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Outage performance of cognitive DF relay networks with nonidentical Rayleigh fading channels and maximal ratio combining☆

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ABSTRACT

In the expression of end-to-end signal-to-noise ratio (SNR) of cognitive relay networks, the channel gaina of the interference links (from secondary nodes to primary nodes in the networks) are usually shared by multiple items in the expression. These shared variables lead to the so called correlation issue, which results in the higher complexity of outage performance analysis for such networks. Till now, for cognitive relay networks with decode-and-forward (DF) relay scheme, we have not found works obtaining explicit closed-form expression of exact outage probability (OP) meanwhile treating the correlation issue completely. In this paper, for cognitive DF relay networks with maximal ratio combing (MRC) and independent non-identical Rayleigh fading channels, we obtain a closed-form expression of exact OP taking consideration of the correlation issue completely. Additionally, by shrinking or expanding the triangular integral region to suitable rectangular regions, we obtain simpler closed-form expressions of the lower and upper bounds of both OP and symbol error probability (SER). Furthermore, the asymptotic expressions of OP and SER are also obtained. The correctness of our analysis results are verified through numerical simulations. Both analysis results and simulation results show that how the correlation issue is treated can affect the coding gain whereas has no effect on the diversity gain of the network. Simulation results also indicate that, exact OP and SER are bounded from both sides by the lower bound and the upper one tightly, whereas the upper bounds of OP and SER are more tighter than the lower bounds.

1. Introduction

Applying multiple antennas enables the terminals to combat with channel fading effects. However, the requirements on hardware size would be prohibitive for hand-held communication devices [1,2]. To that end, cooperative communication is emerging as an alternative approach by forming a virtual antenna array to perform the function of multiple antennas [3]. By allowing secondary users (SUs) to simultaneously share the frequency band licensed to primary users (PUs) without causing harmful interferences to PUs, cognitive radio can significantly improve spectrum efficiency [4–6]. As a combination of these two attractive techniques, i.e., cooperative communication and cognitive radio, cognitive relay networks have gained much research attention in recent years.

For cognitive relay networks, two typical relaying strategies are decode-and-forward (DF) and amplify-and-forward (AF) [7,8]. A DF relay decodes the received signal, re-encodes and forwards it to the destination, whereas a AF relay just amplifies the received signal directly and then forwards it to the destination node [7,8]. At the destination, the receiver employs diversity combining techniques to obtain spatial diversity from signal replicas received from SU relays and the SU source. Typical diversity combining techniques are maximal ratio combining (MRC), equal-gain combining (EGC), selection combining (SC).

In cognitive relay networks, the interference power caused by an SU's transmission on a PU receiver should not exceed the PU's threshold. This is the so called interference power constraint, which is a main issue specific to cognitive relay networks. This interference

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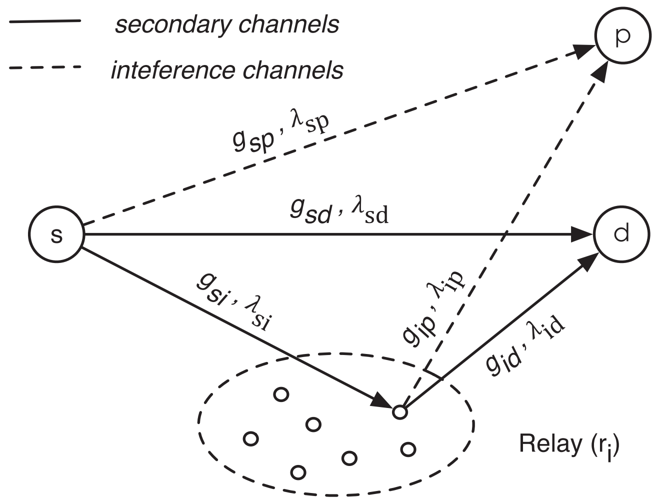

Fig. 1. Network model of targeted dual-hop cognitive relay networks.

power constraint of PU leads to the correlation issue in outage performance analysis of such networks, which intrinsically result from the interference channel gain of the interference link from a SU node to the PU shared by multiple signal-to-noise ratio (SNR) items in the expression of end-to-end SNR of cognitive relay networks. The correlation issue should be elaborately treated otherwise the analysis results will be incorrect.

In the literature, outage performance of cognitive relay networks with DF and MRC have been investigated in many works including references [9,10]. In these works, the correlation issue was treated in different levels. For example, in [9], the SNR items in the expression of end-to-end SNR of cognitive relay networks were all considered as independent variables, thus the correlation issue is completely ignored. This treatment is obviously not appropriate, as has been verified in [10]. However, in [10], the correlation issue was only partially considered, where each set of correlating SNR items is divided into smaller subsets. Then, the correlation among SNR items in the same subset was fully considered, whereas SNR items among different subsets were treated as independent variables.

It is obvious that, to obtain exact analysis results, the correlation issue should be completely considered and treated. Hence, in most recent works, such as [11,12], the correlation issue was considered and treated completely, which is also the case of our work here. In [11], closed-form expression of exact OP of cognitive DF relay networks was obtained with additional consideration of maximum transmit power limits of SUs. In the analysis in [11], the correlation issue was treated completely. However, different from our work here, all channels are assumed to be identical Rayleigh fading channels in [11].

In [12], closed-form expression of OP's upper bound for cognitive relay networks was obtained with the assumption of non-identical Rayleigh fading channels and best relay selection. However, in [12], closed-form expression of exact OP was not obtained, and the work was targeted for networks with AF relaying scheme.

In summary, for cognitive DF relay networks, although there have been some interesting works on outage performance analysis, we have not found works obtaining explicit closed-form expressions of exact outage probability (OP) and symbol error rate (SER) by treating the correlation issue completely. We do this work here.

In this paper, we investigate outage performance of cognitive DF relay networks with MRC and fully non-identical Rayleigh fading channels by treating the correlation issue completely. Out work here is similar to that in [12], except that DF relay scheme is targeted here whereas AF relay scheme was focused in [12]. Closed-form expressions of exact OP and SER of targeted cognitive DF relay networks are obtained. In order to obtain less accurate but more simpler expressions, lower and upper bounds as well as asymptotic expressions of OP and SER of such networks are also obtained. The correctness of our analysis results are verified through numerical simulations. Both analysis results and simulation results show that how the correlation issue is treated can affect the coding gain whereas has no effect on the diversity gain of the network. Exact OP and SER are bounded from both sides by the lower bound and the upper one tightly, whereas the upper bound is more tighter.

The remainder of this paper is organized as follows: Section 2 introduces the network model and the channel model of our targeted cognitive relay network. Then in Section 3, expressions of exact as well as upper and lower bounds of OP and SER of the network are obtained. And then in Section 4, asymptotic expressions of OP and SER are derived. The analysis results are verified through numerical simulations in Section 5. Finally a conclusion is made in Section 6.

2. Network model and channel model

The network model of targeted dual-hop cognitive relay networks is shown in Fig. 1. The network model consists of a PU node p and an SU network consisting of an SU source s, an SU destination d, and N SU relays $\{r_1, \ldots, r_N\}$. All the nodes are equipped with mono antenna and adopt half duplex communication protocol. All channels in the network are assumed to be independent non-identical Rayleigh fading channels with instantaneous channel gain g_{uv}, which is a random variable follows exponential distribution function $f_{g_{uv}}(x) = \lambda_{uv} e^{-\lambda_{uv} x}$, $u \in \{s, 1, \ldots, N\}, v \in \{d, 1, \ldots, N\}$. Here for notation simplification, in the context of g_{uv} and λ_{uv}, if u or v is in set $\{1, \ldots, N\}$, the corresponding node is in fact node r_u or r_v. For easy reference, the notations used in the paper and their meanings are listed in Table 1.