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Performance analysis of cognitive relay systems with spectrum-sharing interference under a primary outage probability constraint

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Abstract

This paper investigates the performance of an underlay cognitive relay system where secondary users (SUs) suffer from a primary outage probability constraint and spectrum-sharing interference imposed by a primary user (PU). In particular, we consider a secondary multi-relay network operating in the selection decode-and-forward (SDF) mode and propose a best-relay selection criterion which takes into account the spectrum-sharing constraint and interference. Based on these assumptions, the closed-form expression of the outage probability of secondary transmissions is derived. We find that a floor of the outage probability occurs in high signal-to-noise ratio (SNR) regions due to the joint effect of the constraint and the interference from the PU. In addition, we propose a generalized definition of the diversity gain for such systems and show that a full diversity order is achieved. Simulation results verify our theoretical solutions.

Keywords cognitive relay systems, spectrum-sharing interference, outage probability, diversity gain

1 Introduction

Cognitive radio (CR) is emerging as a promising technology to improve the utilization of wireless spectrum resources [1]. As one of the CR spectrum sharing schemes, spectrum underlay allows the unlicensed user (secondary user, SU) to simultaneously operate in the spectrum band of the licensed user (primary user, PU) as long as the interference caused to the PU remains below a threshold, i.e., the quality of service (QoS) of primary transmissions is not affected. Therefore, the transmit power of the SU is constrained to guarantee the QoS of the PU. However, when the QoS requirement is stringent, the allowable transmit power of the SU is very low and thus the performance of secondary transmissions can not be guaranteed.

Cooperative diversity has emerged as a good solution to increase spectral and power efficiencies in wireless networks [2]. In cooperative relaying, one or more intermediate nodes (relays) are used to support signal transmissions, which can exploit the user diversity and provide dramatic gains in reliability and capacity increase. Generally, there are two protocols to implement relaying: one is the decode-and-forward (DF) protocol and the other is the amplify-and-forward (AF) protocol. The DF relay decodes the received signal, re-encodes and forwards it to the destination while the AF relay amplifies the received signal and forwards it to the destination.

Since the transmit power of the SU is strictly limited in an underlay spectrum-sharing system, the cooperative relaying technique can be exploited to enhance the performance of the secondary system. Integrating the cooperative relaying technique into the spectrum sharing system sheds new light on higher spectral efficiency. As a result, cognitive relay systems have attracted much interest [3–7]. In Ref. [3], Bao et al. investigate the performance of cognitive AF relay systems with a best relay selection strategy and subject to nonidentical Rayleigh fading when the transmit powers of the secondary source and relay are subject to an interference constraint imposed by the PU. In Ref. [4], Lee et al. develop a model for constraining the SU’s transmit power

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which considers not only the interference constraint imposed by the PU but also the maximum power constraint of the SU. Based on this model, they provide a relay selection criterion and derive the outage probability of cognitive relay systems. Note that these literatures assume that the interference threshold the PU can tolerate is fixed, which is impractical as this threshold is related to the actual situation of the QoS of primary transmissions. Considering this problem, In Ref. [5], Sagong et al. adjust the interference threshold according to the QoS requirement and the link condition of primary transmissions, and investigates the overall average bit error rate, ergodic capacity, and outage probability of the secondary relaying system. However, the existing studies only focus on constraining the induced interference from the SU to the PU while ignoring the influence of the spectrum-sharing interference from the PU on the SU. Especially in the process of performance analysis, the interference from the PU is either ignored [3–7] or treated as noise [8] for simplicity. In fact, this is impractical because the interference might have an immediate impact on the relay selection strategy and the performance of the cognitive relay system.

This paper investigates the performance of cognitive relay systems with consideration of not only the spectrum-sharing constraint but also the spectrum-sharing interference. Specifically, the secondary relaying transmission is subject to an interference constraint of satisfying a required outage probability of primary transmissions and suffers from the Rayleigh-faded interfering signals from the PU. Considering these assumptions, we propose a relay selection criterion and derive the outage probability and the diversity gain for secondary transmissions. We find that with the joint effect of the constraint and the interference from the PU, the outage saturation phenomenon occurs, but the full diversity order can still be achieved.

The rest of this paper is organized as follows. Sect. 2 presents the cognitive relay network architecture, the transmit power constraint model and the secondary relaying protocol. Sect. 3 investigates the outage performance and the diversity gain of secondary transmissions. Simulation results are shown and discussed in Sect. 4. Finally, Sect. 5 concludes the paper.

2 System model

We consider a cognitive relay system with the coexistence of primary and secondary networks as shown in Fig. 1. In the primary network, a primary transmitter (PT) sends data to a primary destination (PD). Meanwhile, in the secondary network, a secondary source (S) communicates with a destination (D) with the help of the M candidate secondary relays denoted by $\mathfrak{R}=\{R_i|i=1, 2, \dots, M\}$. It is assumed that the direct link between S and D is unavailable due to the deep fading. In addition, we assume that all channels are subject to Rayleigh fading, and thus $|h_{A-B}|^2$, which denotes the gain of the channel from node A to node B, is exponentially distributed with the parameter λ_{A-B}.

During the whole transmission, both the secondary source and the secondary relays share the licensed spectrum band with the PUs simultaneously. Therefore, the mutual interference between the PUs and the SUs should be carefully considered. On the one hand, both S and the relays have to constrain their transmit powers to keep the interference level imposed on PD below a predefined threshold, and on the other hand, the secondary relaying protocol, especially the relay selection criterion, should take into account the effect of the spectrum-sharing interference from PT.

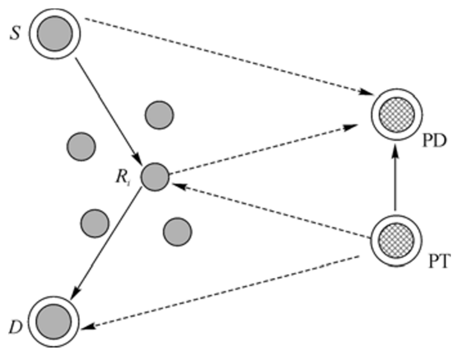

Fig. 1 System model of the cognitive relay system

2.1 Transmit power constraint

In the cognitive relay system, the SUs adjust their transmit powers according to the QoS requirement and link conditions of primary transmissions. Throughout this paper, we use outage performance to quantify the QoS of primary transmissions. Specifically, the outage probability shall be guaranteed to be below a predefined threshold P_0, which can be written by

$$P_{\text{out}}^{\text{P}} = \Pr\left[\frac{\gamma_{\text{P}}|h_{\text{PT-PD}}|^2}{\frac{I}{N_0}+1} < \gamma_0\right] \leqslant P_0 \tag{1}$$