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Outage probability of dual-hop semi-blind relaying with interference at the relay

***Abstract**. In this paper a novel expression for the gain of semi-blind relay in the presence of multiple interferences at the relay is derived. Using this expression for the gain of relay, closed-form expression for outage probability of signal-to-interference and noise ratio (SINR) is derived for dual-hop semi-blind relaying in interference-limited relay environment over Rayleigh fading conditions. Monte Carlo simulation is used to verify the theoretical expression for the outage probability.*

***Streszczenie.** W artykule opisano nowy sposób wyznaczenia wzmocnienia przesyłu typu semi-blind w obecności różnorodnych zakłóceń. Na podstawie otrzymanego wyrażenia, określono wzór jawny na prawdopodobieństwo awarii i zmiany względnego wskaźnika poziomu szumów dla dwu-stopniowego przekazywania semi-blind w środowisku o ograniczonych zakłóceniach, w warunkach zanikania Rayleigh'a. Weryfikacji dokonano metodą Monte Carlo (**Prawdopodobieństwo awarii w dwustopniowym przesyle semi-blind przy zakłóceniach na przekaźniku**).*

Keywords: co-channel interference, outage probability, semi-blind relay.
Słowa kluczowe: zakłócenia wspólno-kanałowe, prawdopodobieństwo awarii, przekazywanie pół-ślepe.

Introduction

Dual-hop relaying transmission has enormous interest in the context of cooperative communication. Transmission via relay improves the throughput and extend the coverage without using large transmitting power [1-2]. In nonregenerative relaying systems or amplify-and-forward (AF) systems, relays just amplify and forward the incoming signal without performing any decoding at all. There are two types of AF protocol: variable and fixed. Channel state information (CSI)-assisted relays have variable gain which requires knowledge of the instantaneous channel realization at the relays. Fixed gain relays have a constant gain and they do not need CSI from the first hop. Those are so-called blind relays [2]. The fixed gain relays could have statistical CSI about the previous hop not requiring continuous monitoring of the channel (as in the case of CSI-assisted relays). This type of relays are called semi-blind relays [3-4].

Semi-blind relaying used in dual-hop transmission, which has gained substantial interest, is considered only in noise limited environment [3-4]. However, in the practical wireless systems, the co-channel interference, which is the result of the aggressive frequency reuse in neighboring cells, can cause performance degradation [5]. In a few published works, the impact of interference on the CSI-assisted AF relaying and the decode and forward (DF) relaying performance has been investigated either at the relay or destination [6-8]. The authors in [3] proposed a specific fixed gain relay, called semi-blind relay. This type of relay has a fixed gain, which depending on first hop CSI average statistics, does not require continuous monitoring of the channel. Related to CSI-assisted relay, this kind of relays provides reduced implementation complexity. In interference-limited relay environment, the gain of semi-blind relay depends on average statistics not only on the first hop but also on co-channel interferences. However, to the best of authors' knowledge there is no published work considering the outage performance of dual-hop transmission with semi-blind relays in the presence of co-channel interferences at the relay.

The main contribution of this paper is the derivation of analytical expression of the gain of semi-blind relay in the presence of co-channel interferences over Rayleigh fading. Moreover, new analytical closed-form expression for outage probability is derived for dual-hop semi-blind relay in interference-limited relay environment over Rayleigh fading condition. Numerical results obtained by analytical approach are verified by Monte-Carlo simulations.

System model

We consider the wireless communication system, in which the transmission from the source terminal *S* to the destination terminal *D* is assisted by a semi-blind relay *R*. The relay terminal is corrupted by N co-channel interferences and additive white Gaussian noise (AWGN) while destination terminal is only perturbed by an AWGN. The level of co-channel interferences at the relay is high enough compared to the level of thermal noise, so the thermal noise at the relay can be neglected as in all interference-limited fading environments.

The end-to-end signal-to-interference and noise ratio (SINR) for this dual hop system is [6]

$$\gamma_{eq} = \frac{|h_{SR}|^2 |h_{RD}|^2 G^2 P_0}{|h_{RD}|^2 G^2 \sum_{i=1}^{N} |h_i|^2 P_i + \sigma_D^2} \tag{1}$$

where h_{SR} and h_{RD} are the fading amplitudes of the channel between *S* and *R* terminals and between *R* and *D* terminals, respectively, $\{h_i\}_{i=1}^{N}$ are amplitudes of the interferers at the input of *R*. Average power of transmitted signal at the terminal *S* output is denoted by P_0 whereas P_i is the average power of each interference. The gain of relay is noted as G and σ_D^2 is the power of AWGN at the relay.

By substituting the fixed gain in the form $G=P_R/C$, where P_R is the power of the transmitted signal at the output of the relay and C is a constant, in (1), SINR has a form

$$\gamma_{eq} = \frac{P_0 |h_{SR}|^2 \dfrac{P_R |h_{RD}|^2}{\sigma_D^2}}{\dfrac{P_R |h_{RD}|^2}{\sigma_D^2} \sum_{i=1}^{N} |h_i|^2 P_i + C} = \frac{\gamma_1 \gamma_2}{\gamma_2 \gamma_3 + C} \tag{2}$$

where $\gamma_1 = |h_{SR}|^2 P_0$, $\gamma_2 = |h_{RD}|^2 P_R / \sigma_D^2$ and $\gamma_3 = \sum_{i=1}^{N} |h_i|^2 P_i$

The fixed gain relay in semi-blind context in the interference-limited environments is chosen as follows

$$G^2 = \mathrm{E}\left[\frac{P_R}{|h_{SR}|^2 P_0 + \sum_{i=1}^{N} |h_i|^2 P_i} \right] \tag{3}$$

where $\mathrm{E}[.]$ is the expectation operator.

The two hops are assumed to be subject to independent Rayleigh fading, while γ_1 and γ_2 have exponential probability density function (PDF) [9]

$$p_{\gamma_i}(\gamma) = \frac{1}{\lambda_i}\exp\left(-\frac{\gamma}{\lambda_i}\right) \tag{4}$$

where $\lambda_1 = \mathrm{E}\left[|h_{SR}|^2\right] P_0$ is the average signal power of *S*−*R* channel and $\lambda_2 = \mathrm{E}\left[|h_{RD}|^2\right] P_R / \sigma_D^2$ is the average signal to noise power ratio of *R*−*D* channel. We assume that co-channel interference fading amplitudes are also modeled as Rayleigh random processes. When all N interferers are identical, γ_3 becomes a central χ^2 random variable with $2N$ degrees of freedom with PDF [9]

$$p_{\gamma_3}(\gamma) = \frac{1}{\lambda_3^N \Gamma(N)}\gamma^{N-1}\exp\left(-\frac{\gamma}{\lambda_3}\right) \tag{5}$$

In the presence of interferences semi-blind gain relay has the average first hop statistics and the average statistics on the co-channel interferences:

$$G^2 = \mathrm{E}\left[\frac{P_R}{\gamma_1+\gamma_3}\right] = \int_0^\infty\int_0^\infty \frac{P_R}{\gamma_1+\gamma_3} p_{\gamma_1}(\gamma_1) p_{\gamma_3}(\gamma_3)\mathrm{d}\gamma_1\mathrm{d}\gamma_3 \tag{6}$$

By substituting (4) for *i*=1 and (5) in (6), and using [10, eq. (6.455)] the gain is

$$G^2 = \frac{P_R}{\lambda_3 N}\, {}_2F_1\left(1,1,N+1;1-\frac{\lambda_1}{\lambda_3}\right) \tag{7}$$

where ${}_2F_1$(a,b,c;x) is the Gauss hypergeometric function defined as [10, eq. (9.111)]. Comparing the (7) and $G^2 = P_R / C$, the constant C is given by:

$$C = \frac{\lambda_3 N}{{}_2F_1\left(1,1,N+1;1-\frac{\lambda_1}{\lambda_3}\right)} \tag{8}$$

Outage probability

The outage probability of the instantaneous equivalent SINR can be expressed as

$$\begin{aligned} F_{\gamma_{eq}}(\gamma_{th}) &= \Pr(\gamma_{eq} \le \gamma_{th}) = \\ &= \int_0^\infty\int_0^\infty \Pr\left(\gamma_1 \le \gamma_{th}(z+1) + \frac{\gamma_{th}C}{y}\right) p_{\gamma_2}(y) p_{\gamma_3}(z)\mathrm{d}y\mathrm{d}z \end{aligned} \tag{9}$$

where $\Pr(.)$ denotes the probability. In order to evaluate (9), the cumulative distribution function (CDF) of γ_1 can be expressed as $F_{\gamma_1}(\gamma) = 1 - \exp(-\gamma/\lambda_1)$ and the PDFs of γ_2 and γ_3 are given by (4) for *i*=2 and (5), respectively. By substituting the corresponding expressions in (9) and replacing constant C with (8) double-fold integrals can be solved in closed-form expressions.

$$\begin{aligned} F_{\gamma_{eq}}(\gamma_{th}) &= 1 - \frac{2}{\lambda_2}\left(\frac{\lambda_3}{\lambda_1}\gamma_{th}+1\right)^{-N} \\ &\cdot \sqrt{\frac{\lambda_2\lambda_3\gamma_{th}N}{\lambda_1 \cdot {}_2F_1\left(1,1,N+1;1-\frac{\lambda_1}{\lambda_3}\right)}} \\ &\cdot K_1\left(2\sqrt{\frac{\gamma_{th}\lambda_3 N}{\lambda_1\lambda_2 \cdot {}_2F_1\left(1,1,N+1;1-\frac{\lambda_1}{\lambda_3}\right)}}\right) \end{aligned} \tag{10}$$

where $K_1(.)$ is the first order modified Bessel function of the second kind defined in [10, eq. (8.432)].

Numerical and simulation results

In this section, according to analytical expression for outage probability of cooperative dual-hop system with semi-blind relay, numerical and simulation results are presented in the figures below.

In Fig. 1 and 2 outage performance for dual-hop semi-blind relaying is shown. The results are compared with the results for outage probability of CSI-assisted relay [6]. In these figs. we assume a single interference at the relay and we use $\rho = E[\gamma_1]/E[\gamma_3] = \lambda_1/\lambda_3$.

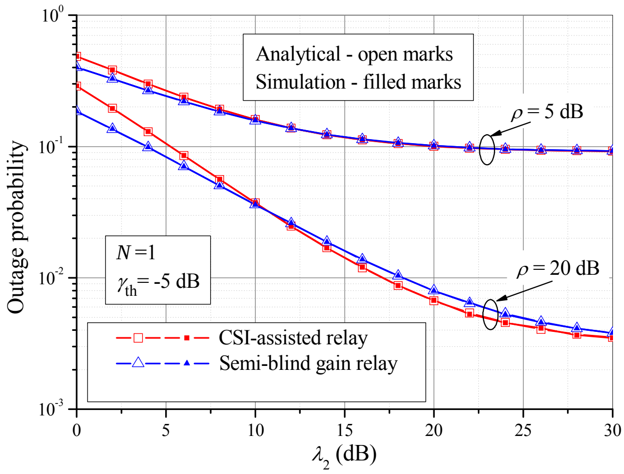

Fig. 1. Outage probability for various values of ρ

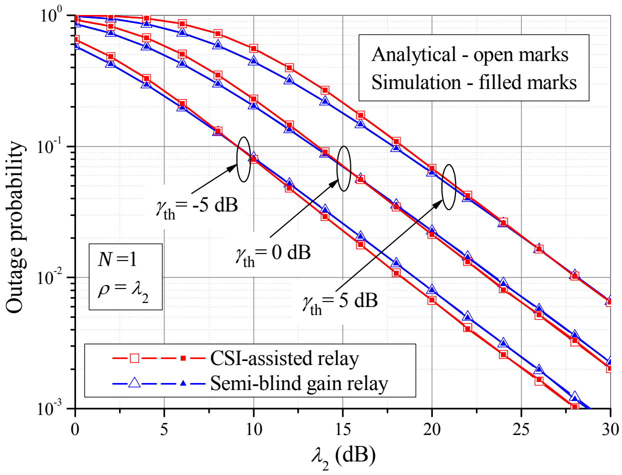

Fig. 2. Outage probability for various values of outage threshold

Outage probability versus second hop average SNR (signal-to-noise ratio) for ρ=5 dB and ρ=20 dB is shown in Fig. 1. Systems with semi-blind gain relay slightly outperform systems with CSI-assisted relay at low second hop average SNR. This is evident for lower SIR values at the first hop (ρ=5 dB) performance improvement of CSI-based relays is insignificant.

Fig. 2. depicts the outage performance for different outage threshold of semi-blind gain relay. It is observed that as γ_{th} increases, the outage probability also increases. When γ_{th} increases from -5dB to 5dB, outage probability changes about 10 times. For medium and large average SNR second hop values, CSI-assisted relaying transmission outperforms those with semi-blind relay. At the other side, for low SNR values semi-blind relay outperforms CSI-based relay.

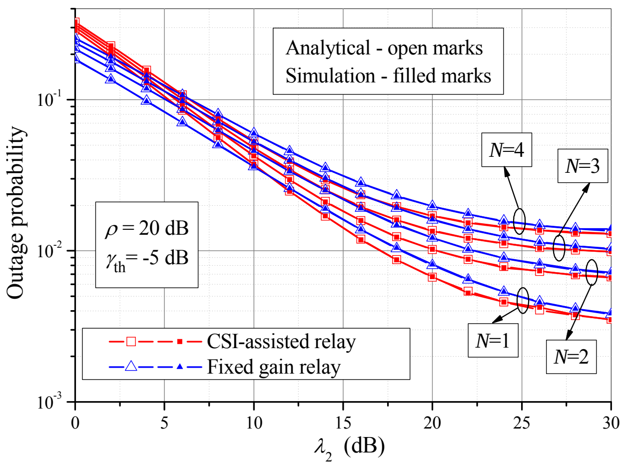

Fig. 3. Outage probability for various number of interferences

Fig. 3. shows the outage performance for different number of interferences. As the number of interference increases, the outage probability also increases, which degrades the system performance. The largest performance degradation is present when the number of interferences increases from one to two.

Numerical results obtained by analytical approach are verified by Monte Carlo simulations. The simulation values of outage probability are determined on the basis of 10^7 samples. It is clear from the figure that curves are essentially indistinguishable.

Conclusion

We have analysed the outage performance of dual-hop semi-blind relaying transmission in the presence of interferences at the relay. New closed-form expressions have been derived for gain of semi-blind relay and for outage probability of end-to-end SINR over Rayleigh fading channels. The analytical results have been compared with the available results for CSI-assisted relay under the same conditions and with simulation results. Considering the higher complexity nature of CSI-based relays, our results show that semi-blind relays may serve as an efficient replacement in relayed transmission when interferences are present at the relay. This results can be used in design of a cellular mobile system to determine optimal values of the outage threshold and interference suppression in order to achieve reasonable outage performance.

REFERENCES

[1] Hasna M.O., Alouini, M.-S., Outage probability of multihop transmission over Nakagami fading channels, *IEEE Communications Letters*, 7 (2003), No. 5, 216-218.

[2] Tsiftsis T.A., Karagiannidis G.K., Mathiopoulos P.T., Kotsopoulos S.A., Nonregenerative Dual-Hop Cooperative Links with Selection Diversity, *EURASIP Journal on Wireless Communication and Networking*, 2006 (2006),1-8

[3] Hasna M.O., Alouini, M.-S., A performance study of dual-hop transmissions with fixed gain relay, *IEEE Transactions on Wireless Communications*, 3 (2004), No. 6, 1963-1968

[4] Karagiannidis G.K., Performance bounds of multihop wireless communications with blind relays over generalized fading channels, *IEEE Transactions on Wireless Communications*, 5 (2006), No. 3, 498-503

[5] Simon M.K., Alouini, M.-S., *Digital Communication Over Fading Channels*, Wiley, New York, 2000.

[6] Suraweera H.A., Garg H.K., Nallanathan A., Performance Analysis of Two Hop Amplify-and-Forward Systems with Interference at the Relay, *IEEE Communications Letters*, 14 (2010), No. 8, 692-694

[7] Zhong C., Jin S., Wong K.-K., Dual-hop systems with noisy relay and interference-limited destination, *IEEE Transactions on Communications*, 58 (2010), No. 3, pp. 764-768

[8] Cvetković A.M., Đorđević G.T., Stefanović M.Č., Performance of interference-limited dual-hop non-regenerative relays over Rayleigh fading channel, *IET Communication*, 5 (2011), No. 2, 135–140

[9] Proakis J.G., *Digital communications*, McGraw-Hill, New York, 2001, 4th edn.

[10] Gradshteyn I.S., Ryzhik, I.M., *Table of Integrals, Series, and* Products, Academic Press, Orlando, 1994, 5th edn.

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