OPTIMUM RELAY SELECTION FOR COOPERATIVE SPECTRUM SENSING AND TRANSMISSION IN COGNITIVE NETWORKS

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ABSTRACT

In this paper, cyclostationarity based cooperative spectrum sensing is presented to detect the idle bands and then locate the secondary users into these bands. The aim is to reduce the processing complexity with using a relay for transmission and spectrum sensing. As such, an optimum relay is selected to perform both cooperative communication and cyclostationarity based spectrum sensing. Performance of transmission, probability of detection, and probability of missing are presented via computer simulations. Results show that proposed jointly optimized relay selection scheme provides sufficient performance for both transmission and spectrum sensing.

Index Terms— cognitive network, cooperative communication, relay selection, cyclostationarity based spectrum sensing, cooperative spectrum sensing

1. INTRODUCTION

Cognitive Radio (CR) is proposed as an intelligent wireless communication system which is aware of its surrounding and it can adapt its internal parameters such as carrier frequency, transmitter power etc. [1]. CR is also accepted as a solution to the need for spectrum utilization efficiency. Spectrum Sensing (SS) is the most essential component of CR that provides effective spectral utilization [1, 2]. The objective of SS is that the frequency bands unused by primary users (PUs) are sensed and assigned to secondary users (SUs).

In the implementation of CR, the most important criterion is that the interference from SUs to PUs should be limited so as to satisfy a desired quality of service (QoS) of primary transmissions [3]. As such, very low transmit power level is allowed for SUs, and thus their throughput will be very limited to satisfy high QoS for the primary user. In order to cope with these constraints, improved transmission techniques as well as sensing the available spectrum of the PUs are necessary to achieve the desired communication performance in cognitive radio networks.

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In order to meet this high performance requirement in cognitive networks, cooperative communication technique is employed because of its advantages in terms of improving the system throughput over fading channels [4]. In cooperative communication, a key issue is how to choose which terminal in the network will be used as a relay. Therefore vast amount of studies have been conducted and still undergoing on relay selection problem in cooperative communication systems. A pioneering study on relay selection is proposed in [5] which shows the effect of relay selection into the system performance. Recently, other relay selection schemes with improved performance have been proposed [6]- [7]. Relay selection problem becomes more complicated in cognitive radio networks compared to the classical cooperative communication systems, because of interference limitations from SU to PU. In some recent studies, cooperative transmission techniques have also been proposed for cognitive radio systems [8]- [9].

In some earlier studies, signal energy measurement based methods are emphasized because of their low computational load and sensing time [10]- [11]. However in later studies, cyclostationarity based spectrum sensing techniques that are more stable to unknown or variable noise levels or against uncertainty are presented [12]- [13]. Spectrum sensing efficiency can further be increased through cooperation with other users in the network [14]. Similar to cooperation for transmission, a relay in the network also senses the spectrum simultaneous with SU, and transmits the result to that SU. Then the SU combines these results using a soft or hard decision method and reaches the final result.

In this paper, we propose a jointly optimized relay selection scheme for both increasing the cooperative transmission and more stable cooperative spectrum sensing in cognitive radio networks, aiming to reduce the computational burden of the selection procedure. Hence, we select an optimum relay with only one selection algorithm for two tasks. The transmission and sensing performances of the proposed method are presented by means of computer simulations. Results demonstrate that our proposed method gives sufficient performance for both cooperative spectrum sensing and transmission tasks.

Rest of the paper is organized as follows. The cognitive radio network system model is explained in section 2, simulation results are given in section 3, and section 4 concludes the paper.

2. RELAY SELECTION FOR COGNITIVE NETWORKS

In this section we present our jointly optimum relay selection scheme for both cooperative communication and spectrum sensing in cognitive radio networks. Our selection algorithm combines two steps; (i) choosing the "best relay" for cooperative transmission, (ii) choosing the "best relay" for spectrum sensing, and finally selecting a single relay to perform both tasks. Clearly, the selected relay will be sub-optimal for either transmission or spectrum sensing. In the following, we briefly explain our cognitive radio network model with cooperation, relay selection algorithm for cooperative transmission and cooperative spectrum sensing.

2.1. Cooperative Cognitive Network Model

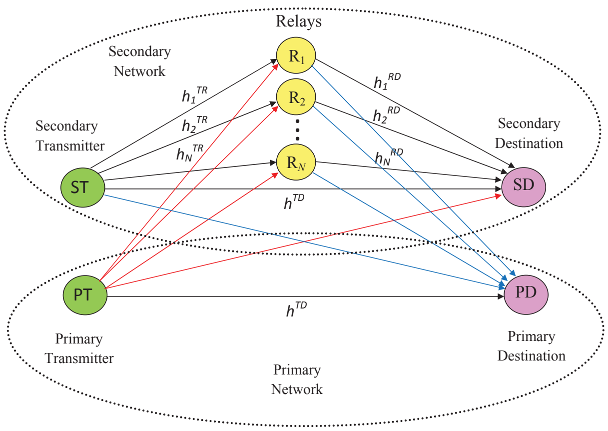

Fig. 1. Cognitive radio network model.

In the cognitive radio system, we consider two networks as shown in Fig. 1; the first one is a primary network and the second one is an amplify-and-forward (AF) cooperative communication secondary network. When the primary user sends data to a primary destination (PD), secondary transmitter (ST) sends its data to a secondary destination (SD) at the same time.

In order to implement the cooperation, we consider the "receive diversity protocol" presented in [4]. We assume that the transmitters, PT, ST, destinations, PD, SD, and relay terminals, $R_1, R_2, \cdots, R_M$ have one transmit and one receive antenna. In the first phase of this protocol, the ST transmits the data to both relay and the SD. Then in the second phase, the ST stays silent, while the relay amplifies and transmits the data. In cognitive radio systems with no spectrum sensing task, the transmit power of ST should be limited to maintain a desired QoS of PT.

PT transmits the signal x_p to PD where the transmit power of PT is denoted by P_{PT} and data rate by R_p. Similarly, ST transmits the signal x_s to SD with transmit power P_{ST}. The outage probability of primary transmissions is limited by a threshold P_{Thr}, to achieve the desired QoS of primary transmission.

2.2. Relay Selection for Cooperative Transmission

In our study, a static method is used to control the ST's P_{ST} and relay's transmit powers P_{SR_i} as in [15]:

$$P_{ST} = \frac{\sigma^2_{PT-PD} P_{PT}}{\sigma^2_{ST-PD}\Theta}\rho^+ \tag{1}$$

$$P_{SR_i} = \frac{\sigma^2_{PT-PD} P_{PT}}{\sigma^2_{SR_i-PD}\Theta}\rho^+ \tag{2}$$

where σ^2_{PT-PD}, σ^2_{ST-PD} and $\sigma^2_{SR_i-PD}$ are the fading variances of the channels from PT to PD and from ST to PD respectively, $\Theta = 2^{R_p} - 1$, $\rho^+ = max(\rho, 0)$, $\rho = (1/(1 - P_{Thr}))exp(-(\Theta/\sigma^2_{PT-PD}\gamma^{PT}) - 1$ and γ^{PT} is the transmit signal-to-noise ratio (SNR) at PT.

In the first phase, signals received at relay i and the destination SD are given respectively by the following;

$$r_{SR_i} = \sqrt{P_{ST}} h_{ST-SR_i} x_s + \sqrt{P_{PT}} h_{PT-SR_i} x_p + n_{SR_i} \tag{3}$$

$$r_{SD} = \sqrt{P_{ST}} h_{ST-SD} x_s + \sqrt{P_{PT}} h_{PT-SD} x_p + n_{SD} \tag{4}$$

where i is the index of the selected relay. Considering path losses and the shadowing effects in these channels, $\sqrt{P_{ST}}$ and $\sqrt{P_{PT}}$ show the signal powers at the relay and the destination, respectively. h_{ST-SR_i}, h_{PT-SR_i}, h_{ST-SD} and h_{PT-SD} represent the complex Gauss fading coefficients for ST and PT, $Source \rightarrow R_i$ and $Source \rightarrow SD$ channels respectively, where n_{SR_i} and n_{SD} show zero mean complex Gaussian noise with $N_0/2$ variance per dimension.

In the second phase, selected relay normalizes the received signal by $\sqrt{E[|r_{SR_i}|^2]}$ and transmits to the destination receiver. The signal at the destination in the second phase is

$$r_{RD_i} = \sqrt{P_{SR_i}} h_{ST-RD_i} \frac{r_{SR_i}}{\sqrt{E[|r_{SR_i}|^2]}} + n_{RD_i}. \tag{5}$$

$\sqrt{P_{SR_i}}$ represents the received signal power at the destination, considering path losses and the shadowing effects in $R_i \rightarrow SD$ channel. h_{ST-RD_i} represents the complex Gauss fading coefficients for this channel, where n_{RD_i} is the zero mean complex Gaussian noise with $N_0/2$ variance per dimension. Now, we consider the relay selection procedures to optimize only transmission, only spectrum sensing, and finally both transmission and spectrum sensing tasks.

(i) The "best relay" for transmission is selected as follows: In the secondary network transmission, the best relay amplifies the ST's signal and achieves the highest received instantaneous signal-to-noise ratio (SINR) at SD. For transmission, the best relay selection criterion is given as:

$$\begin{aligned} R_b &= arg\, max SINR_{SD} \\ &= arg\, max \frac{|h_{SR_i - SD}|^2}{\sigma^2_{SR_i - PD}} \end{aligned} \tag{6}$$

where R_b shows the selected relay. $ST \to R_i$ and $R_i \to SD$ cases are considered in the selection criterion.

(ii) The "best relay" for spectrum sensing is selected as follows: The best relay to sense the spectrum of PU is the relay having the largest channel coefficient. For spectrum sensing, the best relay selection criterion is given by the following:

$$R_b = arg\, max \frac{|h_{PT - SR_i}|^2}{\sigma^2_{SR_i - PD}} \tag{7}$$

(iii) The "optimum relay" for joint cooperative transmission and spectrum sensing: In this study, we propose the following criterion to select a single relay in the secondary network to jointly perform both transmission and spectrum sensing tasks: The selected relay amplifies the ST's signal, achieves the highest received instantaneous signal-to-noise ratio (SINR) at SD and detects the PU. For this optimum solution, the relay selection criterion is given by the following:

$$R_b = arg\, max \frac{|h_{SR_i - SD}|^2 + |h_{PT - SR_i}|^2}{\sigma^2_{SR_i - PD}} \tag{8}$$

In this study, cyclostationarity based cooperative spectrum sensing technique is used. In section 3, we present computer simulations to show the performance of our joint relay selection algorithm.

2.3. Cyclostationarity Based Cooperative Spectrum Sensing

A random process whose statistics is time-invariant is called stationary. A process with periodically changing statistical features is called cyclostationary. In such a case, the average of the signal has some cyclic behaviour. Cyclic statistical features of such processes may be extracted in the frequency domain. It is shown in earlier studies that communication signals exhibit cyclostationary behaviour and that spectral correlation function may be used to detect the existence of the transmit signal.

Cyclostationarity is defined by the features of providing the production of quadratic time-invariant spectral lines and characterized by the cyclic autocorrelation function, $R_x^\alpha(\tau)$. Taking the Fourier transform of $R_x^\alpha(\tau)$, spectral correlation density is:

$$S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha(\tau) e^{-i2\pi f \tau} d\tau \tag{9}$$

obtained [17]. Our spectrum sensing algorithm performs the following steps to determine whether the frequency band is used by the PUs.

1. Determine the highest amplitude θ, at ($\alpha = 0, f = \pm f_c$) and ($\alpha = \pm 2f_c, f = 0$) frequencies from four peaks of $S_x^\alpha(f)$ (see Fig. 5.)

2. Compare θ with an experimentally predetermined threshold λ and amplitude values of the peaks at ($\alpha = 0, f = 0$) frequencies.

If θ is larger than both λ and $\{S_x^\alpha(f = 0), S_x^{\alpha=0}(f)\}$; then the detector decides that the frequency band is full and is being used by the PU. Otherwise, the frequency band is considered empty an maybe assigned to a SU.

In section 3, we illustrate the performance of sensing and missing probabilities of the proposed cooperative spectrum sensing method for different signal to noise ratio values.

3. SIMULATION RESULTS

In this section, we present numerical tests by means of computer simulations via Monte Carlo iterations. We tested our algorithm using four different scenarios:

1. One of the available relays in the secondary network is "randomly chosen" for both cooperative transmission and spectrum sensing.
2. The "best relay" for transmission is selected and used for both transmission and spectrum sensing tasks.
3. The "best relay" for spectrum sensing is selected and used for both tasks.
4. The proposed method of selecting the "optimum relay" for joint transmission and spectrum sensing.

We use a frame size of 130 symbols, and assumed the channel fading coefficients are constant during one frame period. We assume that channel state information is known at the ST, transmitted from the SD to the ST by a feedback, all channels between Source-Destination, Source-Relays, Relays-Destination are Rayleigh fading and Rician fading, and QPSK modulation is considered for the data symbols. Rician fading ratio K is considered 20 for the Rician fading channel.

We investigate the performance of the cognitive network model shown in Fig. 1 and demonstrate by means of "bit error rate (BER)" plots given in Fig. 2 for Rayleigh fading channel and in Fig. 3 for Rician fading channel. It is observed

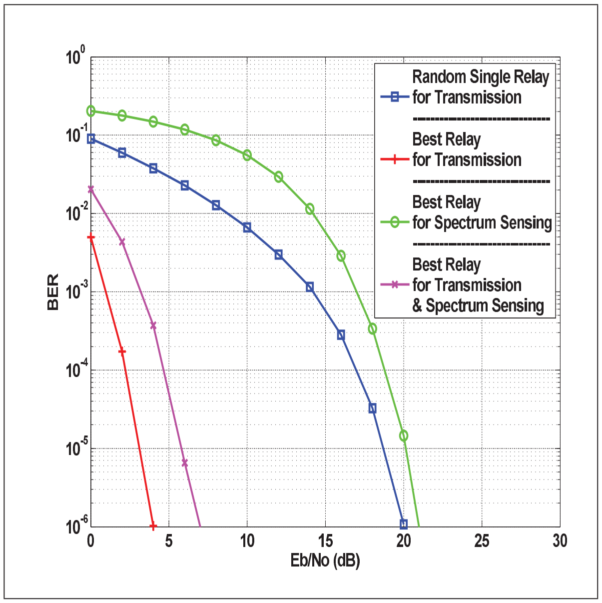

Fig. 2. Error performance curves for 4 different scenarios for Rayleigh fading channel.

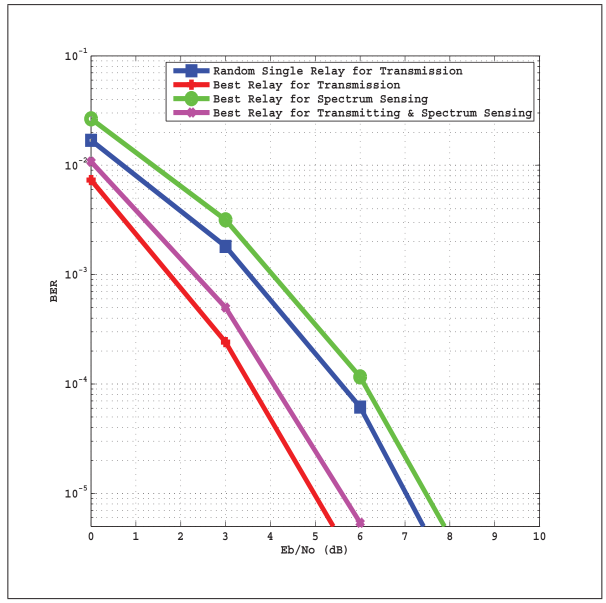

Fig. 3. Error performance curves for 4 different scenarios for Rician fading channel.

from Fig. 2 and 3 that scenario (2) has better error performance than others and scenario (3) has the worst error performance for transmission. However, the proposed method, i.e., scenario (4) has a better error performance than random relay selection, best relay selection for spectrum sensing, and it achieves a close performance to best relay for transmission. Performance of the spectrum sensing is tested for the above scenarios by means of probability of detection and the results are given in Fig. 4 and Fig. 5.

In Fig. 4 for Rayleigh fading channel and Fig. 5 for Rician fading channel, probability of detection values of random selection method are higher than scenario (2), the best relay for transmission. On the other hand, our proposed optimal solution has better values than random relay and best relay for transmission. Finally, values of the proposed best relay selection for joint transmission and spectrum sensing are closer to those of the best relay for spectrum sensing than others. It is observed from Fig. 4 and Fig. 5 that the proposed optimal solution has achieved better performance than the one proposed in [16]. As such, we conclude that the proposed relay selection approach provides sufficient performance for both transmission and sensing.

4. CONCLUSIONS

In this study, we present a jointly optimum relay selection scheme for cooperative communication and spectrum sensing for multiple-relay cognitive radio networks. The most important advantage of the proposed relay selection method is that the jointly selected relay yields sufficient error performance for transmission and sufficient probability of detection for spectrum sensing. Furthermore, thanks to the cyclostationarity based cooperative spectrum sensing for the relay selection, proposed method is more stable, robust to noise and low computational cost. Simulation results show that the proposed method provides an optimum system throughput in multiple-relay cognitive radio networks. In conclusion, our algorithm selects a relay also at lower SNRs that performs sufficiently in terms of secondary network data transmission as well as spectrum sensing of the primary network with low processing complexity.

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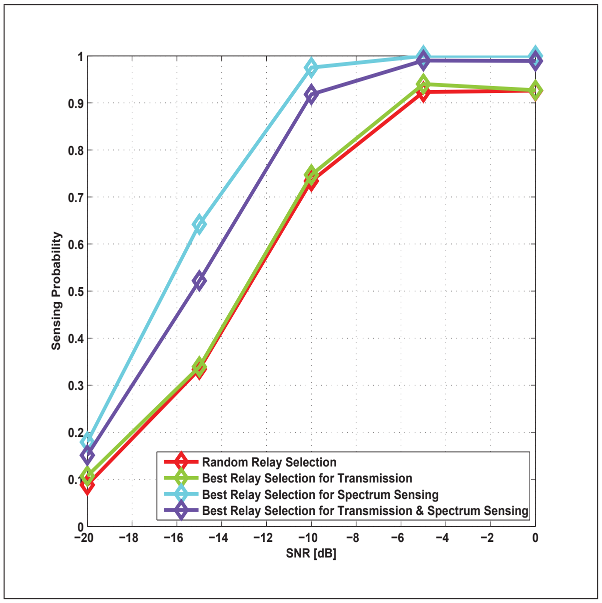

Fig. 4. Sensing probability of cooperative cognitive network for Rayleigh fading channel.

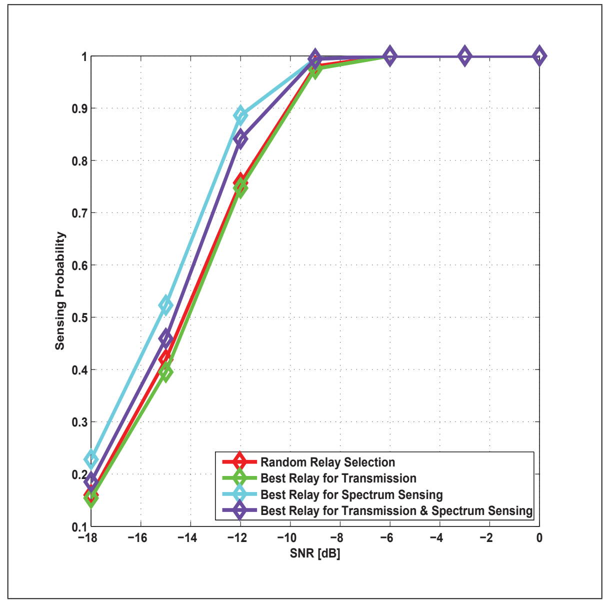

Fig. 5. Sensing probability of cooperative cognitive network for Rician fading channel.

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