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A Reliable Cooperative Spectrum Sensing Strategy for Cognitive Radios

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***Abstract*—In cognitive radio networks (CRNs)[1], the secondary users (SUs) need to continuously detect whether the primary users (PUs) occupy the spectrum. In order to improve the spectrum sensing accuracy, a novel reliable *cooperative spectrum sensing* strategy based on the *detection results relayed twice* from the secondary relays (SRs) to the secondary source (SS), referred to as *CSS-DRT*, is proposed in this paper. In this scheme, the spectrum sensing slot is divided into four equal sub-slots. In the first and third sub-slots, the SS and SRs detect the PU by themselves. Then, in the second sub-slot, if the SRs that detect the PU during the first sub-slot are more than or equal to a prespecified quantity, the corresponding SRs will send their flag signals (FSs) to the SS while the others keep quiet, where the FS is narrowband and indicates that the PU is present. Otherwise, if the SRs that detect the PU during the first sub-slot are less than the prespecified quantity, all the SRs will keep quiet in the second sub-slot. Meanwhile, the SS detects the PU based on the received signals from the PU and SRs. And, the SS uses the same method as employed in the second sub-slot to detect the PU in the last sub-slot wherein the SRs send their FSs based on their detections made during the third sub-slot. Finally, an ultimate decision is made by the OR ruler based on the SS detection results obtained during the spectrum sensing slot. Besides, we derive the closed-form expressions of the false alarm and detection probabilities for the proposed CSS-DRT scheme. In the end, simulation and numerical results show that our proposed scheme can achieve better performance than the non-cooperative method and an existing cooperative spectrum sensing method.**

Keywords- CRN; Cooperative Commuincation, Reliable Spectrum Sensing; relay

I. INTRODUCTION

In traditional spectrum management mechanism, most of the spectrum bands are assigned to the primary users (PUs), which are not allowed to be used by the secondary users (SUs) [1]-[3]. Thus, as wireless applications grow, the spectrum becomes more and more congested. However, Measurement results show that the allocated spectrum is only used by the PUs to a very limited extend while the others are heavily used in many wireless systems [4]. Therefore, the spectrum utilization is often very low due to the inflexible spectrum management policy. In fact, there still exists much access opportunities for the SUs to use the spectrum band even when the PUs are present [5].

A powerful solution to improve the spectrum utilization is spectrum sensing technique, which falls into two categories: non-cooperative spectrum sensing (NCSS) and cooperative spectrum sensing (CSS). In NCSS, three high accuracy strategies are widely used: energy detection (ED), matched filter detection, and cyclostationary feature detection [6]-[8]. However, the performances of these NCSS techniques would be severely degraded by multipath and shadowing. In order to combat the unpredictable dynamics in wireless environments, CSS techniques are proposed, which improve the overall detection probability by using either a centralized or a distributed manner [9] [10]. In the centralized manner, each SU makes its local detection and sends the decision result to the data fusion center independently. Then, the data fusion center will make a final decision based on a certain rule (such as “AND” rule, “OR” rule and “Optimal fusion” rule, etc). In a distributed manner, each SU makes its detection with the help of its neighboring users. In [11], the authors allow the SUs operating in the same band to cooperatively detect the PUs, which reduces the detection time and increases the overall agility. In [12], the authors proposed two new CSS methods, called AR and DR, which achieve better performance than the NCSS method and the method in [11].

In this paper, we employ ED to CSS in the cognitive radio networks (CRNs). In order to improve the CSS precision under a sustainable false alarm probability, a reliable *cooperative spectrum sensing* strategy based on the *detection results relayed twice* from the secondary relays (SRs) to the secondary source (SS) is proposed, which is called *CSS-DRT*. Specifically, in this scheme, we adopt slotted transmissions wherein each slot is divided into the spectrum sensing slot and the data transmission slot and then the spectrum sensing slot is divided into four sub-slots. In the first and third spectrum sensing sub-slots, the SS and SRs respectively detect the PU by themselves. Then, in the second sub-slot, if the SRs that detect the PU during the first sub-slot are more than or equal to a prespecified quantity, the corresponding SRs will send their flag signals (FSs) to the SS while other SRs keep quiet, where the FS is narrowband and used to indicate that the PU is present. Otherwise, if the SRs that detect the PU during the first sub-slot are less than the prespecified quantity, all the SRs will keep quiet during the second sub-slot. Meanwhile, the SS uses ED to detect the PU based on its received signals from the PU and SRs. And,

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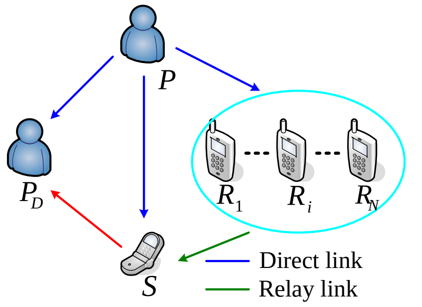

Fig. 1 The CRN of the proposed CSS-DRT scheme.

in the last sub-slot, the SS detects the PU by the same method as used in the second sub-slot, where the difference is that the SRs send their FSs based on their decisions made in the third sub-slot. Finally, an ultimate decision is made by the OR ruler based on the SS detection results obtained during the four spectrum sensing sub-slots. Furthermore, we analyze the performance of the proposed CSS-DRT scheme and derive the closed-form expressions of the false alarm and detection probabilities. In the end, the simulation and numerical results are given and show that our proposed strategy achieves better performance than the non-cooperative method and the method in [12].

This paper is organized as follows. Section II introduces the system model and the details of the proposed CSS-DRT strategy. In Section III, we derive the closed-form expressions of the false alarm and detection probabilities for the non-cooperative strategy and proposed CSS-DRT strategy, respectively. Finally, numerical and simulation results are shown in Section IV and conclusions are drawn in Section V.

II. SYSTEM MODEL AND THE PROPOSED CSS-DRT SCHEME

Consider the CRN depicted in Fig. 1, where all users share the same spectrum band for data transmissions and the PUs have the exclusive rights to use the spectrum band. P and P_D denote the primary source (PS) and primary destination (PD) while S and R_i ($i=1,\cdots N$) denote the SS and SRs, respectively. In this CRN, S needs to detect P before it transmits its own data. If P is detected, S should vacate the spectrum band immediately. Otherwise, if P is not detected, S will proceed its data transmissions. Moreover, P_D and R_i are both located within the transmission ranges of S and P. So, S may cause interference to P_D due to its poor detection performance. Meanwhile, R_i is near to both P and S. Thus, the links from P to R_i and from R_i to S are strong, which means that S can seek help from R_i to detect P. Besides, we assume that the channels are reciprocal and experience independent Rayleigh fading ones, which are invariant during one sub-slot.

In order to improve the detection ability of S, the CSS-DRT scheme is proposed for this CRN. The secondary transmission protocol of the proposed scheme is illustrated in Fig. 2, where each transmission slot consists of the spectrum sensing slot and the data transmission slot which follows the spectrum sensing slot. Meanwhile, the spectrum sensing slot is divided into four sub-slots. The spectrum sensing process of our proposed CSS-DRT is described as follows.

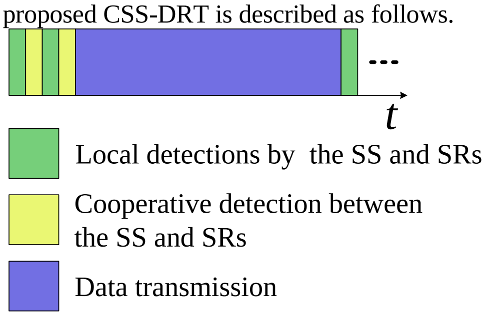

Fig. 2 Illustration of the secondary transmission protocol for the proposed CSS-DRT scheme.

In order to improve the detection ability of S, the CSS-DRT scheme is proposed for this CRN. The secondary transmission protocol of the proposed scheme is illustrated in Fig. 2, where each transmission slot consists of the spectrum sensing slot and the data transmission slot which follows the spectrum sensing slot. Meanwhile, the spectrum sensing slot is divided into four sub-slots. The spectrum sensing process of our proposed CSS-DRT is described as follows.

- In the first spectrum sensing sub-slot, S and R_i receive the signal from P and then use the ED technique to make their first detections of P, respectively.
- Then, in the second sub-slot, we assume that L is the number of the SRs that detect P and K is a prespecified value. If $L \geq K$ during the first sub-slot, the SRs that detect P send their FSs to S while the others keep quiet in the second sub-slot. Otherwise, if $L < K$ during the first sub-slot, all the SRs keep quiet. Here, S makes the second detection of P based on the received signals from P and R_i.
- In the third sub-slot, S makes its third detection and R_i makes its second detection using the same method as employed in the first sub-slot.
- In the last sub-slot, only when $L \geq K$ during the third sub-slot, the SRs that detect P will send their FSs to S while the others keep quiet, which is similar to the second sub-slot. Then, S employs the same method used in the third sub-slot to make the fourth detection.

Finally, an ultimate decision is made by the OR ruler based on the S's four detection results obtained during the spectrum sensing slot. Besides, since the spectrum sensing time is relatively short, the interference to the PUs caused by relaying the FSs is ignored [12].

III. PERFORMANCE ANALYSIS OF THE PROPOSED CSS-DRT SCHEME

In this section, the performances of the NCSS scheme using ED and the proposed CSS-DRT scheme are both analyzed.

A. *The NCSS Scheme*

Assume that P sends data x_P with the power E_P to P_D, where $E\left\{|x_P|^2\right\}=1$. Let θ denote the state of P, where $\theta=1$ indicates that P is present and $\theta=0$ indicates that P is absent. Then, the signal received at J ($\forall J\in\left\{S,R_i\mid i=1,\cdots N\right\}$) can be expressed as

$$y_J=\theta\sqrt{E_P}h_{PJ}x_P+n_J, \tag{1}$$

Where h_{PJ} is the channel fading coefficient from P to J, and n_J denotes the additive white complex Gaussian noise (AWGN) with zero mean and power spectral density N_0. Note that $|h_{PJ}|^2$ obeys an exponential distribution with parameter $1/\sigma_{PJ}$, where $1/\sigma_{PJ}$ denotes the fading variance of the channel from P to J.

For the NCSS scheme using the ED, J detects P by itself. Assume that H_0 and H_1 denote the hypotheses corresponding to the absence and presence of P, respectively. Meanwhile, the ED forms the power statistics $Y_J=|y_J|^2$ and compares it with a threshold T_J which is chosen to satisfy a sustainable false alarm probability. Note that y_J is a complex Gaussian random variable (CGRV). Thus, Y_J follows an exponential distribution. Suppose that σ_{Ji} ($i=0,1$) is the expected value of Y_JH_i. Then, from (1), we have

$$\begin{cases}\sigma_{J0}=N_0, & H_0\\ \sigma_{J1}=E_P\sigma_{PJ}+N_0, & H_1\end{cases}. \tag{2}$$

Thus, the false alarm and detection probabilities of J can be respectively calculated as [12]

$$P_{Jf}=\Pr\left\{Y_J\ge T_J\mid H_0\right\}=\exp\left(-\frac{T_J}{\sigma_{J0}}\right), \tag{3}$$

$$P_{Jd}=\Pr\left\{Y_J\ge T_J\mid H_1\right\}=\alpha^{\sigma_{J0}/\sigma_{J1}}, \tag{4}$$

where α is a prespecified false alarm probability and $T_J=-\sigma_{J0}\ln\alpha$.

B. *The Proposed CSS-DRT Scheme*

For our proposed CSS-DRT scheme, we assume that the false alarm probabilities of S's four detections and R_i's two detections made during the spectrum sensing slot are α while the overall false alarm probability is α_0. Besides, assume that R_i transmits its FS x_{R_i} with the power E_{R_i}, where $E\left\{|x_{R_i}|^2\right\}=1$. The following gives the performance analysis of our proposed CSS-DRT scheme in details.

- In the first spectrum sensing sub-slot, the signals received at S and R_i can be respectively expressed as

$$y_S^{(1)}=\theta\sqrt{E_P}h_{PS}^{(1)}x_P^{(1)}+n_S^{(1)}, \tag{5}$$

$$y_{R_i}^{(1)}=\theta\sqrt{E_P}h_{PR_i}^{(1)}x_P^{(1)}+n_{R_i}^{(1)}, \tag{6}$$

where the superscript $^{(1)}$ denotes the first spectrum sensing sub-slot. And we use the same manner to denote the second, third and fourth sub-slots as $^{(2)}$, $^{(3)}$ and $^{(4)}$, respectively. According to CSS-DRT, S and R_i detect P by themselves in this sub-slot. Thus, from Section III. A, the detection probabilities of S's and R_i's first detections are respectively given by

$$P_{Sd}^{(1)}=\alpha^{\frac{N_0}{E_P\sigma_{PS}+N_0}}, \tag{7}$$

$$P_{R_id}^{(1)}=\alpha^{\frac{N_0}{E_P\sigma_{PR_i}+N_0}}, \tag{8}$$

- In the second sub-slot, if $L\ge K$ in the first sub-slot, the SRs that detect P will send their FSs to S while the others keep quiet. S will receive the signals from S and $\left\{R_1,\cdots,R_i,\cdots,R_N\right\}$, which can be founded as

$$y_S^{(2)}=\theta\sqrt{E_P}h_{PS}^{(2)}x_P^{(2)}+\sum_{i=1}^{N}\theta_i^{(2)}\sqrt{E_{R_i}}h_{SR_i}^{(2)}x_{R_i}^{(2)}+n_S^{(2)}, \tag{9}$$

where $\theta_i^{(2)}$ denotes the state of R_i during the second sub-slot, $\theta_i^{(2)}=1$ indicates that R_i sends its FS to S and $\theta_i^{(2)}=0$ indicates that R_i keeps quiet in this sub-slot. It is easy to verify that the power Y_S in this case follows an exponential distribution wherein its expected values under H_0 and H_1 are given by

$$\begin{cases}\sigma_0^{(2)}=\sum_{i=1}^{N}\theta_i^{(2)}E_{R_i}\sigma_{SR_i}+N_0, H_0\\ \sigma_1^{(2)}=E_P\sigma_{PS}+\sum_{i=1}^{N}\theta_i^{(2)}E_{R_i}\sigma_{SR_i}+N_0, H_1\end{cases}, \tag{10}$$

Assume that $\Omega=\left\{R_i\mid i=1,\cdots,N\right\}$ and $\Phi_{i,j}$ is the $\Omega's$ jth sub-collection that contains i elements wherein $j=1,\cdots\binom{N}{i}$ while $\bar{\Phi}_{i,j}$ is the complement set of $\Phi_{i,j}$. For example, when $\Omega=\left\{R_1,R_2,R_3\right\}$, $\Phi_{0,1}=\Theta$, $\Phi_{1,1}=\left\{R_1\right\}$, $\Phi_{1,2}=\left\{R_2\right\}$, $\Phi_{1,3}=\left\{R_3\right\}$, $\Phi_{2,1}=\left\{R_1,R_2\right\}$, $\Phi_{2,2}=\left\{R_1,R_3\right\}$, $\Phi_{2,3}=\left\{R_2,R_3\right\}$ and $\Phi_{3,1}=\left\{R_1,R_2,R_3\right\}$, where Θ is the null set. Thus, the false alarm and detection probabilities of S's second detection can be calculated as

$$\begin{aligned} P_{Sf}^{(2)} &= \Pr\left\{Y_S \ge T_S, \theta_1^{(2)} = 0, \cdots, \theta_N^{(2)} = 0 \mid H_0\right\} \\ &\quad + \cdots + \Pr\left\{Y_S \ge T_S, \theta_1^{(2)} = 1, \cdots, \theta_N^{(2)} = 1 \mid H_0\right\} \\ &= \sum_{i=0}^{K-1} \sum_{j=1}^{C_N^i} \alpha^i (1-\alpha)^{N-i} \exp\left(-\frac{T_S}{N_0}\right) \\ &\quad + \sum_{i=K}^{N} \sum_{j=1}^{C_N^i} \left\{\alpha^i (1-\alpha)^{N-i} \right. \\ &\quad \left. \cdot \exp\left(-\frac{T_S}{\sum_{R_i \in \Phi_{i,j}} E_{R_i} \sigma_{SR_i} + N_0}\right)\right\} \end{aligned} , \quad (11)$$

$$\begin{aligned} P_{Sd}^{(2)} &= \Pr\left\{Y_S \ge T_S, \theta_1^{(2)} = 0, \cdots, \theta_N^{(2)} = 0 \mid H_1\right\} \\ &\quad + \cdots + \Pr\left\{Y_S \ge T_S, \theta_1^{(2)} = 1, \cdots, \theta_N^{(2)} = 1 \mid H_1\right\} \\ &= \sum_{i=0}^{k-1} \sum_{j=1}^{C_N^i} \left\{\left(\prod_{R_i \in \Phi_{i,j}} P_{Rd_i}\right)\left(\prod_{R_i \in \bar{\Phi}_{i,j}} \left(1 - P_{Rd_i}\right)\right)\right. \\ &\quad \left. \cdot \exp\left(-\frac{T_S}{E_P \sigma_{PS} + N_0}\right)\right\} \\ &\quad + \sum_{i=k}^{N} \sum_{j=1}^{C_N^i} \left\{\left(\prod_{R_i \in \Phi_{i,j}} P_{Rd_i}\right)\left(\prod_{R_i \in \bar{\Phi}_{i,j}} \left(1 - P_{Rd_i}\right)\right)\right. \\ &\quad \left. \cdot \exp\left(-\frac{T_S}{E_P \sigma_{PS} + \sum_{R_i \in \Phi_{i,j}} E_{R_i} \sigma_{SR_i} + N_0}\right)\right\} \end{aligned} , \quad (12)$$

where $C_N^i = \begin{pmatrix} N \\ i \end{pmatrix}$. Because $P_{Sf}^{(2)}$ is supposed to be equal to α, $P_{Sf}^{(2)} = \alpha$, the corresponding power threshold T_S in this case can be yielded from (11) and then $P_{Sd}^{(2)}$ is obtained from (12).

- In the third sub-slot, S makes the third detection and R_i makes the second detection by the same method used during the first sub-slot. Then, in this case, the received signals at S and R_i are

$$y_S^{(3)} = \theta \sqrt{E_P} h_{PS}^{(3)} x_P^{(3)} + n_S^{(3)}, \quad (13)$$

$$y_{R_i}^{(3)} = \theta \sqrt{E_P} h_{PR_i}^{(3)} x_P^{(3)} + n_{R_i}^{(3)}, \quad (14)$$

Thus, the detection probabilities of S's third detection and R_i's second detection are respectively given by

$$P_{Sd}^{(3)} = \alpha^{\frac{N_0}{E_P \sigma_{PS} + N_0}}, \quad (15)$$

$$P_{R_i d}^{(3)} = \alpha^{\frac{N_0}{E_P \sigma_{PR_i} + N_0}}, \quad (16)$$

- In the fourth sub-slot, S and R_i employ the similar method as used in the second sub-slot to collaboratively detect P, where if $L \ge K$ during the third sub-slot, the SRs that detect P will send their FSs to S while the others keep quiet in the last sub-slot. Then, the signal received at S is expressed as

$$y_S^{(4)} = \theta \sqrt{E_P} h_{PS}^{(4)} x_P^{(4)} + \sum_{i=1}^{N} \theta_i^{(4)} \sqrt{E_{R_i}} h_{SR_i}^{(4)} x_{R_i}^{(4)} + n_S^{(4)}, \quad (17)$$

where $\theta_i^{(4)}$ denotes the state of R_i during the fourth sub-slot, i.e., $\theta_i^{(4)} = 1$ indicates that R_i sends its FS to S and $\theta_i^{(4)} = 0$ indicates that R_i keeps quiet in this sub-slot. Therefore, the false alarm and detection probabilities of S 's fourth detection are the same as in the second sub-slot, i.e.,

$$P_{Sf}^{(4)} = P_{Sf}^{(2)} = \alpha, \quad (18)$$

$$P_{Sd}^{(4)} = P_{Sd}^{(2)}, \quad (19)$$

Finally, the ultimate decision is made by the OR ruler based on S's four detections made during the spectrum sensing slot. Thus, the overall false alarm and detection probabilities of our proposed CSS-DRT scheme can be obtained as

$$\begin{aligned} P_f &= 1 - (1 - P_{Sf}^{(1)})(1 - P_{Sf}^{(2)})(1 - P_{Sf}^{(3)})(1 - P_{Sf}^{(4)}) \\ &= 1 - (1 - \alpha)^4 \end{aligned} , \quad (20)$$

$$P_d = 1 - (1 - P_{Sd}^{(1)})(1 - P_{Sd}^{(2)})(1 - P_{Sd}^{(3)})(1 - P_{Sd}^{(4)}), \quad (21)$$

Since the overall false alarm probability P_f is fixed at α_0, we have

$$\alpha = 1 - (1 - \alpha_0)^{\frac{1}{4}}, \quad (22)$$

Therefore, when α_0 is given, α is obtained from (22) and then the corresponding T_S is yielded from (11). Eventually, from (21), the overall detection probability is obtained.

IV. NUMERICAL AND SIMULATION RESULTS

Throughout these simulations, we assume that $\sigma_{PS} = \sigma_{PR_i} = \sigma_{SR_i} = 1$ (i=1,⋯,N) and the transmit powers of all the SRs are the same which are denoted by E_R.

First, we assume that $\alpha_0 = 0.1$, E_R=10dB and E_P changes from 0dB to 20dB. Second, we assume that E_p=E_R=5dB and α_0 changes from 0 to 1. Then, in these two cases, we evaluate the detection performance of our proposed CSS-DRT scheme for both the single-SR (i.e., K=1 and N=1) and multiple-SR (Here, we take K=2 and N=4 for example.) models, respectively. Meanwhile, we compare the performance of our scheme with the method in [12] and the

non-cooperative case. The numerical and simulation results are respectively shown in Fig. 3 and Fig. 4.

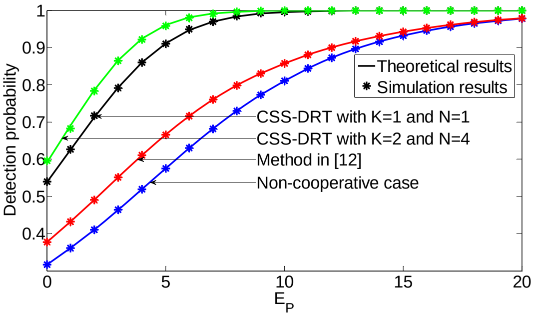

Fig. 3 Detection performance of proposed CSS-DRT scheme versus E_P.

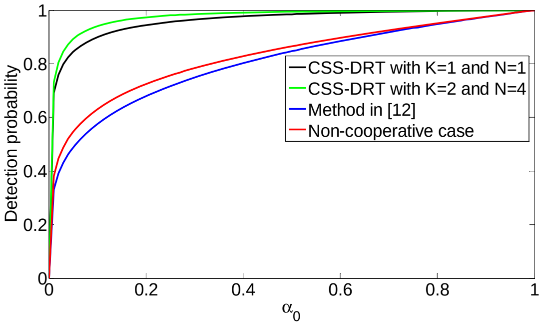

Fig. 4 Detection performance of our proposed CSS-DRT scheme versus α_0.

First, we assume that $\alpha_0 = 0.1$, E_R=*10*dB and E_P changes from 0dB to 20dB. Second, we assume that E_p=E_R=*5*dB and α_0 changes from 0 to 1. Then, in these two cases, we evaluate the detection performance of our proposed CSS-DRT scheme for both the single-SR (i.e., *K*=1 and *N*=1) and multiple-SR (Here, we take *K*=2 and *N*=4 for example.) models, respectively. Meanwhile, we compare the performance of our scheme with the method in [12] and the non-cooperative case. The numerical and simulation results are respectively shown in Fig. 3 and Fig. 4.

Fig. 3 and Fig. 4 show that the theoretical analysis is consistent with the simulations, which also verify that our proposed CSS-DRT scheme has higher detection probability than the method in [12] and the non-cooperative case. Meanwhile, the multiple-SR case achieves better performance than the single-SR case for the proposed scheme. Besides, the detection performance of the CSS-DRT scheme will improve as E_P grows.

Third, we assume that $\alpha_0 = 0.1$, *K*=2, E_p=10dB and the SR number *N* changes from 2 to 16. Then, we evaluate the performance of our proposed CSS-DRT scheme under E_R=5dB, E_R=10dB and E_R=15dB, which is shown in Fig. 5.

Fig. 5 shows that the detection probability of our proposed CSS-DRT scheme can be improved by increasing the SR transmit powers. Meanwhile, the CSS-DRT detection probability can achieve a maximum value as N changes, i.e., the detection probability increases at the beginning and then decreases as N increases. That is due to that properly increasing the SR number can improve the detection probability of the CSS-DRT scheme when K is given. However, at large value N, the false alarm probability of our scheme will increase as N grows under given K. Thus, in this case, the power threshold will be improved to keep the overall false alarm probability at a low level, which results in the overall detection probability decreasing. Thus, when K is given, we should select a proper N to achieve the best detection performance for our proposed CSS-DRT scheme.

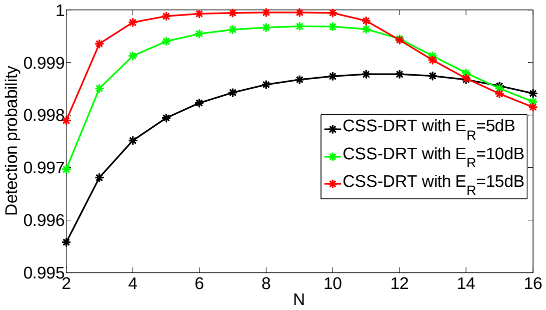

Fig. 5 Detection performance of our proposed CSS-DRT scheme versus *N*.

Finally, we assume that $\alpha_0 = 0.1$, *N*=16, E_P=10dB and K changes from 1 to 16. Then, the CSS-DRT performance evaluations under E_R=5dB, E_R=10dB and E_R=15dB are illustrated in Fig. 6 which shows that the CSS-DRT detection probability can achieve a maximum value as *K* changes under a given *N*. Meanwhile, when *N* is fixed, the overall detection probability will increase at first and then decrease as *K* improves, which means that a proper value *K* should be chosen to achieve the best detection performance for our proposed CSS-DRT scheme under a given *N*.

V. CONCLUSION

In this paper, we propose a reliable CSS strategy based on the detection results relayed twice from the SRs to the SS for CRNs, which is called CSS-DRT. Specifically, each spectrum sensing slot is divided into four sub-slots in the CSS-DRT scheme. In the first and third sub-slots, the SS and SRs respectively detect the PU by themselves. Then, in the second and fourth sub-slots, the SS detects the PU assisted by the SRs. In this case, if the SRs that detect the PU in the first sub-slot are more than or equal to a prespecified amount, the corresponding SRs will send their FSs to the SS during the second sub-slot and then the SS uses the received signals from the PU and SRs to detect the PU by ED technique. And, in the last sub-slot, the SS detects the PU by the similar method used in the second sub-slot, where the SRs send the FSs based on their detections made during the third sub-slot. Besides, we derive the closed-form expressions of the false alarm and detection probabilities for our proposed CSS-DRT scheme. Finally, the numerical and simulation results show that the proposed strategy has better performance than the NCSS method and the method in [12]. In fact, relaying the FSs more times from the SRs to the SS can improve the detection performance of CSS. However, this will increase the spectrum sensing overhead, correspondingly. So, how to obtain the best detection performance under a relative low overhead is crucial, which will be studied in our future works.

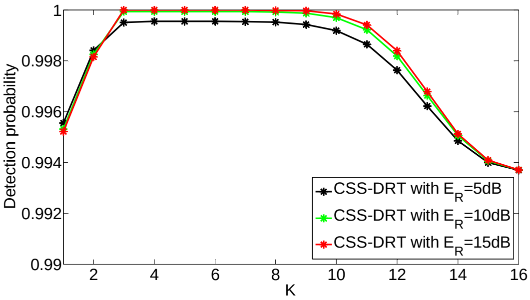

Fig. 6 Detection performance of our proposed CSS-DRT scheme versus K .

REFERENCES

[1] Z. Dai, J. Liu, and K. Long, "Improved energy detection with interference cancellation in heterogeneous cognitive wireless networks," in Proc. IEEE Global Commun. Conf., California, USA, 2012.

[2] Z. Dai, J. Liu, K. Long, "Cooperative relaying with interference cancellation for secondary spectrum access," KSII Transactions on Internet and Information Systems, vol. 6, no. 10, Oct 2012.

[3] Q. Zou, S. Zheng and A. H. Sayed, "Cooperative sensing via sequential detection," IEEE Trans. Signal Process., vol. 58, no. 12, pp. 6266-6282, Dec. 2010.

[4] S. Xie, Y. Liu, Y. Zhang and R. Yu, "A parallel cooperative spectrum sensing in cognitive radio networks," IEEE Trans. Veh. Technol., vol. 59, no. 8, pp. 4079-4092, Oct. 2010.

[5] G. Yuan, R. C. Grammenos, Y. Yang and W. Wang, "Performance analysis of selective opportunistic spectrum access with traffic prediction," IEEE Trans. Veh. Technol., vol. 59, no. 4, pp. 1949-1959, May 2010.

[6] F. F. Digham, M. S. Alouini and M. K. Simon, "On the energy detection of unknown signals over fading channels," in Proc. IEEE ICC, Anchorage, Alaska, vol. 5, pp. 3575–3579, May 2003.

[7] B. Farhang-Boroujeny, "Filter bank spectrum sensing for cognitive radios," IEEE Trans. Signal Process., vol. 56, no. 5, pp. 1801–1811, May 2008.

[8] W. A. Gardner, "Exploitation of spectral redundancy in cyclostationary signals," IEEE Signal Process. Mag., vol. 8, no. 2, pp. 14–36, Apr. 1991.

[9] X. Zheng, J. Wang, Q. Wu and J. Chen, "Cooperative spectrum sensing algorithm based on Dempster-Shafer theory," in Proc. of IEEE Journal of PLA Univ. of Science and Technol., pp. 218-221, 2008.

[10] G. Ganesan and Y. (G.) Li, "Cooperative spectrum sensing in cognitive radio - part I: two user networks," IEEE Trans. Wireless Commun., vol. 6, no. 6, pp. 2204–2213, Jun. 2007.

[11] G. Ganesan and Y. (G.) Li, "Cooperative spectrum sensing in cognitive radio - part II: multiuser networks," IEEE Trans. Wireless Commun., vol. 6, no. 6, pp. 2214–2222, Jun. 2007.

[12] Q. Chen, M. Motani, W. -C. (L.) Wong and A. Nallanathan, "Cooperative spectrum sensing strategies for cognitive radio mesh networks," IEEE J. Sel. Top. Signal Process., vol. 5, no. 1, pp. 56-67, Feb. 2011.