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System Performance Analysis of Half-Duplex Relay Network over Rician Fading Channel

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Abstract

In this paper, the system performance of an amplify-and-forward (AF) relaying network over Rician Fading Channel is proposed, analyzed and demonstrated. For details this analysis, the energy and information are transferred from the source to the relay nodes by two methods: 1) time switching protocol and 2) power splitting protocol. Firstly, due to the constraint of the wireless energy harvesting at the relay node, the analytical mathematical expressions of the achievable throughput and the outage probability of both schemes were proposed and demonstrated. After that, the effect of various system parameters on the system performance is rigorously studied with closed-form expressions for the system performance. Finally, the analytical results are also demonstrated by Monte-Carlo simulation in comparison with the closed-form expressions. The numerical results demonstrated the effect of various system parameters, such as energy harvesting time, power splitting ratio, source transmission to noise power, and the threshold value, on the system performance of AF wireless relay nodes. The results show that the analytical mathematical and simulated results match for all possible parameter values for both schemes.

***Keywords**: amplify-and-forward (AF), relay network, throughput, outage probability, wireless energy harvesting (EH)*

1. Introduction

In the last decades, the proliferation of cellular networks and wireless sensor networks, have demandedthe higher quality of power supply from the source node to wireless devices. In the conventional method, wireless devices are generally powered by batteries, which have to be replaced/recharged on time manually. In the communication network, the process battery replacement can be linked to some disadvantages such as inconvenient, infeasible for some applications [1-4]. In the last few years, wireless energy transfer (WET) technologies by supplying continuous and stable energy over the air is a proposed solution for avoiding disadvantages. This method could significantly reduce the maintenance cost and the frequency of energy outage events due to battery depletion. One of the best ways to transfer energy in the communication network is using RF signals. For wireless energy harvesting using RF signals, there are two main approaches to practice. The first solution is simultaneous wireless information and power transfer (SWIPT). On the second approach, the separated information decoding and energy harvesting receiver for information and power transfer is proposed, and it is named wireless powered communication network (WPCN). In comparison with the second method, the first method is not standard used in practice because of practical circuits for harvesting energy from RF signals are not yet able to decode the carried information directly [5-7].

In the last decades, there are manyworks focused on the WPCN solution. Such as some papers presented the process energy harvesting through the RF signals in cooperative wireless networks by a MIMO relay system the difference between the energy transfer and the information rates to provide the optimal source and relay precoding [8-10]. In the literature of the others, the authors investigated multi-user and multi-hop systems for simultaneous information

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and power transfer with a dual-hop channel with an energy harvesting relay; the transmission strategy depends on the quality of the second link [11-13]. In these previous papers, the authors only focused on the WPCN with using the Rayleigh fading channels. i.e., the channel gains are assumed to be involved Gaussian random variables with zero means. However, in practice, the wireless channels are often found to be Gaussian distributed with anon-zeromean, i.e., Rician fading channel [15-21]. However, there are not many works concentrate on the Rician fading channel yet, and the outage performance analysis of such channels is fundamentalto practice. The remaining gap can fillby this work.

In this work, the system performance, in theterm the achievable throughput and the outage probability, of an amplify-and-forward (AF) relaying network over Rician Fading Channel is proposed, analyzed and demonstrated in details. For details this analysis, the energy and information are transferred from the source to the relay nodes by two methods: 1) time switching protocol (TSP) and 2) power splitting protocol. In TSP, the fraction of the time interval is used for energy harvesting at the relay from the source signal, and the remaining time is used as follows: half of that for from the source to the relay information transmission, and the remaining halffor the relay to destination information transmission. On another way, during the first half of the interval time, the fraction of the received signal power is used for energy harvesting and the remaining received power is used for transmitting source information to the relay node in the remaining half-time in PSP.The main contributions of the paper are summarized as follows:

1) The system model of the half-duplex relaying network over the Rician fading channels is proposed with the PSP and TSP.
2) The closed-form of the outage probability and throughput for the system is derived.
3) The influence of the main parameters on the system performance is demonstrated entirely.
4) The optimal power splitting and time switching factorsis investigated and calculated in connection with the main system parameters.

The structure of this paper is proposed as follows. Sections IIpresents the system model of the amplify-and-forward (AF) relaying network over Rician Fading Channel. Sections III proposed the time switching and power splitting protocols in term of theachievable throughput and the outage probability, respectively. Section IV provides the numerical results and some discussions. Finally, Section V concludes the paper.

2. System Model

In this section, AF relaying cooperative network is presented in Figure 1. In Figure 1, the information is transferred from the source (S) to the destination (D), through an energy constrained intermediate relay (R). For energy harvesting and information processing at the relay by the time switching protocol is presented in Figure 2. In this scheme, T is the block time in which the source fully transmit the information data to the destination. In this time, αT, $\alpha \in (0, 1)$, is the time in which the relay harvests energy from the source signal, and $(1 - \alpha)T$, is used for information transmission in such a way that half of that, $(1 - \alpha)T/2$, is used for the source to relay information transmission and the remaining half, $(1 - \alpha)T/2$, is used for the relay to destination information transmission. Furthermore, the energy harvesting and information processing at the relay by the power splitting protocol is proposed in Figure 3. Where P is the received signal power and T is the block time (Figure 3). Half of the time, T/2 is used for the source to relay information transmission and the remaining half, T/2 is used for the relay to destination information transmission. During the first half, the fraction of the received signal power, ρP is used for energy harvesting and the remaining received power, $(1 - \rho)P$ is used for transmitting source information to the relay node, where $\rho \in (0, 1)$ [17-20]. More details of the analytical mathematical model of the achievable throughput and outage probability over Rician Fading Channel (for the time switching and power splitting protocol) is presented in the following sections [6-8].

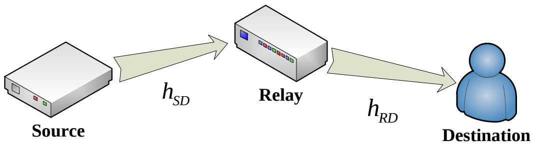

Figure 1. System model

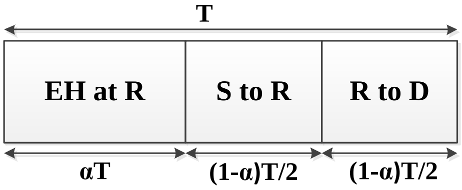

Figure 2. The time switching protocol

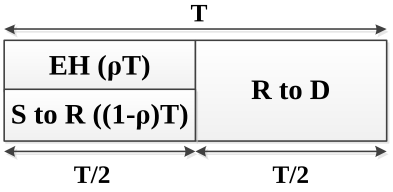

Figure 3. The power splitting protocol

3. The System Performance

Based on the system model on above section, the system performance of the relay network is presented, analyzed and demonstrated with thetime switching and power splitting protocols in details in this section [10-13].

3.1. The Time Switching Protocol (TSP)

Figure 2 presents the key parameters in the time switching protocol for energy harvesting and information processing at the relay. Here the energy harvesting and information processing at the relay node is presented. The received signal at the relay node is given by:

$$y_r^{TS} = h_{SR} x_s + n_r \tag{1}$$

The received signal at the destination is calculated as:

$$y_d^{TS} = h_{RD} x_r + n_d \tag{2}$$

The harvested energyduring energy harvesting time αT at the relay node is given by:

$$E_h^{TS} = \eta P_s \left| h_{SR} \right|^2 \alpha T \tag{3}$$

Where η is the energy conversion efficiency (0< η<1),and $\mathrm{E}\left\{ \left| x_s \right|^2 \right\} = P_s$, E{·} is the expectation operator and |.| is the absolute value operator.

The transmitted power from the relay node is given by:

$$P_R^{TS} = \frac{E_h}{(1-\alpha)T/2} = \frac{\eta P_s \left| h_{SR} \right|^2 \alpha T}{(1-\alpha)T/2} = \frac{2\eta \alpha P_s \left| h_{SR} \right|^2}{1-\alpha} = \zeta P_s \left| h_{SR} \right|^2 \tag{4}$$

In equation (4) we set $\zeta = \frac{2\eta\alpha}{1-\alpha}$, and amplify factor: $\beta = \frac{x_r}{y_r^{TS}} = \frac{\sqrt{P_R^{TS}}}{\sqrt{P_s \left| h_{SR} \right|^2 + N_0}}$.

The final form of received signal at the destination nodeis expressed by:

$$y_d^{TS} = h_{RD} x_r + n_d = h_{RD} \beta y_r^{TS} + n_d = h_{RD} \beta [h_{SR} x_s + n_r] + n_d \tag{5}$$

The received signal at the destination:

$$y_d^{TS} = \underbrace{h_{SR}\beta h_{RD} x_s}_{signal} + \underbrace{h_{RD}\beta n_r + n_d}_{noise} \quad \text{Here } \mathrm{E}\left\{\left|x_r\right|^2\right\} = P_R \tag{6}$$

The end to end signal to noiseratio (SNR) at the destination node is given by (7):

$$\gamma_{SD}^{TS} = \frac{\mathrm{E}\left\{(signal)^2\right\}}{\mathrm{E}\left\{(noise)^2\right\}} = \frac{\left|h_{RD}\right|^2 \beta^2 \left|h_{SR}\right|^2 P_s}{\left|h_{RD}\right|^2 \beta^2 N_0 + N_0} = \frac{\left|h_{SR}\right|^2 \left|h_{RD}\right|^2 P_s}{\left|h_{RD}\right|^2 N_0 + \frac{N_0^2}{P_R} + \frac{N_0}{\zeta}} \tag{7}$$

Because N₀<<P_R so γ_{SD}^{TS} is closed by:

$$\gamma_{SD}^{TS} \approx \frac{\left|h_{SR}\right|^2 \left|h_{RD}\right|^2 P_s}{\left|h_{RD}\right|^2 N_0 + \frac{N_0}{\zeta}} = \frac{\zeta \left|h_{SR}\right|^2 \left|h_{RD}\right|^2 P_s}{\zeta \left|h_{RD}\right|^2 N_0 + N_0} = \frac{\zeta\varphi_1\varphi_2 P_s / N_0}{\zeta\varphi_2 + 1} = \frac{\zeta\varphi_1\varphi_2\gamma_0}{\zeta\varphi_2 + 1} \tag{8}$$

In the equation (8) we denotethat $\varphi_1 = \left|h_{SR}\right|^2, \varphi_2 = \left|h_{RD}\right|^2, \gamma_0 = \frac{P_s}{N_0}$.

The probability density function (PDF) of random variable (RV) φ_i [19], where i=1,2 is given by:

$$f_{\varphi_i}(x) = \frac{(K+1)e^{-K}}{\lambda_i} e^{-\frac{(K+1)x}{\lambda_i}} I_0\left(2\sqrt{\frac{K(K+1)x}{\lambda_i}}\right) \tag{9}$$

Where 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 scattered components and $I_0(\bullet)$ is thezero-th order modified Bessel function of the first kind.

The equation (11) can be rewritten as follows:

$$f_{\varphi_i}(x) = a\sum_{l=0}^{\infty} \frac{(bK)^l}{(l!)^2} x^l e^{-bx} \tag{10}$$

Where $a = \frac{(K+1)e^{-K}}{\lambda_i}, b = \frac{K+1}{\lambda_i}$ and $I_0(x) = \sum_{l=0}^{\infty} \frac{x^{2l}}{2^{2l}(l!)^2}$ could be get from [22].

The cumulative density function (CDF) of RV φ_i, where i=1,2 can be computed in [11]

Here, we assume that $\lambda_1 = \lambda_2$

$$F_{\varphi_i}(\varsigma) = \int_0^{\varsigma} f_{\varphi_i}(x)dx = 1 - \frac{a}{b}\sum_{l=0}^{\infty}\sum_{m=0}^{l} \frac{K^l b^m}{l!m!} \varsigma^m e^{-b\varsigma} \tag{12}$$

Proposition 1: The outage probability at a fixed source transmission rate R is:

$$P_{out} = F_{\gamma_{SD}^{TS}}(\gamma_{th}) = \Pr\left(\gamma_{SD}^{TS} < \gamma_{th}\right) = \Pr\left(\frac{\zeta\varphi_1\varphi_2\gamma_0}{\zeta\varphi_2 + 1} < \gamma_{th}\right) \tag{13}$$

Where $\gamma_{th} = 2^{R} - 1$ is the th SNR threshold value, R is source rate value.
Finally, throughput at the destination node can be given by:

$$\tau^{TS} = (1 - P_{out})\frac{(1-\alpha)R}{2} \tag{14}$$

3.2. The Power Splitting Protocol (PSP)

Figure 3 shows the communication block diagram employing the PSR protocol for energy harvestingand information processing at the relay node.Here the energy harvesting and information processing at the relaynode for the power splitting protocol is proposed. Similar as time switching protocol we have:

$$y_r^{PS} = \sqrt{1-\rho}\, h_{SR} x_s + n_r \tag{15}$$

$$y_d^{PS} = h_{RD} x_r + n_d \tag{16}$$

$$E_h^{PS} = \eta\rho (T/2) P_s \left|h_{SR}\right|^2 \tag{17}$$

$$P_R^{PS} = \frac{E_h^{PS}}{T/2} = \eta\rho P_s \left|h_{SR}\right|^2 \tag{18}$$

In this section, amplify factor as $\kappa = \frac{x_r}{y_r^{PS}} = \sqrt{\frac{P_R^{PS}}{(1-\rho)P_s\left|h_{SR}\right|^2 + N_0}}$.

$$y_d^{PS} = h_{RD} x_r + n_d = h_{RD}\kappa y_r^{PS} + n_d = \underbrace{h_{RD}\kappa\sqrt{1-\rho}\, h_{SR} x_s}_{signal} + \underbrace{h_{RD}\kappa n_r + n_d}_{noise} \tag{19}$$

$$\gamma_{SD}^{PS} = \frac{\mathrm{E}\left\{(signal)^2\right\}}{\mathrm{E}\left\{(noise)^2\right\}} = \frac{\left|h_{RD}\right|^2 (1-\rho)\left|h_{SR}\right|^2 P_s}{\left|h_{RD}\right|^2 N_0 + \frac{N_0\left[(1-\rho)P_s\left|h_{SR}\right|^2 + N_0\right]}{P_R^{PS}}} \tag{20}$$

Using the fact that $N_0 \ll P_R$ and using (26) so we have:

$$\gamma_{SD}^{PS} = \frac{(1-\rho)\varphi_1\varphi_2 P_R^{PS}}{\varphi_1 N_0 + \frac{N_0(1-\rho)}{\eta\rho}} = \frac{\eta\rho\varphi_1\varphi_2\gamma_0}{\frac{\eta\rho\varphi_1}{1-\rho} + 1} = \frac{\eta\rho\varphi_1\varphi_2\gamma_0}{\mu\varphi_1 + 1} \tag{21}$$

Where $\mu = \frac{\eta\rho}{1-\rho}$. The outage probability at the destination node is given by:

$$P_{out} = F_{\gamma_{SD}^{PS}}(\gamma_{th}) = \Pr\left(\gamma_{SD}^{PS} < \gamma_{th}\right) = 1 - 2a^2 e^{-\frac{b\gamma_{th}}{(1-\rho)\gamma_0}}$$

$$\sum_{l=0}^{+\infty}\sum_{k=0}^{+\infty}\sum_{m=0}^{l}\sum_{n=0}^{m}\frac{K^{l+k} b^{m+k-1}}{l!n!(m-n)!(k!)^2}\left(\frac{\gamma_{th}}{\gamma_0}\right)^{m+\frac{k-n+1}{2}} \times \frac{1}{(1-\rho)^{m-n}} \times \frac{1}{(\eta\rho)^{\frac{k+n+1}{2}}} \times K_{k-n+1}\left(2b\sqrt{\frac{\gamma_{th}}{\eta\rho\gamma_0}}\right) \tag{22}$$

Finally, the at the destination node:

$$\tau^{PS} = (1 - P_{out})\frac{R}{2} \quad (23)$$

Where $K_v(\bullet)$ is the modified Bessel function of the second kind and v^{th}order.

3.3. Optimal Power Splitting Factor

The optimal value ρ^* or α^* can be obtained by solving the equation $\frac{d\tau(\rho)}{d\rho} = 0$ and $\frac{d\tau(\alpha)}{d\alpha} = 0$. Given the throughput expression in (12) and (23), this optimization problem does not admit a closed-form solution. However, the optimal ρ^* or α^* is efficiently solved via numerical calculation, as illustrated below.Here, we can use Golden section search algorithm to find the optimal factor ρ^* and α^*. This algorithm has been used in many global optimization problems in communications, for example, in [23]. The detailed algorithm as well as the related theoryis described in [24].

4. Numerical Results and Discussion

In this section, the throughput performance and the outage probability of an energy harvesting AF relaying network over Rician Fading Channelare analyzed in details. The system performance in term of the throughput performance and the outage probabilityis analyzed in connection with α, ρ, P_s/N_0 and R. We consider a network with one source, one relay, and one destination, where source-relay and relay-destination distances are both normalized to unit value.

In Figure 4 and 5, the effect of α ($0 < \alpha < 1$) for the time switching protocol and *ρ* ($0 < \rho < 1$) for the power splitting protocol on the achievable throughput and the outage probability of the AF relay network system is presented. From Figure 4 and 5, the analytical and the simulation results match for all possible values of *α* and *ρ* for both the time switching and the power splitting protocols. Figure 4 shows that the throughput increases as α and ρincreases from 0 to some optimal α and ρ(0.2 for α and 0.6 for ρ) but later, it starts decreasing as α and ρincreases from its optimal value. When the values of *α* smaller than the optimal *α*, there is less time for energy harvesting. Consequently, less energy is harvested and smaller values of throughput are observed at the destination node due to larger outage probability. On the other hand, for the values of *α* greater than the optimal *α*, more time is wasted on energy harvesting and less time is available for information transmission. This is because for the values of *ρ* smaller than the optimal *ρ*, there is less power available for energy harvesting. Consequently, less transmission power P_r is available from the relay node and smaller values of throughput are observed at the destination node due to larger outage probability. On the other hand, for the values of *ρ* greater than the optimal *ρ*(0.6), more power is wasted on energy harvesting and less power is left for the source to relay information transmission.

Furthermore, Figure 6 and 7 plot the influence of the ratio P_s/N_0 on the achievable throughput and the outage probability at the destination node. The achievable throughput increases and the outage probability decreases significantly at the destination node for the time switching protocol while the ratio P_s/N_0 varies from 0 to 30 dB. In the similar, the achievable throughput increases and the outage probability decreases significantly at the destination node for the power splitting protocol while the ratio P_s/N_0 varies from 0 to 30 dB (Figure 8 and 9). It can be prove by the opinion that the strength of the RF signal increases in the direction of increasing the power of the source signals and decreasing the noise interference.

In Figure 10 and 11, the optimal throughput and the outage probability for the time switching and the power splitting protocols is proposed with different values of the source transmission rate, R bits/sec/Hz. Figure 10 shows that the achievablethroughput increases as R increases to a specific value but then starts decreasing for larger values of R. On the other hand, for more great transmission rates R, the receiver fails to correctly decode a significant amount of data in the limited time. Thus, the outage probability increases and the throughput decreases (Figure 11).

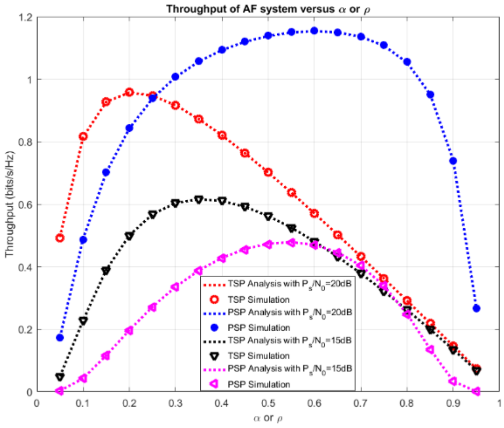

Figure 4. The throughput for different values of α and ρ

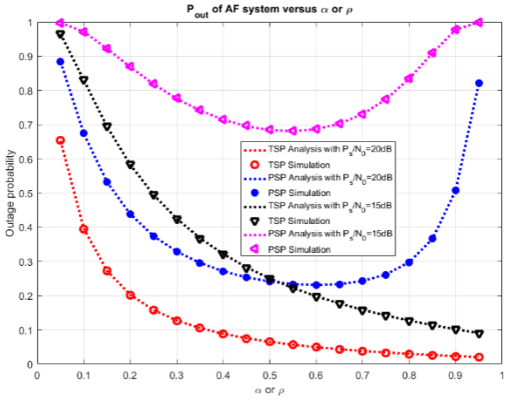

Figure 5. The outage probability for different values of α and ρ

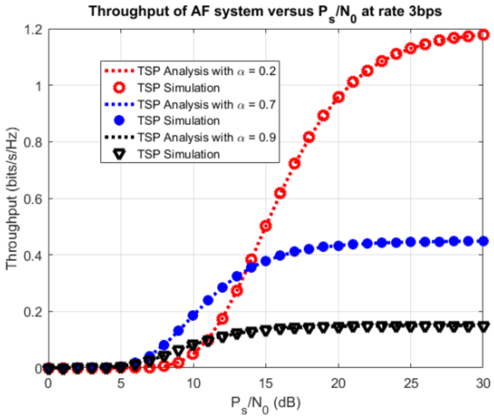

Figure 6. The throughput for different values of ratio P_s/N_0 for time switching protocol

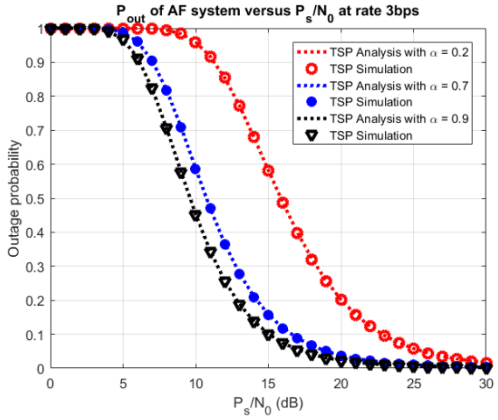

Figure 7. The outage probability for different values of ratio P_s/N_0 for time switching protocol

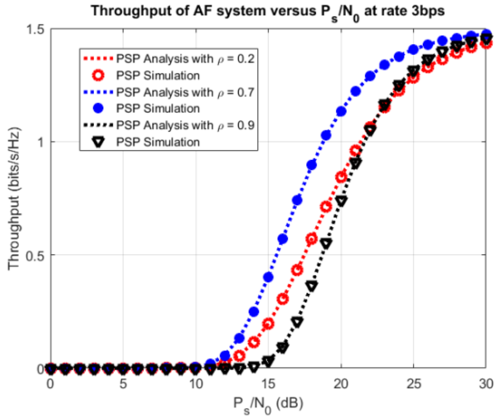

Figure 8. The throughput for different values of ratio P_s/N_0 for power splitting protocol

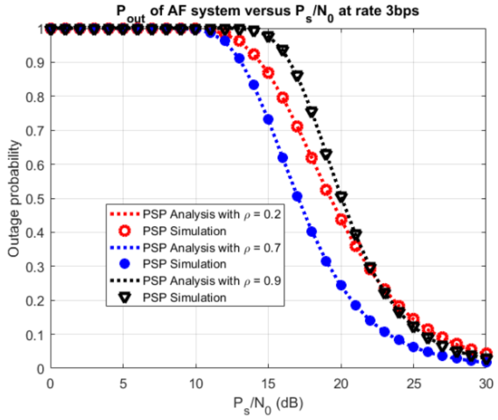

Figure 9. The outage probability for different values of ratio P_s/N_0 power splitting protocol

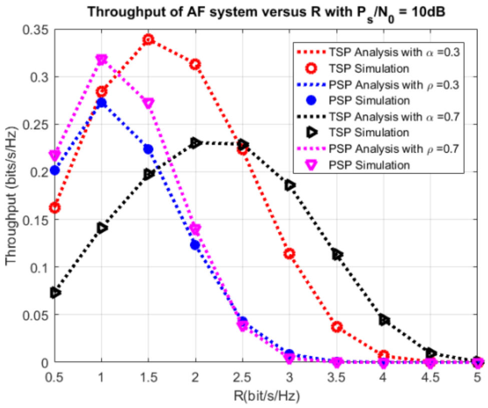

Figure 10. The throughput for different values of source transmissionrate R

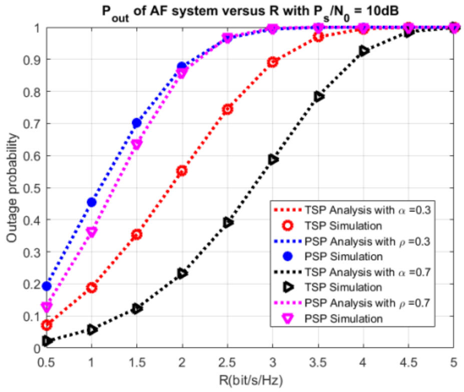

Figure 11. The outage probability for different values of source transmissionrate R

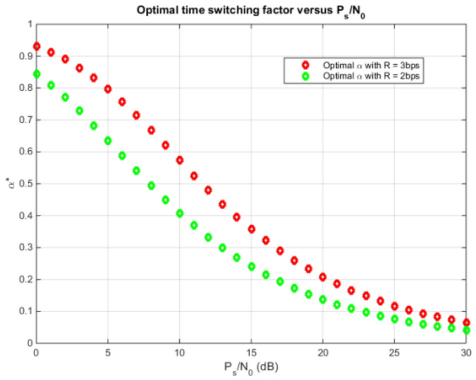

Figure 12. The outage probability for different values of source transmissionrate R

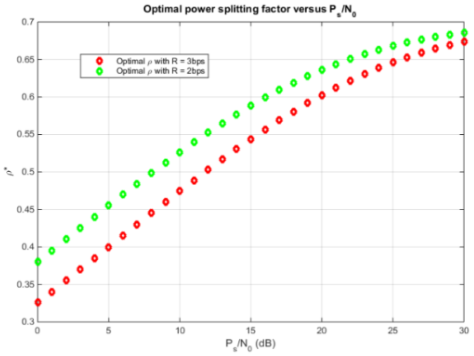

Figure 13. The outage probability for different values of source transmissionrate R

4. Conclusion

In this paper, an amplify-and-forward wireless cooperative networkover Rician Fading Channel with the time switching and the power splitting protocols has been considered. In order toanalyze the system performance at the destination, analytical expressions for the outage probability and the throughput are proposed. The numerical analysis in this paper has provided practical insights into the effect of various system parameters on the system performance of AF relay nodes over Rician Fading Channel. The results show that the analytical mathematical and simulated results match for all possible parameter values for both schemes. The results could be provide the prospective solution for the communication network in the near future.

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