A Cooperative Spectrum Sensing Scheme without Dedicated Reporting Channels: Interference Impact on Primary Users

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Abstract—In cognitive radio networks, cooperative spectrum sensing typically requires two essential phases: the phase of primary user’s signal detection by cognitive users and the phase of initial detection result reporting from the cognitive users to a fusion center, which are referred to as detection and reporting phases, respectively. Common control channels (also called dedicated reporting channels) from the cognitive users to the fusion center are assumed in previous research to avoid interfering with the primary user in the reporting phase. This, however, requires additional channel resources and increases implementation complexity due to the dedicated reporting channels management. In this paper, we propose an alternative cooperative spectrum sensing framework without dedicated reporting channels and present an interference analysis of its impact on primary users. We show that the interference caused by the proposed scheme is controllable and can be constrained to satisfy a given primary user’s quality-of-service (QoS) requirement. By jointly considering the detection and reporting phases, we further examine the receiver operating characteristics (ROC) performance of the proposed cooperative spectrum sensing scheme in Rayleigh fading environment. Numerical results illustrate that, with a guaranteed detection probability constraint, a minimized false alarm probability can be achieved through an optimization of the time durations between the detection and reporting phases.

Index Terms—Cognitive radio, cooperative spectrum sensing, dedicated reporting channels, receiver operating characteristics, interference control, optimization.

I. INTRODUCTION

Cognitive radio is emerging as a promising means to enable unlicensed users (also known as secondary or cognitive users) to access spectrum holes of licensed frequency through spectrum sensing [1], [2]. Generally, spectrum sensing has been identified as a key element in cognitive radio, for which three different signal processing approaches are available: energy detection [3], matched filter detection [4], and feature detection [5], [6].

In [7], the authors have proposed a collaborative spectrum sensing, in which the detection results from multiple users are combined together at a fusion center to combat wireless fading. In [8]-[10], the authors have explored cooperative diversity for spectrum sensing and shown the sensing performance improvement. Paper [10] has examined a Neyman-Pearson criterion based soft combination of the observed energies from different cognitive users for spectrum sensing. Recently, in [11] and [12], we have investigated the cooperative relays in cognitive radio networks by jointly considering the spectrum sensing and secondary data transmissions, where the sensing-transmission tradeoff is discussed in Rayleigh fading environment.

Typically, the cooperative spectrum sensing process consists of two phases: the primary signal detection phase and initial detection result reporting phase. In order to avoid interfering with primary users when cognitive users report their initial detection results, previous research [10] assumed that there are dedicated reporting channels from the cognitive users to fusion center. This approach, however, requires additional channel resources and increases system complexity due to the dedicated reporting channels management. Besides, during each cooperative sensing process, the detection and reporting phases can not be optimized separately since they affect each other. For example, given a certain observation window, a cognitive user may fail to detect the presence of a primary user. While increasing the observation window for the primary signal detection phase improves the detection probability at an individual user, it comes at the cost of a reduction in reporting performance since less time is available for the reporting phase. To that end, it is important to address an optimization of the time durations design for the detection and reporting phases within a cooperative sensing process.

II. PROPOSED COOPERATIVE SENSING SCHEME WITHOUT DEDICATED REPORTING CHANNELS

A. System Model

Typically, each cooperative spectrum sensing process consists of two phases: 1) detection phase, in which all cognitive users (CUs) independently detect the presence of a primary user (PU); and 2) reporting phase, in which all CUs report their initial detection results to a fusion center (FC) that will make a final decision on the presence of PU using a fusion rule, e.g., AND, OR, and majority vote [7]. In this paper, we consider $M$ cognitive users, as denoted by $CU_i$ ($i = 1, 2, \cdots, M$), to detect the presence of PU.
During a cooperative spectrum sensing process, we consider that the detection and reporting phases, respectively, occupy \(\alpha\) and \(1-\alpha\) fraction of one timeslot, where \(\alpha\) is called the signal detection overhead which can be adjusted to optimize the spectrum sensing performance. In the reporting phase, CUs transmit their initial detection results to FC using the \(M\) orthogonal sub-channels that are equally divided from the whole licensed band. One can easily see that all CUs may interfere with PU in the reporting phase. To avoid this interference, previous research [8] - [11] assumed that there are dedicated reporting channels from the cognitive users to the fusion center.

In this paper, we propose a selective-relay based cooperative spectrum sensing scheme without dedicated reporting channels, where a CU transmits its initial detection result in a selective manner. To be specific, if the absence of PU is detected by a CU in its detection phase, a cyclic redundancy code (CRC)-encoded indicator signal will be transmitted to FC; otherwise, no signal is transmitted. At FC side, if the CRC checking passes over \(i\)-th orthogonal sub-channel, FC considers the absence of PU as the initial result detected by CU\(_i\); otherwise, it considers the presence of PU as CU\(_i\)'s detection result. Therefore, in the proposed cooperative sensing scheme, a CU would interfere with the primary user only when it fails to detect the presence of PU given that PU is active. It is worth mentioning that this interference can be controlled and reduced by adjusting the individual detection probability of each CU to a target value.

### B. Signal Model

In this subsection, we present the signal model of the proposed selective-relay based cooperative sensing scheme. Each link between two nodes as depicted in Fig. 1 is modeled as Rayleigh fading and, moreover, the fading coefficient is constant during one timeslot. For notational convenience, let \(P_p\) and \(P_s\) represent the transmit powers of PU and CU, respectively. In addition, let \(H_p(k)\) represent whether PU is active or inactive, namely \(H_p(k) = H_1\) means the presence of PU and \(H_p(k) = H_0\) means its absence.

In the first phase (i.e., the detection phase) of timeslot \(k\), the signal received at CU\(_i\), \(i = 1, 2, \ldots, M\), can be written as

\[
y_i(k, 1) = \sqrt{P_p} h_p(k) \theta(k, 1) + n_i(k, 1)
\]  \hspace{1cm} (1)

where \(P_p\) is the transmit power at PU, \(h_p(k)\) represents the fading of the channel from PU to CU\(_i\), \(n_i(k, 1)\) represents an additive white Gaussian noise (AWGN) with zero mean and variance \(N_0\), and \(\theta(k, 1)\) is defined as

\[
\theta(k, 1) = \begin{cases} 
0, & H_p(k) = H_0 \\
x_p(k, 1), & H_p(k) = H_1 
\end{cases}
\]  \hspace{1cm} (2)

where \(x_p(k, 1)\) represents the primary user’s signal transmitted in the first phase of timeslot \(k\). Notice that \(H_p(k) = H_0\) represents that PU is inactive, and \(H_p(k) = H_1\) denotes the presence of PU and a PU signal \(x_p(k, 1)\) is transmitted. By using the received signal as given by Eq. (1), a CU decides whether PU is present or absent, and the corresponding detection result is called an initial detection result denoted by \(\hat{H}_i(k, 1)\). Throughout this paper, the energy detector [3], [8] is used, and thus the initial detection result \(\hat{H}_i(k, 1)\) can be given by

\[
\hat{H}_i(k, 1) = \begin{cases} 
H_0, & T[y_i(k, 1)] < \lambda_i \\
H_1, & T[y_i(k, 1)] > \lambda_i
\end{cases}
\]  \hspace{1cm} (3)

where \(T[y_i(k, 1)]\) represents the energy detector output at CU\(_i\), which is further given by

\[
T[y_i(k, 1)] = \frac{1}{N} \sum_{n=1}^{N} |y_i^n(k, 1)|^2
\]  \hspace{1cm} (4)

where \(|y_i^n(k, 1)|^2\) represents the energy of the \(n\)-th sample of the received signal at CU\(_i\), \(N = \alpha T f_s\) represents the number of samples, \(T\) and \(f_s\) represent the time slot length and sample frequency, respectively. In the subsequent reporting phase, each CU transmits a signal \(\beta_i(k)\) to FC using an orthogonal sub-channel, i.e.,

\[
y_i(k, 2) = \sqrt{P_s} h_{ic}(k) \beta_i(k) + \sqrt{P_p} h_{pc}(k) \theta(k, 2) + n_i(k, 2)
\]  \hspace{1cm} (5)

where \(P_s\) is the transmit power at cognitive users, \(h_{ic}(k)\) and \(h_{pc}(k)\) are the fading coefficients of the channel from CU\(_i\) to FC and that from PU to FC, respectively, and \(\beta_i(k)\) and \(\theta(k, 2)\) are given by

\[
\beta_i(k) = \begin{cases} 
x_i(k), & \hat{H}_i(k, 1) = H_0 \\
0, & \hat{H}_i(k, 1) = H_1
\end{cases}
\]  \hspace{1cm} (6)

\[
\theta(k, 2) = \begin{cases} 
0, & H_p(k) = H_0 \\
x_p(k, 2), & H_p(k) = H_1
\end{cases}
\]  \hspace{1cm} (7)

where \(x_p(k, 2)\) is the PU’s signal transmitted in the second phase of timeslot \(k\). Thus, by using Eq. (5), FC attempts to decode \(\beta_i(k)\) and performs CRC checking. As known in [11], if the channel capacity falls below a predefined data rate, an outage event occurs and the decoder is deemed to fail to recover the original signal no matter what decoding is used. In this case, the CRC checking fails to pass and FC considers that no indicator signal is transmitted from CU\(_i\), that is, the corresponding initial detection result received at FC is given by \(\hat{H}_i(k, 2) = H_1\); otherwise, \(\hat{H}_i(k, 2) = H_0\). Hence, we have

\[
\hat{H}_i(k, 2) = \begin{cases} 
H_1, & \Theta_{ic}(k, 2) = 1 \\
H_0, & \Theta_{ic}(k, 2) = 0
\end{cases}
\]  \hspace{1cm} (8)

where \(\Theta_{ic}(k, 2) = 1\) represents that an outage event occurs over the channel from CU\(_i\) to FC and \(\Theta_{ic}(k, 2) = 0\) represents the other case. In an information-theoretic sense [11], we can describe the outage event \(\Theta_{ic}(k, 2) = 1\) from Eq. (5) as

\[
\frac{(1 - \alpha) \log_2(1 + \frac{|h_{ic}(k)|^2 \gamma_s |\beta(k)|^2}{|p_{pc}(k)|^2 \gamma_p |\theta(k, 2)|^2 + 1})}{M} < \frac{1}{BT}\]

where \(\gamma_s = P_s / N_0\), \(\gamma_p = P_p / N_0\), \(\beta(k)\) and \(\theta(k, 2)\) are given in Eq. (6) and Eq. (7), respectively, and \(B\) and \(T\) are frequency
bandwidth and time duration of slot $k$, respectively. One can see from Eq. (9) that the event $\Theta_{j,c}(k, 2) = 1$ occurs under the following two scenarios: 1) $\beta_i(k) = 0$ given $\hat{H}_i(k, 1) = H_1$, implying that no CRC-encoded indicator is transmitted; and 2) a small $|h_{ic}(k)|^2$ (e.g., due to deep fading), which leads to the channel capacity from CU$_i$ to FC to be below a predefined rate $1/(BT)$. Note that event $\Theta_{j,c}(k, 2) = 0$ occurs under the condition that a CRC-encoded indicator $x_i(k)$ is transmitted and the channel from CU$_i$ to FC is in good situation. Finally, all $\hat{H}_i(k, 2)$ are combined at FC by using a given fusion rule, resulting in a final decision, $\hat{H}_c(k)$. Considering an “AND” fusion, the final decision $\hat{H}_c(k)$ is given by

$$
\hat{H}_c(k) = \bigotimes_{i=1}^M \hat{H}_i(k, 2)
$$

(10)

where $\bigotimes$ represents the logic AND. We now complete the signal model formulation for the proposed selective-relay based cooperative spectrum sensing scheme.

III. PERFORMANCE ANALYSIS OF THE PROPOSED COOPERATIVE SPECTRUM SENSING

In this section, we first examine the ROC performance for the proposed cooperative sensing scheme and then analyze its interference impact on the primary users.

A. ROC Analysis

For the purpose of performance comparison, let us first consider an all-relay based cooperative spectrum sensing without dedicated reporting channels, in which all CUs always forward their initial detection results to the fusion center over the licensed frequency. Then, FC decodes the received signals and combines the successfully decoded outcomes only, i.e., only the successfully decoded outcomes are used for fusion. For convenience, those CUs whose initial detection results are received and decoded successfully at FC constitute a set $C$. Accordingly, the sample space of all possible such sets is given by $\{C \in \emptyset \cup C_m, m = 1, 2, \ldots, 2^M - 1\}$, where $C_m$ is a non-empty subcollection of the $M$ cognitive users. Without loss of generality, let $C = \emptyset$ represent the case that all the initial detection results from CUs fail to decode at FC and $C = C_m$ correspond to the other case.

- Case $C = \emptyset$: FC fails to decode all the initial detection results from CUs, which can be described as

$$
(1 - \alpha) \log_2 \left( 1 + \frac{|h_{ic}(k)|^2 \gamma_p}{|h_{pc}(k)|^2 \gamma_p |\theta(k, 2)|^2 + 1} \right) < \frac{1}{BT}
$$

(11)

for $i = 1, 2, \ldots, M$, which is obtained from Eq. (9) by replacing $|\beta_i(k)|^2$ with a constant 1, since CU$_i$ will always forward an indicator signal to indicate its detection result. Therefore, given that case $C = \emptyset$ has occurred, FC will discard all the received initial results from CUs and nothing is used for fusion. From the viewpoint of protecting primary user, FC should decide that PU is active at this case, i.e.,

$$
\hat{H}_c(k | C = \emptyset) = H_1
$$

(12)

Although the occurrence of case $C = \emptyset$ will greatly degrade the spectrum sensing performance, the corresponding occurrence probability will be very small, which would decrease as an increased number of CUs.

- Case $C = C_m$: FC successfully decodes these initial detection results from the CUs in set $C_m$, i.e.,

$$
(1 - \alpha) \log_2 \left( 1 + \frac{|h_{ic}(k)|^2 \gamma_p}{|h_{pc}(k)|^2 \gamma_p |\theta(k, 2)|^2 + 1} \right) > \frac{1}{BT}, \quad i \in C_m
$$

$$
(1 - \alpha) \log_2 \left( 1 + \frac{|h_{ic}(k)|^2 \gamma_p}{|h_{pc}(k)|^2 \gamma_p |\theta(k, 2)|^2 + 1} \right) < \frac{1}{BT}, \quad j \in \bar{C}_m
$$

(13)

where $\bar{C}_m$ is the complementary set of $C_m$. In the given case $C = C_m$, the final spectrum sensing result at FC by using an AND-based fusion rule can be expressed as

$$
\hat{H}_c(k | C = C_m) = \bigotimes_{i \in \bar{C}_m} \hat{H}_i(k, 1)
$$

(14)

where $\hat{H}_i(k, 1)$ is the initial detection result of CU$_i$ in the set $C_m$. Considering the cases as discussed above, the probability of detection of the presence of PU at FC, called overall detection probability, for the all-relay based cooperative sensing scheme, as denoted by $P_{d_{\text{ARelay}}}$, is calculated as (see Eq. (24) in [1] for more details)

$$
P_{d_{\text{ARelay}}} = \Pr\{\hat{H}_c(k) = H_1 | H_p(k) = H_1\}
$$

$$
= \Pr\{C = \emptyset | H_p(k) = H_1\}
$$

$$
+ \sum_{m=1}^{2^M-1} \Pr\{C = C_m | H_p(k) = H_1\} \prod_{i \in C_m} P_{d_{i,1}}
$$

(15)

where $P_{d_{i,1}} = \Pr\{\hat{H}_i(k, 1) = H_1 | H_p(k) = H_1\}$ indicates the probability of individual detection of the presence of PU at CU$_i$, called individual detection probability. Similarly, the overall false alarm probability of the all-relay based cooperative sensing scheme, as denoted by $P_{f_{\text{ARelay}}}$, can be calculated as

$$
P_{f_{\text{ARelay}}} = \Pr\{C = \emptyset | H_p(k) = H_0\}
$$

$$
+ \sum_{m=1}^{2^M-1} \Pr\{C = C_m | H_p(k) = H_0\} \prod_{i \in C_m} P_{f_{i,1}}
$$

(16)

where $P_{f_{i,1}} = \Pr\{\hat{H}_i(k, 1) = H_1 | H_p(k) = H_0\}$ indicates the probability of individual false alarm of the presence of PU at CU$_i$, called individual false alarm. In order to guarantee the PU’s quality-of-service (QoS), the individual detection probability $P_{d_{i,1}}$ should be set to a target value. Thus, given a target value of the individual detection probability $P_{d_{i,1}}$, the individual false alarm probability $P_{f_{i,1}}$ can be derived from Eq. (1) as (see Appendix A in [12])

$$
P_{f_{i,1}} = \begin{cases} 
  P_{d_{i,1}}, & P_{d_{i,1}} = Q(-\sqrt{N}) \\
  P_{d_{i,1}} - Q(-1/P_{d_{i,1}} + \sigma_{\gamma_p}^2 / \kappa_i \sigma_i^2) \exp(\xi_i), & \text{others}
\end{cases}
$$

(17)

where $\kappa_i = \gamma_p Q^{-1}(P_{d_{i,1}}) + \sqrt{N} \gamma_p, \xi_i = Q^{-1}(P_{d_{i,1}}) + \sigma_{\gamma_p}^2 / \kappa_i \sigma_i^2$, and the number of samples should satisfy $N \geq [Q^{-1}(P_{d_{i,1}})]^2$. 


Notice that random variables \(|h_{ic}(k)|^2\) and \(|h_{pc}(k)|^2\) follow exponential distribution with parameters \(1/\sigma_{ic}^2\) and \(1/\sigma_{pc}^2\), respectively, and are independent from each other. Therefore, the terms \(\Pr(C = 0|H_p(k) = H_1)\) and \(\Pr(C = 0|H_p(k) = H_0)\) in Eqs. (15) and (16) are calculated from Eq. (11) as

\[
\Pr(C = 0|H_p(k) = H_1) = \prod_{i=1}^{M} \left[1 - \frac{\sigma_{ic}^2}{\sigma_{pc}^2 \gamma_{ip} + \sigma_{ic}^2} \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right)\right]
\]

and

\[
\Pr(C = 0|H_p(k) = H_0) = \prod_{i=1}^{M} \left[1 - \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right)\right]
\]

where \(\Lambda = [2^M/[\{(1-\alpha)BT\}] - 1]/\gamma_s\). Similarly, from Eq. (13), \(\Pr(C = C_m|H_p(k) = H_1)\) and \(\Pr(C = C_m|H_p(k) = H_0)\) are given by

\[
\Pr(C = C_m|H_p(k) = H_1) = \prod_{i \in C_m} \frac{\sigma_{ic}^2}{\sigma_{pc}^2 \gamma_{ip} + \sigma_{ic}^2} \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right)
\]

\[
\times \prod_{j \in C_m} \left[1 - \frac{\sigma_{ic}^2}{\sigma_{pc}^2 \gamma_{ip} + \sigma_{ic}^2} \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right)\right]
\]

and

\[
\Pr(C = C_m|H_p(k) = H_0) = \prod_{i \in C_m} \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right)
\]

\[
\times \prod_{j \in C_m} \left[1 - \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right)\right]
\]

Now, we start the ROC analysis for the selective-relay based cooperative sensing scheme. From Eq. (10), the overall detection probability of the selective-relay based cooperative sensing scheme, as denoted by \(P_{d_{c_{\text{relay}}}}\), is calculated as

\[
P_{d_{c_{\text{relay}}}} = \prod_{i=1}^{M} P_{d_{c,i}} \tag{22}
\]

where \(P_{d_{c,i}} = \Pr\{\hat{H}_i(k,2) = H_1|H_p(k) = H_1\}\). Similarly, from Eq. (10), the overall false alarm probability, \(P_{f_{c_{\text{relay}}}}\), is given by

\[
P_{f_{c_{\text{relay}}}} = \prod_{i=1}^{M} P_{f_{c,i}} \tag{23}
\]

where \(P_{f_{c,i}} = \Pr\{\hat{H}_i(k,2) = H_0|H_p(k) = H_0\}\). By using Eq. (8), \(P_{d_{c,i}}\) can be rewritten as

\[
P_{d_{c,i}} = 1 - \Pr\{\hat{H}_i(k,2) = H_0|H_p(k) = H_1\}
\]

\[
= 1 - \Pr\{\hat{H}_i(k,2) = 0|H_p(k) = H_1\} \tag{24}
\]

Considering Eq. (6) and Eq. (9), the preceding equation is further rewritten as

\[
P_{d_{c,i}} = 1 - (1 - P_{d_{1,i}})
\]

\[
\times \Pr\left\{\frac{(1 - \alpha)}{M} \log_2(1 + \frac{|h_{ic}(k)|^2 \gamma_s}{|h_{pc}(k)|^2 \gamma_p + 1}) > \frac{1}{BT}\right\} \tag{25}
\]

where \(P_{d_{1,i}} = \Pr\{\hat{H}_i(k,1) = H_1|H_p(k) = H_1\}\) indicates the individual detection probability at CU\(_i\). Besides, performing the probability integration in Eq. (25) yields

\[
P_{d_{c,i}} = 1 - \frac{\sigma_{pc}^2}{\sigma_{pc}^2 \gamma_{ip} + \sigma_{ic}^2} \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right) \tag{26}
\]

where \(\Lambda = [2^M/[\{(1-\alpha)BT\}] - 1]/\gamma_s\). Following the same procedures as in deriving \(P_{d_{c,i}}\), we can calculate \(P_{f_{c,i}}\) as follows

\[
P_{f_{c,i}} = 1 - \Pr\{\hat{H}_i(k,2) = H_0|H_p(k) = H_0\}
\]

\[
= 1 - (1 - P_{f_{1,i}}) \exp\left(-\frac{\Lambda}{\sigma_{ic}^2}\right) \tag{27}
\]

where \(P_{f_{1,i}} = \Pr\{\hat{H}_i(k,1) = H_1|H_p(k) = H_0\}\) indicates the individual false alarm probability at CU\(_i\). Notice that the relationship between the individual detection and false alarm probabilities, i.e., \(P_{d_{1,i}}\) and \(P_{f_{1,i}}\), is given by Eq. (17). As mentioned before, in order to guarantee the PU’s QoS, an individual detection probability \(P_{d_{1,i}}\) should be set to a target value and the corresponding individual false alarm probability \(P_{f_{1,i}}\) can be determined from Eq. (17). Using the determined \(P_{d_{1,i}}\) and \(P_{f_{1,i}}\), we can obtain the corresponding \(P_{d_{c,i}}\) and \(P_{f_{c,i}}\) based on Eq. (26) and Eq. (27). Finally, substituting the obtained values of \(P_{d_{c,i}}\) and \(P_{f_{c,i}}\) into Eq. (22) and Eq. (23), we can determine the receiver operating characteristics \(P_{d_{c_{\text{relay}}}}\) and \(P_{f_{c_{\text{relay}}}}\).

**B. Interference Analysis**

Clearly, in the proposed selective-relay based cooperative spectrum sensing scheme, a CU will interfere with PU only when it fails to detect the presence of PU given that PU is active. Therefore, the interference to the primary user induced by the selective-relay based cooperative sensing scheme is given by

\[
I_{s_{\text{relay}}} = \sum_{i=1}^{M} P_{s} (1 - P_{d_{1,i}})|h_{ip}(k)|^2 \tag{28}
\]

Notice that \(|h_{ip}(k)|^2\) follows an exponential distribution with parameter \(1/\sigma_{ip}^2\). Thus, an average interference can be calculated as

\[
\bar{I}_{s_{\text{relay}}} = P_{s} \sum_{i=1}^{M} (1 - P_{d_{1,i}}) \sigma_{ip}^2 \tag{29}
\]

from which the interference is controllable by adjusting the individual detection probability \(P_{d_{1,i}}\).

**IV. Numerical Results and Analysis**

Fig. 1 shows the overall detection probability versus the overall false alarm probability of the all-relay (ARelay) and selective-relay (SRelay) based cooperative sensing schemes. As clearly shown in Fig. 1, the ROC curves of the selective-relay based cooperative sensing scheme are near identical to that of the all-relay based scheme. Therefore, the interference reduction advantage of the selective-relay based cooperative sensing scheme comes without sacrificing the ROC performance.
Fig. 1. The overall detection probability versus the overall false alarm probability of the proposed scheme with $\gamma_p = -5$ dB, $\gamma_s = -10$ dB, $BT = 1250$, $f_s = 100$ kHz, $\alpha = 0.5$, $\sigma_{pc}^2 = 0.5$, and $\sigma_{pi}^2 = \sigma_{ic}^2 = 1$.

Fig. 2 depicts the ROC performance versus the signal detection overhead for the different number of cognitive users, where each individual detection probability is specified to $P_{dl,1} = 0.99$ for the primary user protection. Given $P_{dl,1} = 0.99$, the overall detection probabilities $P_{dl}$ corresponding to $M = 1$, $M = 2$ and $M = 4$ are larger than 0.99, 0.98 and 0.96, respectively, across the whole regions of signal detection overhead. In addition, all cases in Fig. 2 clearly show that an optimal signal detection overhead exists to minimize the overall false alarm probability.

Fig. 3 shows the ROC performance versus the signal detection overhead for different transmit SNR, $\gamma_s$. In Fig. 3, given a target value of $P_{dl,1} = 0.99$, the overall detection probabilities $P_{dl}$ corresponding to the three given cases are larger than 0.94. One can observe from Fig. 3 that a minimized false alarm probability can be obtained by adjusting the signal detection overhead. In addition, as the transmit SNR $\gamma_s$ increases, the optimal value of the signal detection overhead increases. This is because that, with an increased $\gamma_s$, a shorter time duration is required for the reporting phase.

V. CONCLUSION

In this paper, we have proposed a selective-relay based cooperative spectrum sensing scheme without the dedicated reporting channels and presented a comprehensive analysis of the proposed scheme by jointly considering both the signal detection and reporting phases. Closed-form expressions of the overall detection and false alarm probabilities are derived for the proposed cooperative sensing scheme over Rayleigh fading channels. We have shown that the selective-relay based cooperative sensing scheme can effectively reduce the interference to primary users without sacrificing the ROC performance.

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