs) opportunistically access unused spectrum bands pre-allocated to a primary user (PU) [4]. Before accessing the spectrum, CRs are required to sense it so as to decide whether it is used by the PU or not. Sensing is a challenging task since the PU does not cooperate with the CRs. Cooperation among CRs is possible though, and so this paper explores simple cooperation strategies among CRs to enhance the performance of the sensing task.

The goal of sensing is to detect the presence or absence of a PU at a given point in frequency, time and space. The sensing performance can be measured in terms of the probability of miss detection and false alarm [8]. The former affects the interference level to the PU, whereas the latter affects the spectrum occupancy. Most existing spectrum sensing efforts focus on improving the detection performance by, e.g., exploiting partial knowledge of the PU signal [12], [7]. Cooperative and distributed sensing problems have on the other hand focused on combating shadowing effects, hidden-terminal or scheduling problems, among other issues [5], [14], [10], [9].

Another relevant performance metric in the context of sensing is the diversity order [13], [2], which quantifies the robustness of both the probability of miss detection and false alarm to fading effects. Non-cooperative (i.e., local) spectrum sensing schemes achieve low sensing diversity performance. Motivated by this fact, this paper develops a cooperative scheme among cognitive radios (CRs) to increase their spectrum sensing diversity. Specifically, CRs transmit local binary decisions to a fusion center (FC), which in turn uses a simple maximum-likelihood (ML) detector to decide the presence of absence of the PU. Sensing diversity is enabled using power-adaptive transmissions according to the PU-to-CR channel conditions. Similar adaptive schemes have been used in cooperative communication protocols to enable diversity in the transmitted signals [11].

The probability of false alarm and miss-detection under both Neyman-Pearson (NP) and minimum-error-probability detection criteria are analyzed, revealing that under the NP criterion, the miss detection probability can achieve diversity order up to the number of cognitive radios. Under the minimum-error-probability criterion, both the probability of false alarm and miss-detection can achieve diversity order up to the number of CRs. Instead of assuming that fading only happens in the links between PU and CRs [2], or between CRs and the FC, here it is assumed that all links suffer fading. Indeed, as is revealed in [5], without excellent channels between CRs, non-adaptive hard-decision schemes suffer considerably diversity loss when fading is present.

Notation: Throughout the paper, upper (lower) boldface letters are used for matrices (vectors); diag(x) is to diagonalize vector x; ∥ ∥ denotes the Frobenius norm; \( \mathcal{N}(\mu, \sigma^2) \) and \( \mathcal{CN}(\mu, \sigma^2) \) denote real and complex Gaussian distribution with mean \( \mu \) and variance \( \sigma^2 \), respectively.

II. LOCAL SENSING PROBLEM

With reference to Fig. 1, consider a cognitive radio network with a PU, \( N \) CRs and an FC. Each CR, say the \( n \)-th, gets \( K \)
samples of the PU signal, collected in vector \( \mathbf{r}_n \). Denoting \( \mathcal{H}_0 \) as the hypothesis that the PU is silent and \( \mathcal{H}_1 \) as the hypothesis that the PU is transmitting, the sample vector \( \mathbf{r}_n \) is given by

\[
\mathcal{H}_0 : \mathbf{r}_n = \mathbf{w}_n \\
\mathcal{H}_1 : \mathbf{r}_n = h_{pn} \mathbf{s} + \mathbf{w}_n
\]

(1)

where \( s = [s(1), \ldots, s(K)]^T \) is the transmitted signal by the PU with average power \( P_s \) and \( \mathbf{w}_n \) is the additive white Gaussian noise (AWGN) with average power \( \sigma_w^2 \), assumed without loss generality to be the same for all CRs; and \( h_{pn} \sim \mathcal{CN}(0, \sigma_{sn}^2) \) is the PU-to-CR \( n \) channel coefficient, with variance \( \sigma_{pn}^2 \).

In order to decide the presence or absence of the PU signals, the following energy detector is employed at each CR

\[
t_n := \| \mathbf{r}_n \|^2 = \sum_{k=1}^{K} |r_n(k)|^2 \geq \frac{\lambda_n}{\mathcal{H}_0} \geq \frac{\lambda_n}{\mathcal{H}_1}
\]

(2)

where \( t_n \) is the test statistic and \( \lambda_n \) is the corresponding threshold, which depends on the detection criterion (see below). Assuming \( P_s|\mathcal{H}_0| \) and \( \sigma_w^2 \) known, \( t_n \) follows central Chi-square distribution with \( 2K \) degree of freedom, under hypothesis \( \mathcal{H}_0 \) and non-central Chi-square distribution under hypothesis \( \mathcal{H}_1 \). Invoking the central limit theorem, when \( K \) is sufficiently large, \( t_n \) can be assumed asymptotically Gaussian [9]

\[
t_n \sim \begin{cases} 
\mathcal{N}(K \sigma_w^2, 2K \lambda_n), & \text{under } \mathcal{H}_0 \\
\mathcal{N}(K \sigma_w^2(1+\gamma_{pn}), 2K \lambda_n(1+2\gamma_{pn})), & \text{under } \mathcal{H}_1
\end{cases}
\]

(3)

where \( \gamma_{pn} := \frac{P_s|h_{pn}|^2}{\sigma_w^2} \) is the signal-to-noise ratio (SNR) at CR \( n \).

**Remark 1.** Assuming that the channel coherence time is large enough, the PU-to-CR \( n \) received power \( P_s|h_{pn}|^2 \) can be obtained using blind channel estimation techniques. Alternatively, assuming cooperation by the PU, CRs can overhear training sequences transmitted by the PU to estimate \( P_s|h_{pn}|^2 \), see [6], [9] for similar justifications.

From the model in (3), the probability of false alarm \( P_{f}(n) \) and miss-detection \( P_{m}(n) \) at CR \( n \) are respectively given by

\[
P_{f}(n) = \Pr \{ t_n > \lambda_n | \mathcal{H}_0 \} = \frac{\lambda_n - K \sigma_w^2}{\sqrt{2K} \lambda_n}
\]

(4)

and

\[
P_{m}(n) = \Pr \{ t_n < \lambda_n | \mathcal{H}_1 \} = Q \left( \frac{K \sigma_w^2(1+\gamma_{pn}) - \lambda_n}{\sqrt{2K} \sigma_w(1+2\gamma_{pn})} \right)
\]

(5)

where \( Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-t^2/2} dt \).

In the context of spectrum sensing, miss-detection causes interference to the PU, whereas false alarm leads to under-utilization of available gaps. Notice that \( P_{f}(n) \) and \( P_{m}(n) \) in (4) and (5) depend on \( \lambda_n \), which in turn depends on the detection criterion, as described next.

1) **Neuman-Pearson criterion:** If CRs operate according to the Neyman-Pearson (NP) criterion, \( P_{m}^{(CR)}(n) \) at CR \( n \) is minimized while \( P_{f}^{(CR)}(n) \) at CR \( n \) is required to satisfy a given maximum value [8, Ch. 2]. Setting \( P_{f}^{(CR)}(n) = \alpha \), the decision threshold \( \lambda_n \) in (2) is given by [cf. (4)]

\[
\lambda_n = Q^{-1}(\alpha) \sqrt{2K \sigma_w^2} + K \sigma_w^2
\]

(6)

and the probability of miss-detection in (5) can now be written as [cf. (5)]

\[
P_{m}^{(CR)}(n) = Q \left( \frac{Q^{-1}(\alpha) + \sqrt{K/2\gamma_{pn}}}{\sqrt{1+2\gamma_{pn}}} \right).
\]

(7)

2) **Minimum-error-probability criterion:** Under this criterion, CR \( n \) minimizes

\[
P_{e}^{(CR)}(n) = P(\mathcal{H}_0|P_{f}^{(CR)}(n)) + P(\mathcal{H}_1|P_{m}^{(CR)}(n)).
\]

(8)

where \( P(\mathcal{H}_0) \) and \( P(\mathcal{H}_1) \) are the prior probabilities of hypotheses \( \mathcal{H}_0 \) and \( \mathcal{H}_1 \), respectively.

Under this criterion, the optimal threshold \( \lambda_n \) is obtained by differentiating \( P_{e}^{(CR)}(n) \) w.r.t. \( \lambda_n \) and equating it to zero. The possible optimal thresholds are given by

\[
\lambda_n = \frac{1}{2} K \sigma_w^2 \pm \frac{1}{2} K \sigma_w \sqrt{(1+2\gamma_{pn})(1+\kappa)}
\]

(9)

where \( \kappa = \frac{8}{K \gamma_{pn}} \log \left( \frac{(1+2\gamma_{pn}) P(\mathcal{H}_0)}{P(\mathcal{H}_1)} \right) \).

When \( \gamma_{pn} \) and \( K \) are large, there is only one feasible threshold which approximates to

\[
\lambda_n \approx \frac{1}{2} K \sigma_w^2 (1 + \sqrt{1 + 2\gamma_{pn}}).
\]

(10)

Notice that \( \lambda_n \) in (10) does not depend on \( P(\mathcal{H}_0) \) and \( P(\mathcal{H}_1) \).

Substituting \( \lambda_n \) into (4) and (5) yields

\[
P_{f}^{(CR)}(n) \approx P_{m}^{(CR)}(n) \approx Q \left( \sqrt{\frac{K}{8}} \left( \sqrt{1 + 2\gamma_{pn}} - 1 \right) \right).
\]

(11)

A. Sensing Diversity

The performance of the spectrum sensing task will be measured in terms of the diversity order, or sensing diversity, defined as [2]

\[
d := \lim_{\gamma \to \infty} \frac{\log E\{P\}}{\log \gamma}
\]

(12)

where \( P \) can be either \( P_{e}^{(CR)}(n) \), \( P_{f}^{(CR)}(n) \), or \( P_{m}^{(CR)}(n) \) and \( \gamma := P_s/\sigma_w^2 \) denotes the average PU-CR SNR. The expectation is carried over the distribution of \( \gamma_{pn} \), that is, the received SNR of the link PU-to-CR \( n \).

The diversity order measures the degree of robustness to fading effects of the miss-detection, false alarm or error probability. Specifically, under the NP criterion, it is not difficult to show that the diversity order of \( P_{f}^{(CR)}(n) \) at CR \( n \) is \( d_{f}^{(CR)}(n) = 0 \) (since \( P_{f}^{(CR)}(n) \) is constant), whereas the diversity order of \( P_{m}^{(CR)}(n) \) in (7) is \( d_{m}^{(CR)}(n) = 1 \). Likewise, under the minimum-error-probability criterion, the diversity order at CR \( n \) of \( P_{e}^{(CR)}(n) \) in (8) is \( d_{e}^{(CR)} = 1 \).
As seen, local (non-cooperative) spectrum sensing achieves low sensing diversity performance. In the following it is shown that simple cooperation strategies among CRs can enable high sensing diversity gains.

III. COOPERATIVE SENSING

As shown in Fig. 1, CRs cooperate by transmitting local (hard) decisions to an FC. Such binary decisions are mapped to BPSK symbols and transmitted through orthogonal channels (e.g., using different time slots) to avoid inference among CRs. The FC will judiciously combine all received signals to reach a global decision.

The transmitted symbol by CR \( n \) is given by [cf. (2)]

\[
x_n = \begin{cases} 
1, & t_n \geq \lambda_n \\
-1, & t_n < \lambda_n 
\end{cases}
\]  

(13)

Alternatively, CRs can use on-off signaling to report decision results; i.e., \( x_n = 1 \) whenever \( t_n \geq \lambda_n \), and \( x_n = 0 \) otherwise. Although not developed in this paper due to space limitations, the performance claims in terms of diversity order using BPSK modulations as in (13) carry over on-off signaling, see also test case 4 in Section IV.

In order to enable diversity at the FC, symbol \( x_n \) at CR \( n \) is transmitted with adaptive power \( P_n \) given by

\[
P_n = \beta \cdot \min(P_s | h_{pn}|^2, P_n \sigma_{pn}^2)
\]  

(14)

where \( \beta \) is a constant that bounds the transmitting power of each CR and \( \sigma_{pn}^2 \) is the average CR \( n \)-to-FC channel gain, which is assumed known.

Signals \( x_n, n = 1, \cdots, N \) are transmitted in time-orthogonal channels. At the FC, the received signal is given by

\[
y_n = \sqrt{P_n} h_{fn} x_n + w_{fn}
\]  

(15)

where \( h_{fn} \sim \mathcal{CN}(0, \sigma_{fn}^2) \) is the channel coefficient between PU and CR \( n \), which is assumed to remain constant during a report period; and \( w_{fn} \sim \mathcal{CN}(0, \sigma_{wn}^2) \) is the additive Gaussian noise at the FC.

Remark 2. Compared to [5] and [2], this work considers fading effects in both PU-to-CR and CR-to-FC links [cf. (1), (15)]. In [5] fading is present in the CR-to-FC link, whereas the PU-to-CR channels are assumed AWGN but non-fading. The work in [2] assumes in turn that PU-to-CR channels are fading, but communication from CR to FC is error-free. Indeed, as shown through simulated tests, the cooperation strategy investigated in [2] loses considerable diversity gains when CR-to-FC fading is present.

Stacking all received signals into a vector \( \mathbf{y} := [y_1, \ldots, y_N]^T \), signals in (15) can be written in matrix-vector form as

\[
\mathbf{y} = \mathbf{P}_r \mathbf{H}_f \mathbf{x} + \mathbf{w}_f
\]  

(16)

where \( \mathbf{P}_r = \text{diag}(\sqrt{P_1}, \sqrt{P_2}, \cdots, \sqrt{P_N}) \), \( \mathbf{H}_f = \text{diag}([h_{f1}, h_{f2}, \cdots, h_{fN}]) \); \( \mathbf{x} = [x_1, x_2, \cdots, x_N] \) and \( \mathbf{w}_f = [w_{f1}, w_{f2}, \cdots, w_{fN}] \).

Optimal decoding of the transmitted symbols \( x_n \) in (13) at the FC requires knowledge of \( P(\mathcal{H}_0) \), \( P(\mathcal{H}_1) \), \( P_{m}^{(CR)}(n) \), \( P_{f}^{(CR)}(n) \) (and consequently \( h_n \)). To circumvent this problem, the FC uses the following (sub-optimal) ML detector [8]

\[
x^* = \arg\min_{x = -1, \cdots, 1} \{ |y - \mathbf{P}_f \mathbf{H}_f x|^2 \}
\]  

(17)

where \( 1_N \) is an \( N \)-dimensional all-ones column vector. Note that \( x^* = 1_N \) corresponds to deciding hypothesis \( \mathcal{H}_1 \) and \( x^* = -1_N \) corresponds to deciding \( \mathcal{H}_0 \) [c.f. (13)]. The receiver in (17) is ML in the sense that it maximizes the probability of having a received vector \( \mathbf{y} \) in (16) given that either \( 1_N \) or \(-1_N \) was transmitted. The detector is clearly sub-optimal since \( \{1_N, -1_N\} \) may not be the actual transmitted symbols, nor their prior probabilities are the same. However, in the next section it will be shown that this simple decoding rule suffices to collect high sensing diversity gains at the FC.

A. Diversity analysis

In this section, the sensing diversity under both NP and minimum-error-probability detection criteria is studied. In the subsequent analysis the following Lemma is instrumental.

Lemma 1. Let \( \mathcal{E}_f := \{ n \mid x_n \neq -1, n = 1, \cdots, N \} \) denote the set of CRs with false alarm and \( \mathcal{E}_m := \{ n \mid x_n \neq 1, n = 1, \cdots, N \} \) denote the set of CRs with miss-detection and \( \mathcal{C}_f := \mathcal{E}_f \) and \( \mathcal{C}_m := \mathcal{E}_m \) their respective complements. Using the ML detector in (17), the probability of false alarm and miss-detection at the FC for a given transmitted vector \( \mathbf{x} \), namely \( P_f^{(FC)}(\mathbf{x}) \) and \( P_m^{(FC)}(\mathbf{x}) \) are given by

\[
P_f^{(FC)}(\mathbf{x}) = Q \left( \frac{\sqrt{2} \left( \sum_{n \in \mathcal{E}_f} P_n |h_{fn}|^2 - \sum_{n \in \mathcal{E}_m} P_n |h_{fn}|^2 \right)}{\sqrt{\sum_{n=1}^{N} P_n |h_{fn}|^2}} \right)
\]  

(18)

and

\[
P_m^{(FC)}(\mathbf{x}) = Q \left( \frac{\sqrt{2} \left( \sum_{n \in \mathcal{C}_f} P_n |h_{fn}|^2 - \sum_{n \in \mathcal{C}_m} P_n |h_{fn}|^2 \right)}{\sqrt{\sum_{n=1}^{N} P_n |h_{fn}|^2}} \right)
\]  

(19)

Using Lemma 1 and applying the law of total probability, the probability of false alarm and miss-detection at the FC, namely \( P_f^{(CR)} \) and \( P_m^{(CR)} \), can be written as

\[
P_f^{(CR)} = \sum_{x = \{-1,1\}}^{N} \Pr(\mathbf{x} \mid \mathcal{H}_0) P_f^{(FC)}(\mathbf{x})
\]

\[
= \sum_{x = \{-1,1\}}^{N} \prod_{m \in \mathcal{E}_f} (1 - P_{m}^{(CR)}(m)) \prod_{n \in \mathcal{E}_m} P_f^{(CR)}(n) \times Q \left( \frac{\sqrt{2} \left( \sum_{n \in \mathcal{E}_f} P_n |h_{fn}|^2 - \sum_{n \in \mathcal{E}_m} P_n |h_{fn}|^2 \right)}{\sqrt{\sum_{n=1}^{N} P_n |h_{fn}|^2}} \right)
\]  

(20)

and

\[
P_m^{(CR)} = \sum_{x = \{-1,1\}}^{N} \Pr(\mathbf{x} \mid \mathcal{H}_1) P_m^{(FC)}(\mathbf{x})
\]

\[
= \sum_{x = \{-1,1\}}^{N} \prod_{m \in \mathcal{C}_f} (1 - P_{m}^{(CR)}(m)) \prod_{n \in \mathcal{C}_m} P_m^{(CR)}(n) \times Q \left( \frac{\sqrt{2} \left( \sum_{n \in \mathcal{C}_f} P_n |h_{fn}|^2 - \sum_{n \in \mathcal{C}_m} P_n |h_{fn}|^2 \right)}{\sqrt{\sum_{n=1}^{N} P_n |h_{fn}|^2}} \right)
\]  

(21)

1Proofs for all lemmas and propositions in this paper are omitted due to space limitations.
Substituting $P_f^{(CR)}(n) = \alpha$ and $P_m^{(CR)}(n)$ as in (7) into (20) and (21) and averaging over the fading leads to the following Proposition.

**Proposition 1.** Under the Neyman-Pearson criterion in Section II-1 and using the developed cooperative scheme with power-adaption as in (14), the probability of miss-detection $P_m^{(FC)}$ in (21) achieves diversity order up to the number of CRs $N$; i.e.,

$$d_f^{(FC)} = \lim_{\gamma \to \infty} \frac{\log E[P_f^{(FC)}]}{\log \gamma} = N \tag{22}$$

for a bounded probability of false alarm $P_f^{(FC)}$.

Note also that although the length of samples $K$ may affect the probability of false alarm and miss-detection, it does not affect the achievable diversity gain.

Substituting $P_f^{(CR)}(n)$ and $P_m^{(CR)}(n)$ as in (11) in (20) and (21) leads now to the following Proposition.

**Proposition 2.** Under the minimum-error-probability criterion in Section II-2 and using the developed cooperative scheme with power-adaption as in (14), both the probability of false alarm $P_f^{(FC)}$ and miss-detection $P_m^{(FC)}$ can achieve diversity order up to the number of CRs; i.e.,

$$d_f^{(FC)} = \lim_{\gamma \to \infty} \frac{\log E[P_f^{(FC)}]}{\log \gamma} = N. \tag{23}$$

where $P_f^{(FC)} = P(\mathcal{H}_1)P_f^{(FC)} + P(\mathcal{H}_0)P_f^{(FC)}$.

Propositions 1 and 2 establish that full diversity for the miss-detection probability or error probability can be achieved using the detector in (17) along with the power-adaptive coefficient in (14). Since the detector in (17) is sub-optimal, Propositions 1 and 2 automatically prove that the optimal demodulation rule at the FC will also achieve full diversity.

Compared to other methods, the high-diversity scheme allow system designers to use a smaller amount of cognitive radios to meet a desired performance requirement. This will be further explored in the next section, showing that indeed, high performance is not only guaranteed in the medium and high SNR regime, but also in all practical SNR ranges.

**IV. SIMULATIONS**

In this section the performance of the developed cooperative scheme is evaluated through numerical simulations. For simplicity, all PU-to-CR and CR-to-FC SNRs are set to be the same; i.e., $\gamma_{pn} = \gamma_{fn} = \gamma_{SNR} \forall n$. The PU is active 50% of the time; i.e., $P(\mathcal{H}_0) = P(\mathcal{H}_1) = 0.5$. Unless otherwise stated, the sample length at each CR is set to $K = 100$. Local decisions are transmitted to the FC using BPSK signaling [cf. (13)]. For a fair comparison, $\beta$ in (14) is adjusted so as to guarantee that all cooperative schemes transmit with the same average power.

1) Test Case 1: Here, the performance under the NP criterion is simulated. The probability of false alarm at all CRs is constrained to $P_f^{(CR)}(1) = \ldots = P_f^{(CR)}(N) = 10^{-1}$. Fig. 2 shows the averaged miss-detection and false alarm probabilities at the FC as a function of the SNR. For comparison, the probability of false alarm and miss-detection at a given CR is included, as well as the ones obtained using the non-adaptive hard-decision scheme in [2]. As shown in Fig. 2, both non-cooperative and non-adaptive schemes achieve diversity of order one. The non-adaptive hard-decision scheme improves the performance of the non-cooperative one, but still limited to diversity one. The adaptive scheme developed here, on the other hand, achieves miss-detection diversity of order of 2 and 3 for $N = 2$ and $N = 3$ respectively, as predicted in Proposition 1. Also, the average probability of false alarm is lower than the one at any given CR.

2) Test case 2: In this case, the average probability of false alarm and miss-detection under the minimum-error-probability criterion are studied. As shown in Fig. 3, the diversity order is equal to the number of cognitive radios, as predicted in Proposition 2. Both non-cooperative and non-adaptive alter-
natives achieve diversity one, which for moderate-high SNRs implies considerable performance losses. For example, when the average probability of false alarm (or miss-detection) is $10^{-2}$ at a given CR, the hard-decision scheme reaches $10^{-3}$, while the scheme developed here approaches $10^{-4}$ when $N = 3$.

3) Test Case 3: Here, the effect of the number of samples $K$ is analyzed. Fig. 4 plots both average miss-detection and false alarm curves for different values of $K$ under the NP criterion. As seen, changes in $K$ effect parallel shifts of the curves, but the diversity order remains the same. Notice however that when $K$ is small the average probability of miss-detection is specially poor at low SNR, while it barely improves when $K$ is larger than 10. This hints to the fact that, rather than increasing the number of samples, performance can only be improved in this case by including more CRs.

4) Test Case 4: In this case, on-off signaling instead of BPSK is used (cf. (13)). Fig. 5 shows the average detection performance under the NP criterion. Compared to Fig. 2, on-off signaling incurs in considerable performance loss. However, diversity gains are still achieved. On-off signaling can be of interest when PUs exhibit low activity $P(H_0) >> P(H_1)$. Since CRs only transmit when the PU signal is detected, larger power savings than BPSK would be expected in this case.

V. CONCLUSION

In this paper a high-diversity cooperative sensing scheme was developed to combat channel fading effects during the sensing task. CRs adaptively transmit local binary decisions to a fusion center (FC), which in turn uses a simple maximum-likelihood detector to decide the presence of absence of the primary user (PU). It was shown that under the NP criterion, the miss-detection probability of this scheme can achieve diversity order up to the number of cognitive radios with a bounded probability of false alarm. Under the minimum-error-probability criterion, both the probability of false alarm and miss-detection can achieve the diversity order up to the number of cognitive radios. The derived scheme is robust to fading effects in both PU-to-CR and CR-to-FC links. Simulated tests corroborate the theoretical claims showing considerable performance gains compared to existing cooperative and non-cooperative sensing schemes.

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