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Outage Probability of Dual-Hop CSI-assisted Relay Systems over Rayleigh/Nakagami-*m* Fading Channels with Interferences at the Relay

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Introduction

Dual-hop relaying technology is a well-known technique that has a number of advantages when compared to traditional communication networks. This technology is frequently used when the direct link between the source terminal and the destination terminal is in deep fade. Dual-hop transmission systems, depending on the nature and complexity of the relays used for system nodes, can be classified into two dominant categories: regenerative or decode-and-forward (DF) and nonregenerative or amplify-and-forward (AF) systems [1]. Regenerative systems have nodes that use relays when decoding the signal that propagates through the first hop, retransmitting decoded version into the second hop. Nonregenerative systems have nodes with relays which simply amplify and forward the incoming signal to the next node without performing any decoding at all. There are two types of AF relays: channel state information (CSI)-assisted relays and fixed-gain relays. The CSI-assisted relays have variable gain and require knowledge of instantaneous CSI from the previous hop to produce their gain leading to a power control of the retransmitted signal. Fixed-gain relays only require long-term statistics of the channel, which introduce a fixed gain and a variable signal power at the output, but lower complexity compared to CSI-assisted relays [1, 2].

Co-channel interference (CCI) is an important issue and should be taken in consideration. Consideration of CCI is necessary because of the aggressive reuse of frequency channels for high spectrum utilization in cellular systems [3–5]. In few published works, the impact of interference on the AF and the DF relaying performance have been investigated either at the relay(s) and/or the destination(s) [6–8]. In [6], the performance of a two hop CSI-assisted AF system with CCI at the relay over Rayleigh fading was analyzed. Analytical closed-form expressions for outage probability of dual-hop AF and DF systems over channel where relay is effected by an additive white Gaussian noise (AWGN) and destination by CCI were derived in [7]. The paper [8] studies the outage probability of both types of the AF relays over Rayleigh fading channels in an interference-limited environment (the relay and destination nodes are corrupted by CCI).

In this paper, we focus on dual-hop AF relay transmission systems and study their performance over mixed Rayleigh and Nakagami-*m* fading channels in the presence of co-channel interferences at the relay. In practice, different links in relay networks can experience separate fading conditions. Base station-relay link is considered as Rayleigh, while the relay-mobile link is observed as Nakagami-*m* link because of a better fading condition. In the following analysis, we assume that there are multiple Nakagami-*m* interferers at the relay node independent of the desired signal. Closed-form expression for the outage probability of the end-to-end signal-to-interference and noise ratio (SINR) for CSI-assisted relayed systems is derived for integer values of Nakagami-*m* fading parameter on the second hop.

System model

We consider a dual-hop system, as shown in Fig. 1. Transmission from the source terminal S to the destination terminal D is assisted by a nonregenerative CSI-assisted relay. The relay terminal R is corrupted by co-channel interferences and AWGN while destination terminal is only perturbed by an AWGN.

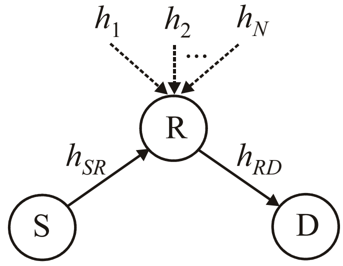

Fig. 1. System model

We assume that terminal S transmits a desired symbol, s_0, with an average power $\mathrm{E}\left[|s_0|^2\right] = P_0$ (E[.] is the expectation operator). The level of co-channel interference at the relay is high enough compared to the level of thermal noise, so the thermal noise can be neglected as in all interference-limited fading environments.

The received signal at relay terminal R, in interference-limited fading environment, can be written as

$$r_R = h_{SR} s_0 + \sum_{i=1}^{N} h_i s_i \,, \tag{1}$$

where h_{SR} is the fading amplitude of the channel between terminals S and R, $\{h_i\}_{i=1}^{N}$ are amplitudes of the interferers at the input of R and $\{s_i\}_{i=1}^{N}$ are interfering symbols with an average power P_i each of them. In nonregenerative systems, the signal r_R is then multiplied by the gain G of terminal R and retransmitted to terminal D effected by an AWGN. The received signal at terminal D can be presented as

$$r_D = h_{RD} G\left(h_{SR} s_0 + \sum_{i=1}^{N} h_i s_i \right) + n_D \,, \tag{2}$$

where h_{RD} is the fading amplitude of the channel between terminals R and D, and n_D is the AWGN at the input of D with $\mathrm{E}\left[|n_D|^2\right] = \sigma_D^2$.

The overall SINR at the receiving end can be expressed as [6]

$$\gamma_{eq} = \frac{|h_{SR}|^2 |h_{RD}|^2 G^2 P_0}{|h_{RD}|^2 G^2 \sum_{i=1}^{N} |h_i|^2 P_i + \sigma_D^2} = \frac{|h_{SR}|^2 P_0 \dfrac{|h_{RD}|^2 P_R}{\sigma_D^2}}{\dfrac{|h_{RD}|^2 P_R}{\sigma_D^2} \sum_{i=1}^{N} |h_i|^2 P_i + \dfrac{P_R}{G^2}} \,, \tag{3}$$

where P_R is the power of the transmitted signal at the output of the relay.

When terminal R has available instantaneous CSI from the first hop, the gain G is given by

$$G^2 = \frac{P_R}{|h_{SR}|^2 P_0 + \sum_{i=1}^{N} |h_i|^2 P_i} \,. \tag{4}$$

In this case instantaneous end-to-end SINR can be obtained by substituting (4) in (3) and can be written as

$$\gamma_{eq1} = \frac{\gamma_1 \gamma_2}{\gamma_3(\gamma_2 + 1) + \gamma_1} \,, \tag{5}$$

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

We consider Rayleigh fading scenario of the $S-R$ and Nakagami-m fading scenario $R-D$ links. If a link experiences Rayleigh fading, γ_1 are exponential distributed by probability density function (PDF) given by

$$p_{\gamma_1}(\gamma) = \frac{1}{\bar{\gamma}_1} \exp\left(-\frac{\gamma}{\bar{\gamma}_1} \right), \tag{6}$$

where $\bar{\gamma}_1 = \mathrm{E}\left[|h_{SR}|^2\right] P_0$ is the average signal power of $S-R$ channel.

If a link experiences Nakagami-m fading, γ_2 are Gamma distributed by probability density function (PDF) given by

$$p_{\gamma_2}(\gamma) = \left(\frac{m_2}{\bar{\gamma}_2} \right)^{m_i} \frac{1}{\Gamma(m_2)} \gamma^{m_2 - 1} \exp\left(-\frac{m_2}{\bar{\gamma}_2} \gamma \right), \tag{7}$$

where $\bar{\gamma}_2 = \mathrm{E}\left[|h_{RD}|^2\right] P_2 / \sigma_D^2$ is the average SNR per hop of $R-D$ channel. We assume that co-channel interference fading amplitudes are also modeled as Nakagami-m random processes. When all N interferers are identical, γ_3 has the PDF

$$p_{\gamma_3}(\gamma) = \left(\frac{m_3}{\bar{\gamma}_3} \right)^{m_3 N} \frac{1}{\Gamma(m_3 N)} \gamma^{m_3 N - 1} \exp\left(-\frac{m_3}{\bar{\gamma}_3} \gamma \right), \tag{8}$$

where $\bar{\gamma}_3 = \mathrm{E}\left[|h_i|^2\right] P_i$, i=1,2,...N, is the average power of each CCI. For the calculation of overall SINR is necessary to know the CDF of γ_1

$$P_{\gamma_1}(\gamma) = 1 - \exp\left(-\frac{\gamma}{\bar{\gamma}_1} \right). \tag{9}$$

Outage probability

Outage probability is one of the accepted performance measures for wireless systems over fading channels. This performance measure is very useful in communication system design, especially in the cases where co-channel interference is present. Roundly speaking for this case, outage probability is defined as probability that the instantaneous equivalent SINR, falls below a predetermined protection ratio. Above this protection value, the quality of service is satisfactory.

In the case of CSI-assisted relay transmission, the outage probability of instantaneous end-to-end SINR is given by [4]

$$\begin{aligned} P_{eq}(\gamma_{th}) &= \Pr(\gamma_{eq} < \gamma_{th}) = \\ &= \int_0^\infty \int_0^\infty P_{\gamma_1}\left(\frac{\gamma_1 \gamma_2}{\gamma_3(\gamma_2 + 1) + \gamma_1} \le \gamma_{th} \middle| \gamma_2, \gamma_3 \right) p_{\gamma_2}(\gamma_2) p_{\gamma_3}(\gamma_3) \mathrm{d}\gamma_2 \mathrm{d}\gamma_3 = \\ &= \int_0^\infty \int_0^\infty P_{\gamma_1}\left(\gamma_1 \le \frac{\gamma_{th}(y+1) z}{y - \gamma_{th}} \right) p_{\gamma_2}(y) p_{\gamma_3}(z) \mathrm{d}y \mathrm{d}z \,. \end{aligned} \tag{10}$$

Substituting (7), (8) and (9) in (10) the outage probability is

$$\begin{aligned} P_{eq}(\gamma_{th}) &= 1 - \frac{\exp\left(-\dfrac{m_2}{\bar{\gamma}_2} \gamma_{th} \right)}{\Gamma(m_2) \Gamma(m_3 N)} \left(\frac{m_2}{\bar{\gamma}_2} \right)^{m_2} \left(\frac{m_3}{\bar{\gamma}_3} \right)^{m_3 N} \times \\ &\times \int_0^\infty \int_0^\infty \exp\left(-\frac{1}{\bar{\gamma}_1} \frac{\gamma_{th}(y + \gamma_{th} + 1) z}{y} \right) (x + \gamma_{th})^{m_2 - 1} z^{m_3 N - 1} \times \\ &\times \exp\left(-\frac{m_2}{\bar{\gamma}_2} y \right) \exp\left(-\frac{m_3}{\bar{\gamma}_3} z \right) \mathrm{d}y \mathrm{d}z \,. \end{aligned} \tag{11}$$

To evaluate the integration of (11) we assumed integer fading parameter on the second hop, m_2, and we derived closed-form analytical expression for the outage probability of SINR. For solving the integral (11) in closed-form it is necessary that the parameter m_2 has integer values which allows us to use the series representation of binomial formula [9, eq. 1.111]. For non integer values of m_2, outage probability can be calculated from (11)

$$P_{eq}(\gamma_{th}) = 1 - \frac{\exp\left(-\frac{m_2}{\bar{\gamma}_2}\gamma_{th}\right)}{\Gamma(m_2)}\left(\frac{m_2}{\bar{\gamma}_2}\right)^{m_2} \times$$
$$\times \left(\frac{m_3\bar{\gamma}_1}{\bar{\gamma}_3\gamma_{th}(\gamma_{th}+1)}\right)^{m_3N} \sum_{i=0}^{m_2-1}\binom{m_2-1}{i}\gamma_{th}^{m_2-i-1} \times$$
$$\times \Gamma(m_3N+i+1)\left(\frac{\bar{\gamma}_3\gamma_{th}(\gamma_{th}+1)}{\bar{\gamma}_3\gamma_{th}+m_3\bar{\gamma}_1}\right)^{m_3N+i+1} \times$$
$$\times U\left(m_3N+i+1, i+2, \frac{m_2\bar{\gamma}_3\gamma_{th}(\gamma_{th}+1)}{\bar{\gamma}_2(\bar{\gamma}_3\gamma_{th}+m_3\bar{\gamma}_1)}\right). \qquad (12)$$

Eq. (12) can be reduced to the previously published result presented in [6] for the case of Rayleigh fading channels. Substituting the parameters m_2=m_3=1 in (12), we get (13) in [6].

Numerical results

Outage probability, as a function of average SNR of $R-D$ channel $\bar{\gamma}_2$ for various values of ρ, where $\rho = \bar{\gamma}_1 / \bar{\gamma}_3$, is presented in Fig. 2. for different outage threshold. It is observed that as γ_{th} increases, the outage probability also increases. Improving the second hop condition by increasing average SNR, does not contribute to performance gain above some particular values of average SNR. For high second hop SNR, there are outage floors depending on outage threshold values.

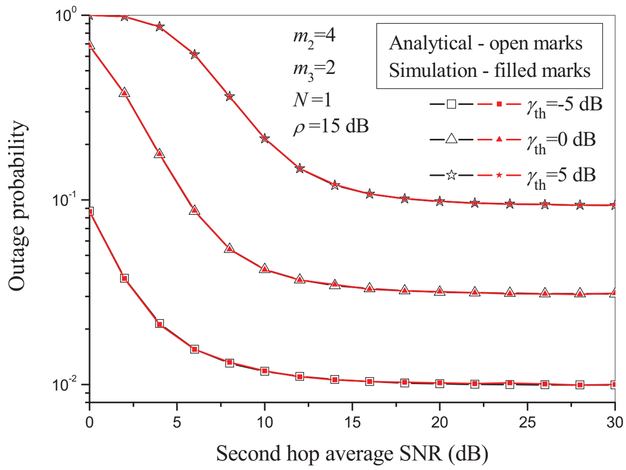

Fig. 2. Outage probability for various values of outage threshold

Fig. 3. depicts the outage performance for various values of the second hop Nakagami-*m* fading parameter. This fading parameter affects the outage performance i.e. outage probability decreases as m_2 increases. The improvement in performance is the greatest when Rayleigh fading (m_2=1) changes in Nakagami-*m* fading, with parameter m_2=2. It is noticeable that for particular values of average SNR, values of the outage probability tend to irreducible outage floor. We can also see that outage floor does not depend on fading parameter of the second hop, but only on the first hop average SIR. Increasing the SNR value of the second hop does not contribute reducing outage probability at high range of average SNR.

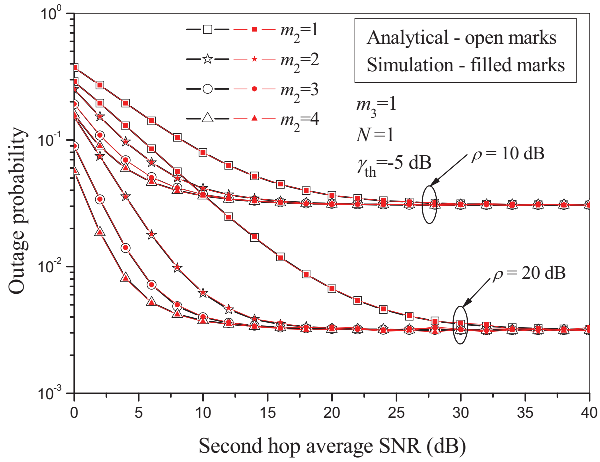

Fig. 3. Outage probability for various fading parameter

Fig. 4. shows the outage performance for different number of interferences. As the number of interference increases, outage probability increases, which degrades the system performance. The largest performance degradation is present when the number of CCI increases from one to two. At lower values of average second hop SNR, outage probability decreases with increasing SNR. But, above 10 dB of average SNR, further improvement of SNR does not affect the system performance.

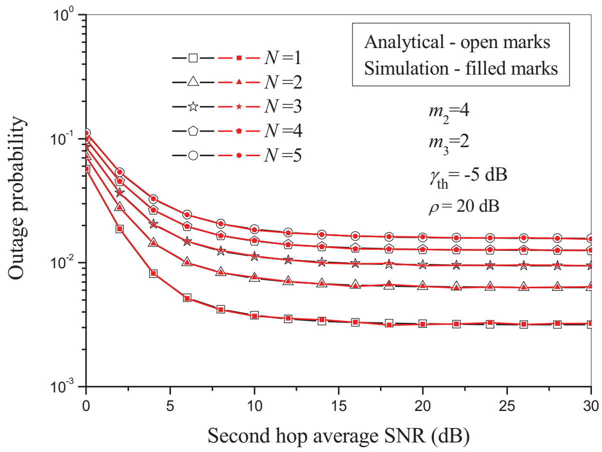

Fig. 4. Outage probability for various number of co-channel interferences

Numerical results obtained by the analytical approach are confirmed by simulation results. Monte Carlo simulations for Nakagami-*m* fading channels is assisted on paper [10]. The values of the outage probability are calculated based on over 10^7 Nakagami-*m* fading samples. Fig. 2–Fig. 4 contain both analytical and simulation results, and it is easily recognized that there is an excellent match between them.

Due to the outage floor we can conclude that the increasing relay power does not always have impact to the reduction of the outage probability. 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.

Conclusions

We have derived the closed-form expression for the outage probability of the instantaneous SINR for dual-hop transmission with CSI-assisted relays operating over Rayleigh and Nakagami-*m* fading channels. Effects of the outage threshold, co-channel interferers and various values of Nakagami-*m* fading parameter on the performance gain were presented. This performance analysis and results can be used in design of a cellular mobile system to determine optimal values of system parameters in order to achieve reasonable influence of interferers and noise on the outage.

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This paper studies the performance of a dual-hop amplify-and-forward system where the source-relay and the relay-destination channels experience Rayleigh and Nakagami-*m* fading, respectively. The relay node is corrupted by Nakagami-*m* faded multiple co-channel interferences while destination node is perturbed by only an additive white Gaussian noise. New closed-form expression for the outage probability of the end-to-end signal-to-interference and noise ratio (SINR) is derived for integer value of fading parameter on the second hop. The results of this paper show influence of the outage threshold, co-channel interferers and various values of fading parameter on the system performance. Numerical results obtained by analytical approach are verified by Monte Carlo simulations. Ill. 4, bibl. 10 (in English; abstracts in English and Lithuanian).

A. M. Cvetkovic, M. C. Stefanovic. Dvigubo perėjimo KBI relinių sistemų per Reilėjaus ir Nakagami-m slopinimo kanalus su interferencija relėje prastovos tikimybė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 6(122). – P. 97–100.

Nagrinėjamas dvigubo perėjimo stiprinimo ir siuntimo sistemų, kurių šaltinio relės ir paskirties relės kanaluose pasireiškia atitinkamai Reilėjaus ir Nakagami-*m* slopinimai, našumas. Relinis mazgas yra veikiamas Nakagami-*m* daugybinių tarpkanalinių interferencijų, o paskirties mazgas trikdomas tik baltojo triukšmo. Išvesta prastovos tikimybės išraiška slopinimo parametro reikšmei antrajame perėjime. Rezultatai rodo prastovos lygio, tarpkanalinių trikdžių ir įvairių slopinimo parametro verčių įtaką sistemos našumui. Analitiškai gauti rezultatai patikrinti naudojant Monte Karlo modeliavimą. Il. 4, bibl. 10 (anglų kalba; santraukos anglų ir lietuvių k.).