

The influence of hardware impairment on the system performance of two-way relaying network

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ABSTRACT

In this research, the system performance of the half-duplex two-way relay network under hardware impairment condition is presented and investigated. In this system model, the time switching protocol and amplify-and-forward (AF)-based are considered. First, of all, the analytical expressions of the outage probability, and achievable throughput with the exact closed form and asymptotic form were proposed and derived. Furthermore, the research results are obtained and convinced by Monte-Carlo calculation. The numerical results demonstrated and convinced the analytical and the simulation results are agreed for all possible system parameters.

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1. INTRODUCTION

Generally, one-way relaying network with one-way information transmission is the typical way to improve the system performance regarding coverage, throughput, and reliability [1-3]. Regularly, bidirectional information transmission between source and destination nodes via a relay in the relaying network requires four channels. On another hand, this information can be exchanged efficiently by two channel over two-way relaying networks. In such this relay network, the bidirectional information-transmission are proposed. From that point of view, the spectral efficiency of two-way relay network is twice that of the one-way relay network. According to the massive improvements, the two-way relaying network has been considered as a next-generation wireless communication network [4-7].

In the last decades, many works focus on the system performance of the two-way relay network. In common, the outage probability for the two-way relaying network has been investigated in details in [8, 9] with the Rayleigh and in [10, 11] with the Nakagami- m fading channels. Moreover, the outage performance of the two-way relaying network with outdated channel state information is proposed in [12] over a Rayleigh fading channel and is extended to multi-user, multi-relay in [13, 14]. As far as authors' knowledge, there are not many works to concentrate on the system performance analysis of the two-way amplify-and-forward (AF)-based relay network over the Rician fading channels in the influence of the hardware impairment yet. It is the remaining gap could be filled in by this research.

In this research, the system performance analysis of the half-duplex two-way relaying network under hardware impairment over the Rician fading channels is proposed in details. For this purpose, the exact closed-form and the asymptotic expressions of the achievable throughput, outage probability of the model system were introduced and derived. Furthermore, the analytical results could be demonstrated and convinced by Monte-Carlo simulation with helping Mat Lab software. The research results show that the analytical and simulated results are agreed for all proposed system parameters. The research results provided the practical solution for the progress of the WPCN. Here, we can recommend the main contributions of the paper as follows:

- The system model of the half-duplex two-way relay network under hardware impairment over the Rician fading channels is proposed.
- The exact closed-form and asymptotic expressions of the throughput, and the outage probability proposed system is derived.
- The influence of hardware impairment on system performance is demonstrated entirely.

The remaining of this paper is proposed as follows. Sections II presents the proposed system model. Sections III introduces and demonstrates the analytical expressions of the throughput and outage probability of the proposed system. Section IV gives numerical results and some discussions. Finally, Section V concludes the paper.

2. SYSTEM MODEL AND SYSTEM PERFORMANCE ANALYSIS

Figure 1 presents the system model of the half-duplex two-way relay network under hardware impairment. In Figure 1, the information is transferred between the nodes S1 and S2, through an intermediate relay (R). The information processing at the relay is proposed in Figure 2 with T is the block time. In this proposed system model, the nodes S1, S2 transfer information signal to the relay node R in the first interval time $T/2$, then the relay R transfers the information signal back to the nodes S1, S2 in the remaining interval time $T/2$ [15, 16].

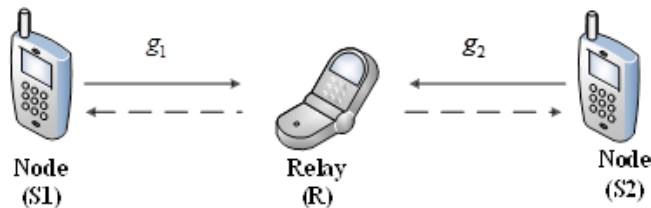


Figure 1. System model

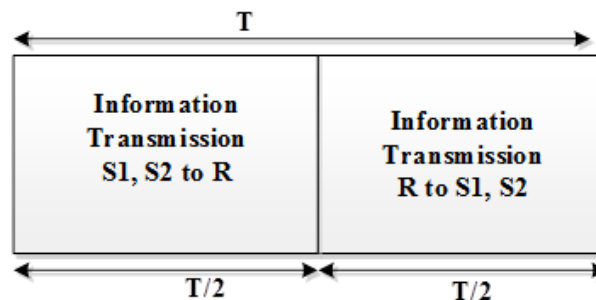


Figure 2. The energy harvesting and information processing

In this section, a three-node relaying network is considered. In this model, each node operates in half-duplex mode and has a single antenna. In this network, two nodes S1 and S2 have no direct connection and communicate with each other via the help of relay R over Rician fading channels. In the first interval time $T/2$, both nodes S1 and S2 simultaneously transfer their signal to relay node R. The received signal at the relay node R can be calculated as the following:

$$y_r = \sum_{i=1}^2 g_i (s_i + \eta_i) + n_r, \quad i=1, 2 \tag{1}$$

where $E[|s_i|^2] = P_i$, S_i : transmit signal at node I, P_i : transmit power at the node I, η_i denotes the distortion noise with zero mean and variance $\kappa_i^2 P_i$, κ_i is the aggregate level of impairments of the channel, and n_r is the additive white Gaussian noise (AWGN) at R with zero mean and variance σ_r^2 .

The received signal of node S_i from R can be given by:

$$y_i = g_i (r + \eta_r) + n_i, \quad i=1, 2 \tag{2}$$

where r is the transmit signal at R, η_r denotes the distortion noise with zero mean and variance $\kappa_r^2 P_r$, n_i is the additive white Gaussian noise (AWGN) at S_i with zero mean and variance σ_i^2 , and κ_r is the aggregate level of impairments of the channel.

In this analysis amplify factor can be formulated as the following:

$$\beta = \frac{r}{y_r} = \sqrt{\frac{P_r}{\varphi_1 P_1 + \varphi_1 P_1 \kappa_1^2 + \varphi_2 P_2 + \varphi_2 P_2 \kappa_2^2 + \sigma_r^2}} \tag{3}$$

Where $\varphi_i = |g_i|^2$ denotes the channel gain between nodes S_i and relay R.

2.1. The exact analysis

In this proposed system, because of the symmetry of S1 and S2, we first provide the expression of the y_1 :

$$y_1 = g_1 (r + \eta_r) + n_1 = g_1 (\beta y_r + \eta_r) + n_1 \tag{4}$$

By substituting (1) and (2) into (4), we obtain:

$$y_1 = \beta |g_1|^2 s_1 + \beta |g_1|^2 \eta_1 + \beta |g_1| |g_2| s_2 + \beta |g_1| |g_2| \eta_2 + \beta |g_1| n_r + |g_1| \eta_r + n_1 \tag{5}$$

S_1 wants to extract s_2 from y_1 . Since it knows its transmitted symbol s_1 , it can correctly eliminate the similar self-interference term $\beta |g_1|^2 s_1$.

From (5), we can rewrite:

$$y_1 = \underbrace{\beta |g_1| |g_2| s_2}_{\text{signal}} + \underbrace{\beta |g_1|^2 \eta_1 + \beta |g_1| |g_2| \eta_2 + \beta |g_1| n_r + |g_1| \eta_r + n_1}_{\text{noise}} \tag{6}$$

Therefore, the end to end signal to noise ratio (SNR) at S_1 for detection of the symbol y_1 is given by [1]:

$$\gamma_1 = \frac{E\{|signal|^2\}}{E\{|noise|^2\}} = \frac{\beta^2 |g_1|^2 |g_2|^2 P_2}{\beta^2 |g_1|^4 P_1 \kappa_1^2 + \beta^2 |g_1|^2 |g_2|^2 P_2 \kappa_2^2 + \beta^2 |g_1|^2 \sigma_r^2 + |g_1|^2 P_r \kappa_r^2 + \sigma_1^2} \tag{7}$$

After doing some algebra, we obtain the final expression for γ_1 :

$$\gamma_1 = \frac{\varphi_1 \varphi_2}{\varphi_1 \varphi_2 A_1 + \varphi_1^2 B_1 + \varphi_1 C_1 + \varphi_2 D_1 + E_1} \tag{8}$$

where we denote:

$$A_1 = \kappa_2^2 + \kappa_r^2(1 + \kappa_2^2), B_1 = \{\kappa_1^2 + \kappa_r^2(1 + \kappa_1^2)\} \frac{P_1}{P_2}$$

$$C_1 = \frac{\sigma_r^2}{P_2} + (1 + \kappa_1^2) \frac{P_1 \sigma_1^2}{P_r P_2} + \kappa_r^2 \frac{\sigma_r^2}{P_2}$$

$$D_1 = (1 + \kappa_2^2) \frac{\sigma_1^2}{P_r}, E_1 = \frac{\sigma_r^2 \sigma_1^2}{P_r P_2}$$

By the same way, the end to end signal to noise ratio (SNR) of y_2 is also given by the following:

$$\gamma_2 = \frac{\varphi_1 \varphi_2}{\varphi_1 \varphi_2 A_2 + \varphi_2^2 B_2 + \varphi_2 C_2 + \varphi_1 D_2 + E_2} \tag{9}$$

where we denote:

$$A_2 = \kappa_1^2 + \kappa_r^2(1 + \kappa_1^2), B_2 = \{\kappa_2^2 + \kappa_r^2(1 + \kappa_2^2)\} \frac{P_2}{P_1}$$

$$C_2 = \frac{\sigma_r^2}{P_1} + (1 + \kappa_2^2) \frac{P_2 \sigma_2^2}{P_r P_1} + \kappa_r^2 \frac{\sigma_r^2}{P_1}, D_2 = (1 + \kappa_1^2) \frac{\sigma_2^2}{P_r}, E_2 = \frac{\sigma_r^2 \sigma_2^2}{P_r P_1}$$

Theorem 1. The exact closed-form expression of the outage probability P_{out_1} and P_{out_2} at the source nodes S1, S2 of the proposed system could be calculated by the following:

$$P_{out_1} = 1 - 2a^2 e^{-b \left(\frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 + \frac{\gamma_{th} D_1}{\mathcal{G}_1} \right)}$$

$$\sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \sum_{v=0}^k \sum_{m=0}^l \sum_{n=0}^{m-n} \sum_{p=0}^{m-n} \frac{K^{l+k} b^{m+k-1} \gamma_{th}^{m+v} B_1^{m-n-p} \xi_1^n D_1^v}{l! n! v! p! k! (m-n-p)! (k-v)! \mathcal{G}_1^{p-m-v}}$$

$$\times \left(\frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 \right)^p \times \left(\frac{\xi_1}{B_1 + \mathcal{G}_1} \right)^{\frac{m-2n-p+k-v+1}{2}} \times K_{m-2n-p+k-v+1} \left(2 \frac{b}{\mathcal{G}_1} \sqrt{(B_1 + \mathcal{G}_1) \xi_1} \right) \tag{10}$$

$$P_{out_2} = 1 - 2a^2 e^{-b \left(\frac{B_2 \gamma_{th} D_2}{\mathcal{G}_2^2} + \theta_2 + \frac{\gamma_{th} D_2}{\mathcal{G}_2} \right)}$$

$$\sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \sum_{v=0}^k \sum_{m=0}^l \sum_{n=0}^{m-n} \sum_{p=0}^{m-n} \frac{K^{l+k} b^{m+k-1} \gamma_{th}^{m+v} B_2^{m-n-p} \xi_2^n D_2^v}{l! n! v! p! k! (m-n-p)! (k-v)! \mathcal{G}_2^{p-m-v}}$$

$$\times \left(\frac{B_2 \gamma_{th} D_2}{\mathcal{G}_2^2} + \theta_2 \right)^p \times \left(\frac{\xi_2}{B_2 + \mathcal{G}_2} \right)^{\frac{m-2n-p+k-v+1}{2}} \times K_{m-2n-p+k-v+1} \left(2 \frac{b}{\mathcal{G}_2} \sqrt{(B_2 + \mathcal{G}_2) \xi_2} \right) \tag{11}$$

Proof:

The probability density function (PDF) of a random variable (RV) φ_i where $i=1,2$ can be calculated as in [17].

$$f_{\varphi_i}(x) = \frac{(K+1)e^{-K}}{\lambda_i} e^{-\frac{(K+1)x}{\lambda_i}} I_0 \left(2 \sqrt{\frac{K(K+1)x}{\lambda_i}} \right) \tag{12}$$

In which λ_i is the mean value of RV φ_i which $i=1,2$ respectively. Moreover, K is the Rician K-factor defined as the ratio of the power of the line-of-sight (LOS) component to the separate components and $I_0(\bullet)$ is the zero-th order modified Bessel function of the first kind.

The (A1) can be rewritten as follow:

$$f_{\varphi_i}(x) = a \sum_{l=0}^{\infty} \frac{(bK)^l}{(l!)^2} x^l e^{-bx} \tag{13}$$

where we denote $a = \frac{(K+1)e^{-K}}{\lambda_i}, b = \frac{K+1}{\lambda_i}$ and $I_0(x) = \sum_{l=0}^{\infty} \frac{x^{2l}}{2^{2l} (l!)^2}$ [18].

The cumulative density function (CDF) of RV φ_i where $i=1,2$ can be computed as in [19] with $\lambda_1 = \lambda_2$:

$$F_{\varphi_i}(\zeta) = \int_0^{\zeta} f_{\varphi_i}(x) dx = 1 - \frac{a}{b} \sum_{l=0}^{\infty} \sum_{m=0}^l \frac{K^l b^m}{l! m!} \zeta^m e^{-b\zeta} \tag{14}$$

We have the outage probability at the source S1:

$$\begin{aligned} P_{out_1} &= F_{\gamma_1}(\gamma_{th}) = \Pr(\gamma_1 < \gamma_{th}) \\ &= \Pr\left(\frac{\varphi_1 \varphi_2}{\varphi_1 \varphi_2 A_1 + \varphi_1^2 B_1 + \varphi_1 C_1 + \varphi_2 D_1 + E_1} < \gamma_{th}\right) \end{aligned} \tag{15}$$

where $\gamma_{th} = 2^{2R} - 1$ and R is the source rate.

From (A4) we have:

$$\begin{aligned} &\Pr\left(\frac{\varphi_1 \varphi_2}{\varphi_1 \varphi_2 A_1 + \varphi_1^2 B_1 + \varphi_1 C_1 + \varphi_2 D_1 + E_1} < \gamma_{th}\right) \\ &= \Pr\left\{\varphi_2(\varphi_1 - \gamma_{th} \varphi_1 A_1 - \gamma_{th} D_1) < \gamma_{th} \varphi_1^2 B_1 + \gamma_{th} \varphi_1 C_1 + \gamma_{th} E_1\right\} \\ &= \left\{ \Pr\left\{\varphi_2 < \frac{\gamma_{th} \varphi_1^2 B_1 + \gamma_{th} \varphi_1 C_1 + \gamma_{th} E_1}{\varphi_1 - \gamma_{th} \varphi_1 A_1 - \gamma_{th} D_1}, \varphi_1 \geq \frac{\gamma_{th} D_1}{1 - \gamma_{th} A_1}\right\} \right. \\ &\quad \left. , \varphi_1 < \frac{\gamma_{th} D_1}{1 - \gamma_{th} A_1} \right\} \end{aligned} \tag{16}$$

In this analysis, we assume that $1 - \gamma_{th} A_1$ is positive because if it is negative then the probability is always equal 1. Furthermore:

$$\begin{aligned} P_{out_1} &= \int_{\frac{\gamma_{th} D_1}{1 - \gamma_{th} A_1}}^{\infty} F_{\varphi_2}\left(\frac{\gamma_{th} \varphi_1^2 B_1 + \gamma_{th} \varphi_1 C_1 + \gamma_{th} E_1}{\varphi_1 - \gamma_{th} \varphi_1 A_1 - \gamma_{th} D_1}\right) f_{\varphi_1} d\varphi_1 \\ &+ \int_0^{\frac{\gamma_{th} D_1}{1 - \gamma_{th} A_1}} f_{\varphi_1} d\varphi_1 \end{aligned} \tag{17}$$

$$\begin{aligned} P_{out_1} &= 1 - \int_{\frac{\gamma_{th} D_1}{1 - \gamma_{th} A_1}}^{\infty} \frac{a}{b} \sum_{l=0}^{\infty} \sum_{m=0}^l \frac{K^l b^m}{l! m!} \left(\frac{\gamma_{th} \varphi_1^2 B_1 + \gamma_{th} \varphi_1 C_1 + \gamma_{th} E_1}{\varphi_1 - \gamma_{th} \varphi_1 A_1 - \gamma_{th} D_1}\right)^m \\ &\quad \times e^{-b\left[\frac{\gamma_{th} \varphi_1^2 B_1 + \gamma_{th} \varphi_1 C_1 + \gamma_{th} E_1}{\varphi_1 - \gamma_{th} \varphi_1 A_1 - \gamma_{th} D_1}\right]} \times a \sum_{l=0}^{\infty} \frac{(bK)^l}{(l!)^2} \varphi_1^l e^{-b\varphi_1} d\varphi_1 \end{aligned} \tag{18}$$

Here, we consider:

$$\begin{aligned} I &= \frac{\varphi_1^2 B_1 + \varphi_1 C_1 + E_1}{\varphi_1 - \gamma_{th} \varphi_1 A_1 - \gamma_{th} D_1} = \frac{\varphi_1^2 B_1 + \varphi_1 C_1 + E_1}{\vartheta_1 \varphi_1 - \gamma_{th} D_1} = \frac{B_1 \varphi_1}{\vartheta_1} + \frac{C_1}{\vartheta_1} + \frac{\gamma_{th} B_1 D_1}{\vartheta_1^2} \\ &+ \frac{E_1 + \gamma_{th} D_1 \left(\frac{C_1}{\vartheta_1} + \frac{\gamma_{th} B_1 D_1}{\vartheta_1^2}\right)}{\vartheta_1 \varphi_1 - \gamma_{th} D_1} = \frac{B_1 \varphi_1}{\vartheta_1} + \theta_1 + \frac{\xi_1}{\vartheta_1 \varphi_1 - \gamma_{th} D_1} \end{aligned} \tag{19}$$

In which we denote $\vartheta_1 = 1 - \gamma_{th} A_1$, $\theta_1 = \frac{C_1}{\vartheta_1} + \frac{\gamma_{th} B_1 D_1}{\vartheta_1^2}$, $\xi_1 = E_1 + \gamma_{th} D_1 \left(\frac{C_1}{\vartheta_1} + \frac{\gamma_{th} B_1 D_1}{\vartheta_1^2}\right)$.

After that, the (A7) can be rewritten as the following:

$$P_{out_1} = 1 - \int_0^{\frac{\gamma_{th} D_1}{1-\gamma_{th} A_1}} \frac{a}{b} \sum_{l=0}^{\infty} \sum_{m=0}^l \frac{K^l b^m \gamma_{th}^m}{l! m!} \left(\frac{B_1 \varphi_1}{\mathcal{G}_1} + \theta_1 + \frac{\xi}{\mathcal{G}_1 \varphi_1 - \gamma_{th} D_1} \right)^m \times a \sum_{l=0}^{\infty} \frac{(bK)^l}{(l!)^2} \varphi_1^l e^{-b\varphi_1} d\varphi_1 \tag{20}$$

By changing variable $t = \mathcal{G}_1 \varphi_1 - \gamma_{th} D_1$ into the (A9), we have:

$$P_{out_1} = 1 - \int_0^{\frac{\gamma_{th} D_1}{1-\gamma_{th} A_1}} \frac{a^2}{b} \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \sum_{m=0}^l \frac{K^{l+k} b^{m+k} \gamma_{th}^m}{l! m! (k!)^2} \left(\frac{B_1 t}{\mathcal{G}_1^2} + \frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 + \frac{\xi}{t} \right)^m \times e^{-b \left[\frac{B_1 t}{\mathcal{G}_1^2} + \frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 + \frac{\xi}{t} \right]} \times \left(\frac{t + \gamma_{th} D_1}{\mathcal{G}_1} \right)^k e^{-b \left(\frac{t + \gamma_{th} D_1}{\mathcal{G}_1} \right)} \frac{dt}{\mathcal{G}_1} \tag{21}$$

Apply the equation $(x + y)^m = \sum_{n=0}^m \binom{m}{n} x^{m-n} y^n$ into (A10) we have:

$$P_{out_1} = 1 - \int_0^{\frac{\gamma_{th} D_1}{1-\gamma_{th} A_1}} \frac{a^2}{b} \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \sum_{m=0}^l \frac{K^{l+k} b^{m+k} \gamma_{th}^m}{l! m! (k!)^2} \sum_{n=0}^m \binom{m}{n} \left(\frac{B_1 t}{\mathcal{G}_1^2} + \frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 \right)^{m-n} \left(\frac{\xi}{t} \right)^n \times e^{-b \left[\frac{B_1 t}{\mathcal{G}_1^2} + \frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 + \frac{\xi}{t} \right]} \times \left(\frac{t + \gamma_{th} D_1}{\mathcal{G}_1} \right)^k \times e^{-b \left(\frac{t + \gamma_{th} D_1}{\mathcal{G}_1} \right)} \frac{dt}{\mathcal{G}_1} \tag{22}$$

$$P_{out_1} = 1 - \int_0^{\frac{\gamma_{th} D_1}{1-\gamma_{th} A_1}} \frac{a^2}{b} \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \sum_{m=0}^l \frac{K^{l+k} b^{m+k} \gamma_{th}^m}{l! m! (k!)^2} \sum_{n=0}^m \binom{m}{n} \sum_{p=0}^{m-n} \binom{m-n}{p} \left(\frac{B_1 t}{\mathcal{G}_1^2} \right)^{m-n-p} \times \left(\frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 \right)^p \left(\frac{\xi}{t} \right)^n \times e^{-b \left[\frac{B_1 t}{\mathcal{G}_1^2} + \frac{B_1 \gamma_{th} D_1}{\mathcal{G}_1^2} + \theta_1 + \frac{\xi}{t} \right]} \times \sum_{v=0}^k \binom{k}{v} \left(\frac{t}{\mathcal{G}_1} \right)^{k-v} \left(\frac{\gamma_{th} D_1}{\mathcal{G}_1} \right)^v \times e^{-b \left(\frac{t + \gamma_{th} D_1}{\mathcal{G}_1} \right)} \frac{dt}{\mathcal{G}_1} \tag{23}$$

By doing some substitution and using equation [3.471,9] in [18], we can obtain the (10). In which, $K_\nu(\bullet)$ is the modified Bessel function of the second kind and ν^{th} order.

Similarity we can formulate (11). In which, we denote:

$$\mathcal{G}_2 = 1 - \gamma_{th} A_2, \theta_2 = \frac{C_2}{\mathcal{G}_2} + \frac{\gamma_{th} B_2 D_2}{\mathcal{G}_2^2}, \xi_2 = E_2 + \gamma_{th} D_2 \left(\frac{C_2}{\mathcal{G}_2} + \frac{\gamma_{th} B_2 D_2}{\mathcal{G}_2^2} \right)$$

2.2. Asymptotic analysis

In this section, the asymptotic outage probability at high SNRs is proposed and investigated. In this case, we assume that $P_1 = P_2 = \varepsilon P_r$ ($\varepsilon > 0$) (without significant loss of generality). Then we have:

$$\beta_\infty = \frac{r}{\gamma_r} = \sqrt{\frac{P_r}{\varphi_1 P_1 + \varphi_1 P_1 \kappa_1^2 + \varphi_2 P_2 + \varphi_2 P_2 \kappa_2^2 + \sigma_r^2}} = \frac{1}{\sqrt{\varepsilon \varphi_1 (1 + \kappa_1^2) + \varepsilon \varphi_2 (1 + \kappa_2^2)}} \tag{24}$$

Moreover, the SNR in (7) and (8) can be rewritten as (25) and (26), respectively.

$$\gamma_1^\infty = \frac{\varphi_2}{A_1 \varphi_2 + B \varphi_1} \tag{25}$$

$$\gamma_2^\infty = \frac{\varphi_1}{A_2 \varphi_1 + C \varphi_2} \tag{26}$$

Where we denote $A_1 = \kappa_2^2 + \kappa_r^2(1 + \kappa_2^2)$, $B = \kappa_1^2 + \kappa_r^2(1 + \kappa_1^2) \frac{\sigma_2^2}{\sigma_1^2}$, $A_2 = \kappa_1^2 + \kappa_r^2(1 + \kappa_1^2)$, and $C = \kappa_2^2 + \kappa_r^2(1 + \kappa_2^2) \frac{\sigma_1^2}{\sigma_2^2}$.

Theorem 2. *The asymptotic expression of the outage probability P_{out_1} and P_{out_2} at the source nodes S1, S2 of the proposed system could be calculated by the following:*

$$P_{out_1}^\infty = 1 - a^2 \sum_{l=0}^\infty \sum_{k=0}^\infty \sum_{m=0}^l \frac{K^{l+k} b^{m+k-1} (m+k)!}{l! m! (k!)^2} \left(\frac{\gamma_{th} B}{1 - \gamma_{th} A_1} \right)^m \times \left[\frac{b \gamma_{th} B}{1 - \gamma_{th} A_1} + b \right]^{-m-k-1} \tag{27}$$

$$P_{out_2}^\infty = 1 - a^2 \sum_{l=0}^\infty \sum_{k=0}^\infty \sum_{m=0}^l \frac{K^{l+k} b^{m+k-1} (m+k)!}{l! m! (k!)^2} \left(\frac{\gamma_{th} C}{1 - \gamma_{th} A_2} \right)^m \times \left[\frac{b \gamma_{th} C}{1 - \gamma_{th} A_2} + b \right]^{-m-k-1} \tag{28}$$

Proof:

The asymptotic outage probability of the source node S1 can be formulated by the followings:

$$P_{out_1}^\infty = F_{\gamma_1^\infty}(\gamma_{th}) = \Pr(\gamma_1^\infty < \gamma_{th}) = \Pr\left(\frac{\varphi_2}{A_1 \varphi_2 + B \varphi_1} < \gamma_{th} \right) \tag{29}$$

$$P_{out_1}^\infty = \Pr[\varphi_2(1 - \gamma_{th} A_1) < \gamma_{th} B \varphi_1] = \Pr\left(\varphi_2 < \frac{\gamma_{th} B \varphi_1}{1 - \gamma_{th} A_1} \right) \tag{30}$$

Furthermore

$$P_{out_1}^\infty = \int_0^\infty F_{\varphi_2} \left(\frac{\gamma_{th} B \varphi_1}{1 - \gamma_{th} A_1} \right) f_{\varphi_1}(\varphi_1) d\varphi_1 \tag{31}$$

After that, we have:

$$P_{out_1}^\infty = 1 - a^2 \sum_{l=0}^\infty \sum_{k=0}^\infty \sum_{m=0}^l \frac{K^{l+k} b^{m+k-1}}{l! m! (k!)^2} \left(\frac{\gamma_{th} B}{1 - \gamma_{th} A_1} \right)^m \times \int_0^\infty \varphi_1^{m+k} \times e^{-b \left[\frac{\gamma_{th} B \varphi_1}{1 - \gamma_{th} A_1} + \varphi_1 \right]} d\varphi_1 \tag{32}$$

By using equation [3.351,3] in [18] we can obtain the (25). By the same way for the source node S2 we formulate the (26).

3. RESULTS AND DISCUSSION

In this section, some simulation results are proposed to investigate the system performances of the proposed network under hardware impairment over the Rician fading channels. Both in theoretical and Monte Carlo simulation results evaluate the system performance analysis. All system simulation parameters are presented in Table 1.

Table 1. Simulation parameters

Symbol	Name	Values
λ_1	Mean of $ g_1 ^2$	1
λ_2	Mean of $ g_2 ^2$	1
K	Rician K-factor	3
$P_1 = P_2 = P_r = P$	Source power to noise ratio	0-40dB
$\kappa_1 = \kappa_2 = \kappa_r = \kappa$	Hardware impairment levels	0-0.3
R	Source rate	1 bit/s/Hz

In this analysis, Figure 3a and 3b show the influence of K on the outage probability and throughput of the model system, respectively. In this simulation process, the main parameters of the proposed system are set as the following: $P=20$ dB, $\kappa_1=\kappa_2=\kappa_r=0; 0.15; 0.25$. Figure 3 shows that the outage probability decreased and the throughput increased crucially while K varied from 0 to 8. Moreover, the analytical results agree well with the Monte Carlo simulation results.

On another hand, Figure 4a and 4b illustrate the effect of κ on the outage probability and the achievable throughput of the model system. Here, $P_1=P_2=P_r=P$ is set at 15; 20; 25 dB. From the simulation, it is clear foud that the achievable throughput increases and the outage probability decrease significantly while $\kappa_1=\kappa_2=\kappa_r$ varies from 0 to 0.3. In these cases, the figures reveal that the simulation results match tightly with analytical expressions in section 3.

Moreover, Figure 5a and 5b present the effect of the P on the outage probability and the achievable throughput with $\kappa_1=\kappa_2=\kappa_r=0.1; 0.2$ for the proposed system. From the results, it is shown that the achievable throughput increases and the outage probability decreased significantly when the P increased from 0 to 40 dB. In these figures, all the analytical and the simulation results are the same values.

In the same way, the influence of the system rate R on the outage probability and the achievable throughput of the system model with $P=20$ dB and $\kappa_1=\kappa_2=\kappa_r=0.025; 0.05$ are illustrated in the Figure 6a and 6b. Figure 6a showed that the outage probability increases crucially with increasing the rate R. However, the system throughput only increased in the interval R from 0 to the optimal value around 2. After that, it significantly fell to 0 at the rate around 4. In particular, the simulation lines wholly matched with the analytical lines in all the above figures.

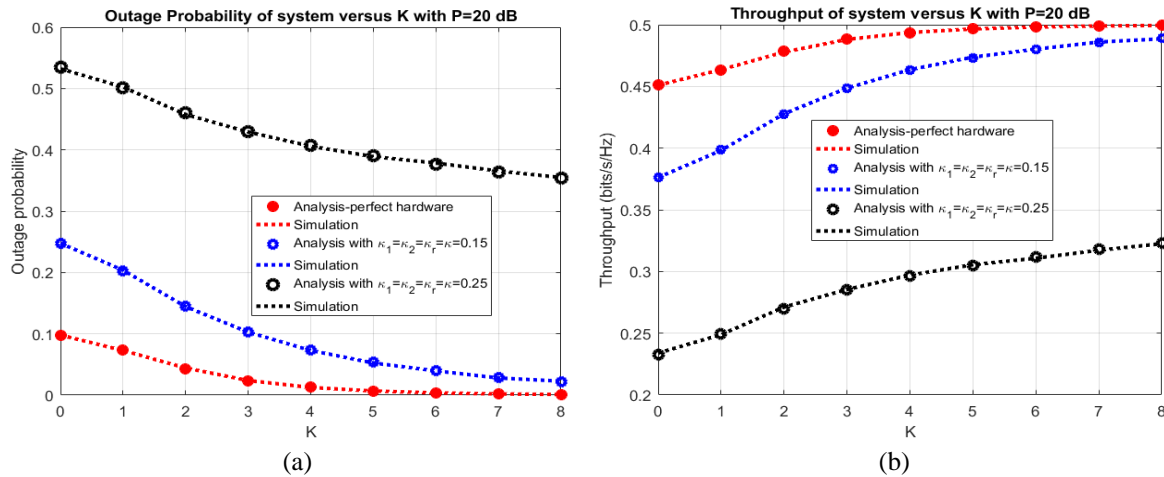


Figure 3. Outage probability (a) and achievable throughput (b) of the system model versus κ

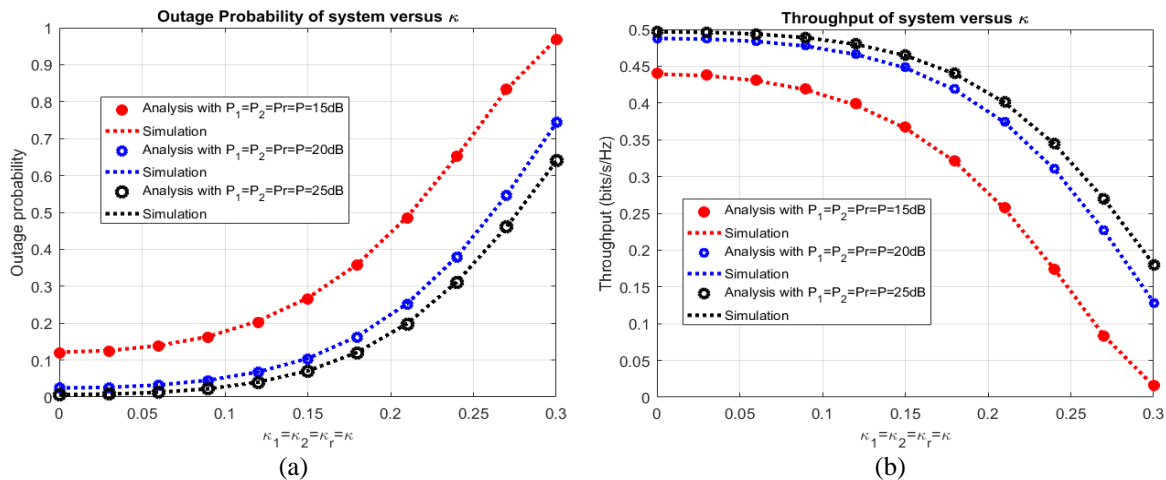


Figure 4. Outage probability (a) and achievable throughput (b) of the system model versus κ

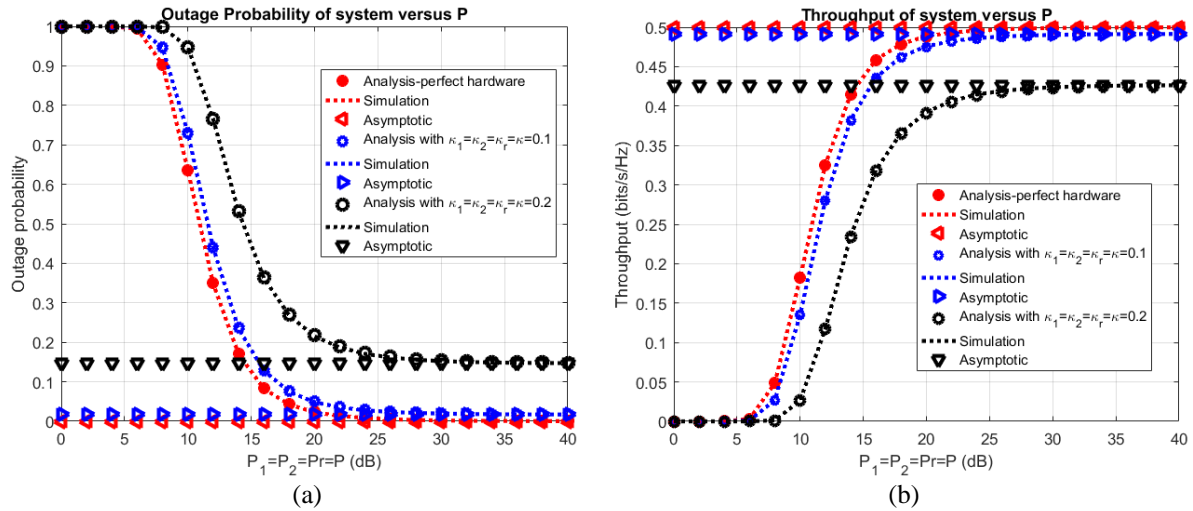


Figure 5. Outage probability (a) and achievable throughput (b) of the system mode versus P

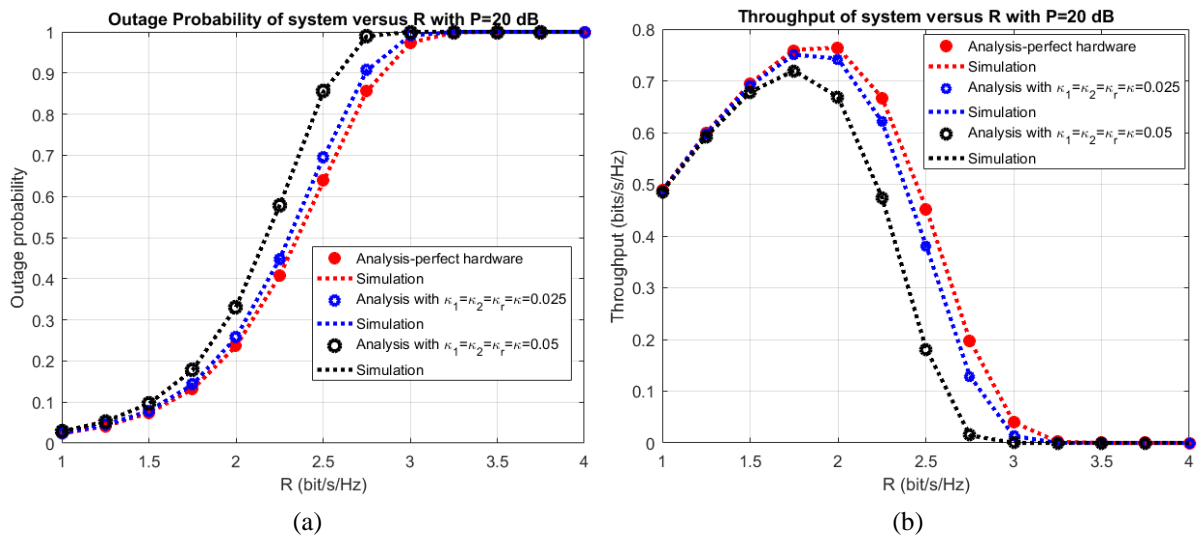


Figure 6. Outage probability (a) and achievable throughput (b) of the system mode versus R

4. CONCLUSION

In this paper, we investigate the system performance of the two-way half-duplex relay network under hardware impairment condition. The analytical expressions of the outage probability and achievable throughput with the exact closed form and asymptotic form were proposed and derived. Furthermore, the analytical results are also demonstrated and convinced by Monte-Carlo simulation, and the analytical and the simulation results are matched well with each other for all possible system parameters. The research results can provide the essential recommendations for the communication network research and practice directions.

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