

Outage performance of a cognitive amplify-and-forward relay network with primary user interference over Nakagami- m fading channels

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Abstract: In this study, primary user (PU) interference in a cognitive amplify-and-forward relay network is considering over a Nakagami- m fading channel, and the outage probability is derived for the secondary users. This PU interference has not previously been considered in the literature. Results are presented which show that PU interference can significantly degrade secondary user performance, and thus should be considered in the design of a cognitive radio network.

1 Introduction

Cognitive radio is a technique which can be employed to improve spectrum efficiency [1]. For example, spectrum sharing allows a secondary user (SU) to use licensed spectrum with constraints on the interference to primary receivers. A cooperative relay network is an efficient means of mitigating the effects of fading in wireless networks [2]. Cooperative relaying fits well with spectrum sharing because the transmit power of secondary users is limited. Several cooperative relaying protocols have been developed, the most popular being amplify-and-forward (AF) and decode-and-forward (DF) [2]. These protocols can be used in a cognitive radio network to enhance the performance of secondary users.

For a cognitive AF relay network, the outage performance has been derived for Rayleigh fading channels with a constraint on the secondary user interference to the primary user (PU) [3, 4]. For a cognitive DF relay network, the outage performance with multiple relays over Rayleigh fading channels has been derived [5–7], but the interference from the primary transmitter has either been ignored or considered as noise, which is not accurate. Subsequently, the outage performance considering interference from the primary transmitter was derived over Rayleigh fading channels in [8–11]. The outage performance of a cognitive AF relay network for a more practical Nakagami- m fading channel was analysed in [12, 13], but interference from the primary transmitter was not considered.

Primary transmitter (PUT) interference is an important factor which can have a significant effect on network performance. Thus in this paper, the exact outage probability (OP) for a cognitive AF relay network with Nakagami- m fading channels is derived considering the effect of PUT interference on the secondary users. The results are validated using Monte Carlo simulation and show that this interference should not be ignored in the design of a cognitive relay network.

2 System model

We consider a cognitive AF relay network with spectrum sharing and interference from a primary transmitter. The system model is shown in Fig. 1. The primary transmitter u transmits data to the receiver v with fixed transmit power P_u . This results in interference to the secondary users. A secondary source s (SU_s) transmits data to the destination d (SU_d) via the relay r . Time division multiplexing is used at the relay for simplicity. The direct link between SU_s and SU_d is assumed to be unusable because of channel impairments such as shadowing. Further, the channels in Fig. 1 are assumed to

be independent and non-identical Nakagami- m fading channels with integer m . The instantaneous channel gains h_i ($i = 1, 2, \dots, 6$) are then Nakagami- m distributed with parameters m_i and channel powers Ω_i . Thus, $|h_i|^2$ is Gamma distributed with PDF and CDF given by

$$f_{|h_i|^2}(x) = \frac{\alpha_i^{m_i}}{\Gamma(m_i)} x^{m_i-1} \exp(-\alpha_i x) \quad (1)$$

$$F_{|h_i|^2}(x) = \frac{1}{\Gamma(m_i)} \Upsilon(m_i, \alpha_i x)$$

respectively, where $\alpha_i = m_i/\Omega_i$. The secondary users are limited to a maximum transmit power P , and the interference at the primary receiver v is constrained to below a threshold I . Thus, the transmit power of the secondary source and relay, SU_s and r , must satisfy $P_s \leq \min((I/|h_2|^2), P)$ and $P_r \leq \min((I/|h_5|^2), P)$, respectively. Note that secondary users are also affected by interference from the primary transmitter u .

3 Outage probability

According to the cognitive AF protocol [13], the end-to-end signal to interference plus noise ratio (SINR) between SU_s and SU_d can be expressed as

$$\gamma_{\text{tot}} = \max(\min(\gamma_{\text{sr}}, \gamma_{\text{rd}})) \quad (2)$$

where γ_{sr} and γ_{rd} denote the received SINR at the relay r and SU_d , respectively. In this paper, the transmit power of the secondary

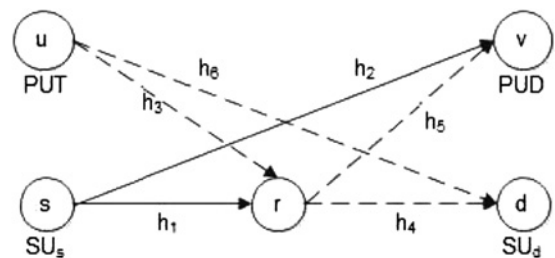


Fig. 1 Cognitive relay network model

source SU_s is assumed to be P_s , and the relay r to be P_r , so that

$$\gamma_{sr} = \frac{\min((I/|h_2|^2), P)|h_1|^2}{P_u|h_3|^2 + N_0}, \quad (3)$$

$$\gamma_{rd} = \frac{\min((I/|h_5|^2), P)|h_4|^2}{P_u|h_6|^2 + N_0}$$

where N_0 is the power spectral density of the additive white Gaussian noise. For a cognitive AF relay network, the OP can be expressed as

$$\Pr(\gamma_{\text{tot}} < \gamma_{\text{th}}) = 1 - (1 - F_{\gamma_{sr}}(\gamma_{\text{th}}))(1 - F_{\gamma_{rd}}(\gamma_{\text{th}})) \quad (4)$$

where γ_{th} is the outage threshold. The CDFs of γ_{sr} and γ_{rd} can be derived in a similar manner. Thus, we focus on $F_{\gamma_{sr}}(\gamma_{\text{th}})$, which is given by

$$F_{\gamma_{sr}}(\gamma_{\text{th}}) = \underbrace{\Pr(|h_1|^2 P \leq (P_u|h_3|^2 + N_0)\gamma_{\text{th}}, \frac{I}{|h_2|^2} > P)}_{P1} + \underbrace{\Pr(I|h_1|^2 \leq |h_2|^2(P_u|h_3|^2 + N_0)\gamma_{\text{th}}, \frac{I}{|h_2|^2} \leq P)}_{P2} \quad (5)$$

Using (8.350.2) and (8.352.6) in [14], $P1$ and $P2$ can be derived as

$$P1 = \Pr(|h_1|^2 \leq \frac{\gamma_{\text{th}}}{P}(P_u|h_3|^2 + N_0)) \Pr(|h_2|^2 < \frac{I}{P})$$

$$= \frac{\Upsilon(m_2, (\alpha_2 I/P))}{\Gamma(m_2)} \left[1 - \frac{\alpha_3^{m_3}}{\Gamma(m_3)} \sum_{k=0}^{M_1-1} \sum_{j=0}^k \binom{k}{j} \frac{\alpha_1^k}{k!} \left(\frac{N_0}{P}\right)^{k-j} \right]$$

$$\times \left(\frac{P_u}{P}\right)^j \exp\left(-\frac{\alpha_1 N_0 \gamma_{\text{th}}}{P}\right) \frac{\Gamma(m_3 + j)}{(\alpha_3 + (\alpha_1 P_u \gamma_{\text{th}}/P))^{m_3+j}} \quad (6)$$

$$P2 = \Pr(|h_1|^2 \leq \frac{\gamma_{\text{th}}|h_2|^2}{I}(P_u|h_3|^2 + N_0), |h_2|^2 \geq \frac{I}{P})$$

$$= \frac{\Gamma(m_2, (\alpha_2 I/P))}{\Gamma(m_2)} - \frac{\alpha_3^{m_3} \alpha_2^{m_2}}{\Gamma(m_3)\Gamma(m_2)} \sum_{k=0}^{M_1-1} \sum_{j=0}^k \sum_{l=0}^{m_2+k-1} \binom{k}{j}$$

$$\times \binom{m_2+k-1}{l} \left(\frac{\alpha_1 \gamma_{\text{th}}}{I}\right)^k \frac{1}{k!} (N_0)^{k-j} P_u^j \Gamma(m_3 + j)$$

$$\times \left(\frac{I}{P_u \alpha_1 \gamma_{\text{th}}}\right)^{m_2+k} (-\alpha_3)^{m_2+k-1-l} \exp(A\alpha_3)$$

$$\times \frac{\Gamma(l - m_3 - j + 1, A((\alpha_3 + \alpha_1 \gamma_{\text{th}} P_u)/P))}{A^{l-m_3-j+1}} \quad (7)$$

where $A = (\alpha_2 + \alpha_1 N_0(\gamma_{\text{th}}/I))(I/P_u \alpha_1 \gamma_{\text{th}})$. Substituting (6) and (7) into (5) gives

$$F_{\gamma_{sr}}(\gamma_{\text{th}}) = \Pr \gamma_{sr}(m_1, m_2, m_3, \alpha_1, \alpha_2, \alpha_3) \quad (8)$$

Using a similar approach, $F_{\gamma_{rd}}(\gamma_{\text{th}})$ is obtained as

$$F_{\gamma_{rd}}(\gamma_{\text{th}}) = \Pr \gamma_{rd}(m_4, m_5, m_6, \alpha_4, \alpha_5, \alpha_6) \quad (9)$$

Finally, substituting (8) and (9) into (4) provides the OP.

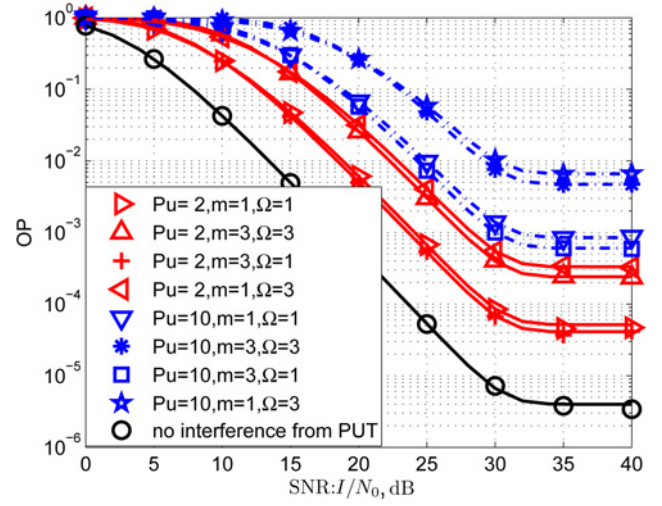


Fig. 2 OP against I/N_0

4 Performance results

In this section, results are presented to evaluate and verify the system performance. Fig. 2 presents the OP against I/N_0 for different values of P_u , which determines the primary transmitter interference to the secondary users. The system parameters are $m_1 = 2$, $m_2 = 3$, $\Omega_1 = \Omega_2 = 1$, $m_4 = 2$, $m_5 = 3$, $\Omega_4 = \Omega_6 = 1$, $N_0 = 1$, $P = 30$ dB and $\gamma_{\text{th}} = 1$. To simplify the evaluation, $m_3 = m_6 = m$ and $\Omega_3 = \Omega_5 = \Omega$ were employed. The simulation results (shown as symbols) verify the analytic results (shown as solid lines).

Fig. 2 provides several interesting and important results. First, the OP increases rapidly with increasing P_u . For example, the OP increases from $<10^{-5}$ to approximately 10^{-3} when P_u increases from 0 to 10 dB at $I/N_0 = 30$ dB. Thus, the OP of the secondary users is very sensitive to primary transmitter interference. Second, a change in Ω has a significant effect on the OP for fixed P_u and m , whereas the effect of changing m is relatively small for fixed P_u and Ω . Third, an outage floor exists when $I/N_0 > 30$ dB because the maximum power constraint on the secondary user is $P = 30$ dB. Thus, it can be concluded that the interference from the primary transmitter should not be ignored when evaluating the system performance.

5 Conclusion

In this paper, a cognitive AF relay network with spectrum sharing and interference from the primary transmitter was examined over Nakagami- m fading channels, and the OP was derived. This OP was used to evaluate the impact of a transmit power limit, an interference power constraint and interference from the primary transmitter, on system performance. Results were presented which show that the interference from the primary transmitter can have a significant effect on secondary user performance.

6 Acknowledgment

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7 References

- [1] Goldsmith A., Jafar S.A., Maric I., Srinivasa S.: 'Breaking spectrum gridlock with cognitive radios: an information theoretic perspective', *Proc. IEEE*, 2009, **97**, (5), pp. 894–914
- [2] Laneman J.N., Tse D., Wornell G.W.: 'Cooperative diversity in wireless networks: efficient protocols and outage behavior', *IEEE Trans. Inform. Theory*, 2004, **50**, (12), pp. 3062–3080

- [3] Duong T.Q., Bao V.N.Q., Tran H., Zepernick H.-J.: 'Exact outage probability of cognitive AF relaying with underlay spectrum sharing', *Electron. Lett.*, 2011, **47**, (17), pp. 1001–1002
- [4] Chen J., Li Z., Si J., Huang H., Gao R.: 'Outage probability analysis of partial AF relay selection in spectrum-sharing scenario with multiple primary users', *Electron. Lett.*, 2012, **48**, (19), pp. 1211–1212
- [5] Guo Y., Kang G., Zhang N., Zhou W., Zhang P.: 'Outage performance of relay-assisted cognitive-radio system under spectrum-sharing constraints', *Electron. Lett.*, 2010, **46**, (2), pp. 182–183
- [6] Luo L., Zhang P., Zhang G., Qin J.: 'Outage performance for cognitive relay networks with underlay spectrum sharing', *IEEE Commun. Lett.*, 2011, **15**, (7), pp. 710–712
- [7] Yan Z., Zhang X., Wang W.: 'Exact outage performance of cognitive relay networks with maximum transmit power limits', *IEEE Commun. Lett.*, 2011, **15**, (12), pp. 1317–1319
- [8] Yang P., Luo L., Qin J.: 'Outage performance of cognitive relay networks with interference from primary user', *IEEE Commun. Lett.*, 2012, **16**, (10), pp. 1695–1698
- [9] Duong T.Q., Yeoh P.L., Nguyen V., Bao Q., Elkashlan M., Yang N.: 'Cognitive relay networks with multiple primary transceivers under spectrum-sharing', *IEEE Signal Process. Lett.*, 2012, **19**, (11), pp. 741–744
- [10] Xu W., Zhang J., Zhang P., Tellambura C.: 'Outage probability of decode-and-forward cognitive relay in presence of primary user's interference', *IEEE Commun. Lett.*, 2012, **16**, (8), pp. 1252–1255
- [11] Si J., Li Z., Huang H., Chen J., Gao R.: 'Capacity analysis of relay networks with the PU's interference', *IEEE Commun. Lett.*, 2012, **16**, (12), pp. 2020–2023
- [12] Asghari V., Aissa S.: 'Performance of cooperative spectrum-sharing systems with amplify-and-forward relaying', *IEEE Trans. Wirel. Commun.*, 2012, **11**, (4), pp. 1295–1300
- [13] Duong T.Q., da Costa D.B., Elkashlan M., Nguyen V., Bao Q.: 'Cognitive amplify-and-forward relay networks over Nakagami- m fading', *IEEE Trans. Veh. Tech.*, 2012, **16**, (5), pp. 2368–2374
- [14] Gradshteyn I.S., Ryzhik I.M.: 'Tables of integrals, series, and products' (Academic Press, Waltham, MA, 2007, 7th edn.)