Volume 2 No. 11, November 2012 ISSN 2223-4985

International Journal of Information and Communication Technology Research

http://www.esjournals.org

Cognitive Radio Networks with Best Relay Selection Method

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ABSTRACT

In this paper, we propose a cognitive transmission scheme with the best relay selection in a multiple-relay cognitive radio network to improve the secondary transmission performance while guaranteeing the quality-of-service (QoS) of the primary transmissions. We derive the closed-form expression of outage probability for the secondary transmissions, called *Secondary outage probability*, with the constraint of ensuring a target outage probability of primary transmissions *(primary outage probability)* for both the traditional non-relay and proposed best-relay selection based cognitive transmission schemes. Numerical results illustrate that, under a primary outage probability constraint, a secondary outage probability floor of the cognitive transmission occurs in high signal-to–noise ratio regions. Besides, the secondary outage probability floor of the proposed scheme is lower than that of the non-relay transmission, which is further reduced with an increasing number of cognitive relays.

Keywords: *Cognitive radio, cognitive transmission, relay selection, outage probability.*

I. INTRODUCTION

Cognitive radio is emerging as a means to improve the wireless spectrum utilization [1], [2], for which an interference temperature is proposed as a metric to quantify the interference in wireless radio environment. This allows a secondary user (SU) to access a licensed spectrum simultaneously with a primary user (PU)) as long as the interference from SU to PU is below a required threshold, i.e., the primary QoS is not affected. Hence, the transmit power of SU should be controlled to satisfy a given primary QoS. However, when the primary QoS is very strict, overly low transmit power is allowed for secondary transmissions and thus the secondary throughput is limited. Cooperative diversity [3] has been proposed as an effective approach to compact fading effect and enhance channel throughput. However, the advantage of traditional cooperative diversity protocols presented in [3] – [6] comes at the cost of a reduction in spectrum efficiency, since the relays forward their received signals over orthogonal channels to avoid interfering with each other. To overcome this issue, the relay-selection based cooperative diversity has studied in [7] – [9], where the "best" relay only is chosen to participate in forwarding the received signal and thus only two channels, i.e. the best-relay link and direct link, are needed. It has been proven that the cooperative diversity with best-relay selection not only avoids the complex system synchronization issue, but also achieves the full diversity with a careful relay selection design. In this paper, we focus on the application of the best relay selection protocol to the secondary transmissions in a multiple-relay cognitive radio network. The main contributions of this paper are described as follows. Firstly, differing from the previous works about relay selection in traditional non cognitive radio networks, we explore the best-relay selection for secondary transmissions in cognitive radio networks, where an additional mutual interference between the primary and secondary users are taken into account. Secondly, unlike the asymptotic or performance bound analyses conducted in [7], [8], [9], we derive an exact closed-form outage probability expression for secondary transmissions under a primary outage probability constraint. Thus remainder of this paper is described as follows. Section II Presents a system model of a cognitive transmission, based on which a best-relay selection scheme is proposed for multiple-relay cognitive radio networks. In Section III, We introduce the relay selection methods which are used in our paper. In Section IV, we conduct an outage probability analysis for the proposed cognitive transmission scheme, simulation results are provided to show the outage performance of cognitive transmissions in Section V. Finally, we provide the concluding remarks in Section VI.

II. SYSTEM MODEL

In a wireless network, the data which is transferred from a sender to a receiver has to propagate through the air. During propagation, several phenomena will distort the signal such as noise, path loss and Rayleigh fading. Path loss and fading are multiplicative, noise is additive. The output of the transmitter after passing channel is expressed as:

$$y_d[n] = h_{s,d}[n] \,.\, x_s[n] + z_{s,d}[n] = d_{s,d} \,.\, \alpha_{s,d}[n] \,.\, x_s[n] + z_{s,d}[n] \,, \quad (1)$$

where the suffixes s and d denote the sender and the destination, respectively. $x_s[n]$ is the transmitted symbol and $y_d[n]$ is the received symbol. $h_{s,d}[n]$ is attenuation and $d_{s,d}$ is path loss. $\alpha_{s,d}[n]$ is fading and $z_{s,d}[n]$ is noise.

There are several approaches to implement diversity in a wireless transmission [10], [11]. Multiple antennas can be used to achieve space and/or frequency diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality. To get diversity, an interesting approach might be to build an ad-hoc network using another mobile station as a relay. The model of such a system is illustrated in Fig.1. The sender S That represent the Primary user (PU) sends the data to the Destination D That

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represent the secondary user (SU), while the relay station R is used as a station. The relay sends this received data burst after processing to the destination as well, where the two received signals are combined. Orthogonal channels are used for the two transmissions. Without loss of generality, this can be achieved using time divided channels.

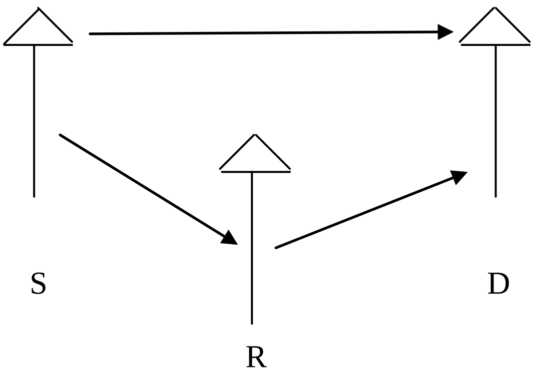

Fig.1. System Model

The received signal of a simple wireless channel model with fading and path loss is given by [12]

$$y = \delta \sqrt{\left(\frac{d}{d_r}\right)^{a}}\, h\, s + n = \sqrt{p}\, h\, s + n \qquad (2)$$

Where δ is the free space signal power attenuation factor between the source and a reference distance d_r, d is the distance between the source and destination, and α is the propagation exponent. $h \sim c\,N\,(0,\ \sigma_n^2\ )$ is a complex Gaussian random variable with variance σ_n^2 , $n \sim c\,N\,(0,\ N_o)$, S is the transmitted signal. In Equation (2), $p = \sigma^2 \left(\frac{d}{d_r}\right)^{a}$ denotes the equivalent transmitted power after taking into account the effect of path loss, we also define as:

$$p_{o=}\ \delta^2 \left(\frac{d_r}{d_o}\right)^{a} \qquad p_{1=}\ \delta^2 \left(\frac{d_r}{d_1}\right)^{a}$$

$$p_{t=}\ \delta^2 \left(\frac{d_r}{d_t}\right)^{a}$$

III. RELAY SELECTION METHODS

In this section we describe the details of our proposed relay selection methods. Particularly, Best relay selection and Nearest relay selection method. In both of these schemes, one or two relays can be selected in the second phase. If one relay is selected, as shown in fig.1. half of process is done at the S and another half is done as shown in Fig 2 at the selected R. In the case of two relay selection, AAF transmission scheme is not performed at the S instead half of AAF Scheme is done at one of selected Rs and another half is performed at the other R.

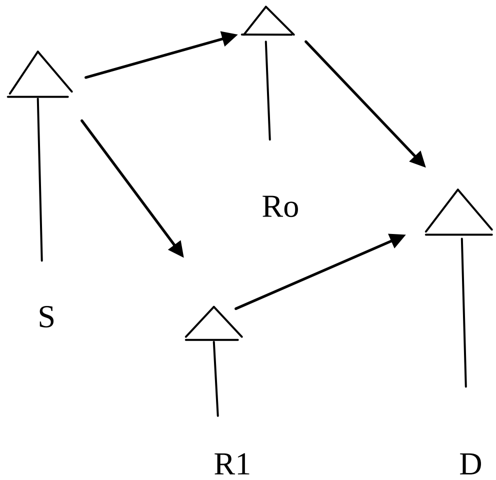

Fig.2. System Model when two relays are selected.

A. Best Relay Selection Method

The proposed relay selection scenario is performed in a per-subchannel manner. In practice the allocation in the frequency domain is not addressed at the level of subcarriers. Typically, subchannels which are the smallest granular units in the allocation are created by grouping subcarriers in an OFDM symbol in various ways. The formation of these subchannels from subcarriers is important concept in OFDMA systems. The formation can be classified in two types; one is mapping Contiguous group of subcarriers into a subchannel called as adjacent subcarrier mode (ASM) and the other is the permutation based grouping called as diversity subcarrier mode (DSM) [13]. Each sub-channel can be modeled as a flat fading channel with approximately equal SNR level. The S chooses to use the best R in the first phase. Such decision is done for each subchannel so that, the best relay is chosen prior to S transmission. It's needed for each R to know the received SNR at R and D $\left(SNR_{s,r}^{(n)}, SNR_{r,d}^{(n)}\right)$ for relaying the nth subchannel. The best relay for transmission of each subchannel is selected to maximize the minimum of the received SNR at R and D for all available Rs.

B. Nearest Relay Selection Method

In the first phase of this relaying scheme, each R is assigned to the destination (D) with the shortest distance to it then the selected R listens to S transition. This scheme requires infrastructures for knowledge or estimation of distances.

C. Two Best Relay Selection Method

This relaying method is based on the best relay selection is explained above, but two best relays are chosen in the first phase. That is to say, after minimums of received SNR at R

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and D pair for all Rs, min $\left(SNR_{s,r_k}^{(n)}, SNR_{r_{k,d}}^{(n)}\right)$, k=1,……,k , are sorted in decreasing order, simply relay stations which are assigned to first and second values are chosen. Then, the S transmits its data to them. Moreover, in the second phase these two Rs transmit for the D. Like the previous cases relaying in done in per subchannel manner.

D. Two Nearest Relay Selection Method

This relaying scheme is similar to nearest relaying selection. In the first phase the S transmit to two nearest Rs and in the second phase these two Rs relay to the S.

IV. OUTAGE ANALYSIS

In this section, we first analyze the outage probability of the proposed cooperative Cognitive Radio. For the best relay selection scenario, the mutual information between S and D can be shown to be:

$$I^{(n)} = \frac{1}{2}\log\left(1 + SNR_{s,d}^{(n)} + SNR_{best}^{(n)}\right) \qquad (3)$$

$$SNR_{best}^{n,k} = \arg\, max_k \, \min\left(SNR_{s,r_k}^{(n)}, SNR_{r_{k},d}^{(n)}\right)$$

$$SNR^* = \min(SNR_{s,r_k}^{(n)}, SNR_{r_k,d}^{(n)})$$

Where r_k is k^{th} relay station, $k = 1, \dots\dots, K$ the outage probability is bounded as follows:

$$P(I^{(n)}) < R) = P(SNR_{s,d}^{(n)} + SNR_{best}^{n,k} < 2^{2R} - 1)$$

$$= P\,(SNR_{s,d}^{(n)} + \max(SNR^*) < 2^{2R} - 1)$$
$$> P(max(SNR_{s,d}^{(n)} + SNR^*) < 2^{2R} - 1)$$

$$= \prod_k P(SNR_{s,d}^{(n)} + SNR^* < 2^{2R} - 1) \qquad (4)$$

Since SNR^* is the minimum of two independent exponential random variables, it is exponential random variable with parameter $\sigma_*^{-2} = (\sigma_{s,r_k}^{-2} + \sigma_{r_k,d}^{-2})$. So $(SNR_{s,d}^{(n)} + SNR^*)$ is the sum of two independent exponential random variables with distinct parameters and its c.d.f is obtained from theorem 2 in [14]. Considering above notifications, the lower bound for outage probability yields:

$$P(I^{(n)} < R) >$$

$$\prod_k \left(1 - \left\{\begin{matrix}\left(1 - \frac{\sigma_*^{-2}}{\sigma_{s,d}^{-2}}\right)^{-1} e^{\frac{-(2^{2R}-1)}{\sigma_{s,d}^{-2}}} + \\ \left(1 - \frac{\sigma_{s,d}^{-2}}{\sigma_*^{-2}}\right)^{-1} e^{\frac{-(2^{2R}-1)}{\sigma_*^{-2}}}\end{matrix}\right\}\right) \qquad (5)$$

The mutual information between S and D for nearest relay selection can be written as:

$$I^{(n)} = \frac{1}{2}\log\left(1 + SNR_{s,d}^{(n)} + SNR_{r_{nearest},d}^{(n)}\right) \qquad (6)$$

And the outage probability is given by:

$$P(I^{(n)} < R) = P\left(SNR_{s,d}^{(n)} + SNR_{nearest}^{(n)} < 2^{2R} - 1\right)$$

$$=1- \left\{\begin{matrix}\left(1 - \frac{\sigma_{r_{nearest},d}^{-2}}{\sigma_{s,d}^{-2}}\right)^{-1} e^{\frac{-(2^{2R}-1)}{\sigma_{s,d}^{-2}}} + \\ \left(1 - \frac{\sigma_{s,d}^{-2}}{\sigma_{r_{nearest},d}^{-2}}\right)^{-1} e^{\frac{-(2^{2R}-1)}{\sigma_{r_{nearest},d}^{-2}}}\end{matrix}\right\}$$

V. SIMULATION RESULTS

a. Simulation Condition

Each Cognitive radio system consists of Some of OFDMA symbol, each symbol has 1024 subcarriers which are partitioned into subchannels containing 24 data subcarriers. System bandwidth and carrier frequency are 10MHZ and 2.5 GHZ, respectively. The cell is equally divided into 3 sectors. In each sector, 4 Rs are placed, with 0.6 × cell radius distance to S and central angle of 2π/15. The cell radius is fixed at 2Km. The heights of the D, S and R are 1.5 m, 50m and 30 m and path loss at each link is calculated accordingly [15].

b. Simulation Result

Fig.3 shows the outage probability versus the average channel SNR and compares the performance of the proposed relay selection schemes (Best relay selection, two best relay selections, Nearest relay selection, Two nearest relay selection and original (lower bound)). We consider rate R=1 b/s/Hz. It can be seen that the best relay selection scheme outperforms the nearest selection scheme significantly. Besides, in both schemes a diversity gain is observed in the selection of two relays compare to the selection of just one relay whether the best one or the nearest one.

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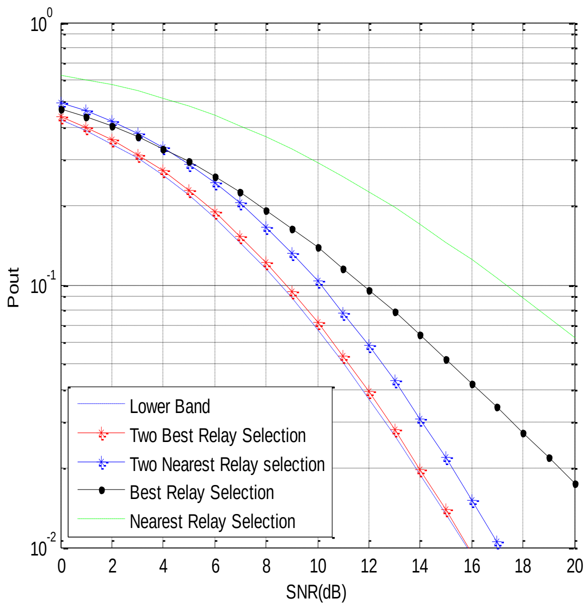

Fig.3 Outage performance of Best and Nearest relay selection methods each for two cases: one and two relay selection along with lower bound for Best relay selection.

VI. CONCLUSION

In this paper, we examined the problem of relay selection for cognitive radio network. We proposed two relay selection methods: Best relay selection method and Nearest relay selection method, both of these methods are done in a per subchannel mode. We analyzed the outage performance of proposed relaying schemes and showed that best relay selection method outperforms nearest relay selection method. In both cases when two relay selected instead of just one relay the performance is significantly improved.

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