Lower and upper bound form for outage probability analysis in two-way of half-duplex relaying network under impact of direct link

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ABSTRACT

In this paper, the system performance of the two-way of half-duplex (HD) relaying network under the impact of the direct link is studied. The model system has two sources (S) and one destination (D) communicate by direct link and via relay (R). For system performance analysis, we derived the lower and upper bound for outage probability (OP). Furthermore, the analytical expressions of the system performance are verified by using the Monte Carlo simulation in the effect of main parameters. As shown in the results, we can the simulation and analytical results have a good agreement.

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1. INTRODUCTION

Nowadays, wireless powered communication network (WPCN) is the best solution for overcoming the limitation in energy harvesting in the wireless-powered communication with the considerable demand energy in energy-constrained wireless networks. Based on the fact that human-made radio frequency (RF) can carry both energy and information, WPCN is considered as the leading solution for at our time [1-6]. In this time, many researched focus on the efficiency of the WPCN and its solution. Authors in [7] studied the outage probability between some points based on the tradeoff fundamental and [8] proposed and designed the practical receiver for energy and information transmission and its advantages for the communication network. Furthermore, authors in [9] presented and demonstrated the practical energy harvesting communication network, and [10] proposed and investigated the continuous energy and power transmission in the cognitive relaying communication network. Moreover, the time switching and the power splitting protocols design for the communication network and the comparison between these protocols are proposed and investigated in [11-15].

In this paper, the system performance of the two-way of half-duplex (HD) relaying network under the impact of the direct link is studied. The model system has two sources (S) and one destination (D) communicate by direct link and via relay (R). For system performance analysis, we derived the lower and upper bound for outage probability (OP). Furthermore, the analytical expressions of the system performance are verified by using the Monte Carlo simulation in the effect of main parameters. As shown in the results, we can the simulation and analytical results have a good agreement.

2. SYSTEM MODEL

In this section, Figure 1 proposed the system model. The energy harvesting (EH) and information transferring (IT) phases are drawn in Figure 2 [16-20]. The energy harvesting and information transmission is formulated as the followings.

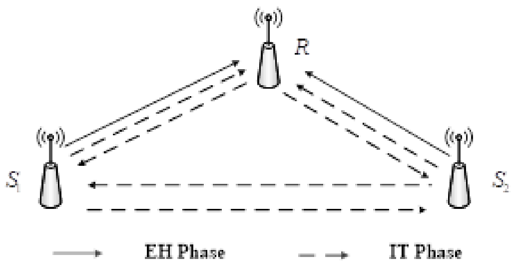

Figure 1. System model

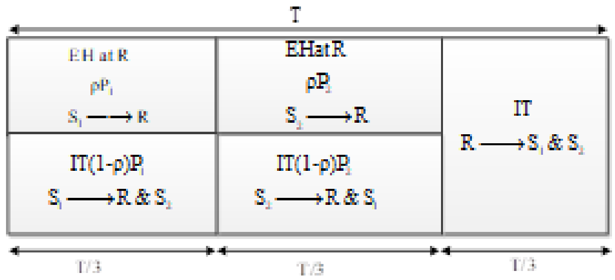

Figure 2. The EH and IT phases

2.1. Energy harvesting process

The received signal at R and S_2 are;

$$y_{1,R}^{I} = h_{1,R}x_1 + n_r^I,$$
$$y_{1,2}^{I} = h_{1,2}x_1 + n_2^I \tag{1}$$

The harvested energy at R is;

$$E_h^I = \eta\rho(T/3)P_1\left|h_{1,R}\right|^2 \tag{2}$$

where $0 < \eta \leq 1$ is energy conversion efficiency and $0 < \rho < 1$ is the power splitting factor. The received signals at R and S_1 are;

$$y_{2,R}^{II} = h_{2,R}x_2 + n_r^{II},$$
$$y_{2,1}^{II} = h_{2,1}x_2 + n_1^{II} \tag{3}$$

where $E\{|x_2|^2\} = P_2$. The total harvested energy at R is;

$$E_h = \eta\rho(T/3)\left(P_1\left|h_{1,R}\right|^2 + P_2\left|h_{2,R}\right|^2\right) \tag{4}$$

From (4), we have;

$$E_h = \eta\rho(T/3)\left(P_1\left|h_{1,R}\right|^2 + P_2\left|h_{2,R}\right|^2\right) = \eta\rho(T/3)P\left(\left|h_{1,R}\right|^2 + \left|h_{2,R}\right|^2\right) \tag{5}$$

where $P_1 = P_2 = P$ The average transmit power at R is;

$$P_R = \frac{E_h}{T/3} = \eta\rho P\left(\left|h_{1,R}\right|^2 + \left|h_{2,R}\right|^2\right) \tag{6}$$

2.2. Information transmission phase

The received signal at R and S_2 can be calculated as;

$$y_{1,R}^{I} = \sqrt{1-\rho}h_{1,R}x_1 + n_r^I, \qquad (7)$$
$$y_{1,2}^{I} = h_{1,2}x_1 + n_2^I$$

The received signal at R and S_1 are;

$$y_{2,R}^{II} = \sqrt{1-\rho}h_{2,R}x_2 + n_r^{II}, \qquad (8)$$
$$y_{2,1}^{II} = h_{2,1}x_2 + n_1^{II}$$

The received signal at S_1 and S_2 can be formulated as;

$$y_1^{III} = h_{R,1}x_R + n_1^{III}, \qquad (9)$$
$$y_2^{III} = h_{R,2}x_R + n_2^{III}$$

where $\mathrm{E}\left\{\left|x_R\right|^2\right\} = P_R$. In AF protocol, the amplifying coefficient χ can be formulated as;

$$\chi = \frac{x_R}{y_R} = \sqrt{\frac{P_R}{(1-\rho)\left[P_1\left|h_{1,R}\right|^2 + P_2\left|h_{2,R}\right|^2\right] + N_0}} = \sqrt{\frac{P_R}{(1-\rho)P\left[\left|h_{1,R}\right|^2 + \left|h_{2,R}\right|^2\right] + N_0}} \qquad (10)$$

From (9), the received signal at S_1 can be rewritten as;

$$y_1^{III} = h_{R,1}\chi y_R + n_1^{III} = h_{R,1}\chi\left(y_{1,R}^{I} + y_{2,R}^{II}\right) + n_1^{III} \qquad (11)$$

Replace (7), (8) into (11), finally we have;

$$\begin{aligned} y_1^{III} &= h_{R,1}\chi\left(y_{1,R}^{I} + y_{2,R}^{II}\right) + n_1^{III} \\ &= h_{R,1}\chi\left[\sqrt{1-\rho}h_{1,R}x_1 + \sqrt{1-\rho}h_{2,R}x_2 + n_r^I + n_r^{II}\right] + n_1^{III} \qquad (12) \\ &= \underbrace{\chi h_{R,1}h_{1,R}\sqrt{1-\rho}x_1 + h_{R,1}\chi\sqrt{1-\rho}h_{2,R}x_2}_{signal} + \underbrace{h_{R,1}\chi n_r + n_1^{III}}_{noise} \end{aligned}$$

Therefore, as shown in (12) can be rewritten as;

$$y_1^{III} = \underbrace{h_{R,1}\chi\sqrt{1-\rho}h_{2,R}x_2}_{signal} + \underbrace{h_{R,1}\chi n_r + n_1^{III}}_{noise} \qquad (13)$$

From (13), the signal to noise ratio (SNR) of S_2-R-S_1 link can be formulated as;

$$\gamma_{2,1}^{AF} = \frac{E\left[|signal|^2\right]}{E\left[|noise|^2\right]} = \frac{\left|h_{R,1}\right|^2\left|h_{2,R}\right|^2 P_2\chi^2(1-\rho)}{\left|h_{R,1}\right|^2\chi^2 N_0 + N_0} = \frac{\left|h_{R,1}\right|^2\left|h_{2,R}\right|^2 P(1-\rho)}{\left|h_{R,1}\right|^2 N_0 + \frac{N_0}{\chi^2}} \qquad (14)$$

From (10) and (14), we have;

$$\gamma_{2,1}^{AF} \simeq \frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1 + (1-\rho)} \qquad (15)$$

where $\Psi = \frac{P_2}{N_0} = \frac{P}{N_0}, \varphi_1 = \left|h_{R,1}\right|^2, \varphi_2 = \left|h_{2,R}\right|^2$. From (8) the received signal at D is

$$\gamma_{2,1}^{direct} = \frac{P_2\left|h_{2,1}\right|^2}{N_0} = \Psi\varphi_3 \qquad (16)$$

where $\varphi_3 = \left|h_{2,1}\right|^2$. Finally, the overall SNR at S_1 is;

$$\gamma_{MRC}^{AF} = \gamma_{2,1}^{AF} + \gamma_{2,1}^{direct} = \frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1+(1-\rho)} + \Psi\varphi_3 = X + Y \tag{17}$$

where $X = \frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1+(1-\rho)}$ and $Y = \Psi\varphi_3$

3. OUTAGE PROBABILITY (OP) ANALYSIS

3.1. Exact analysis

The OP of the system at the source S_1 can be difined as;

$$OP = Pr(\gamma_{MRC}^{AF} < \gamma_{th}) = Pr(X + Y < \gamma_{th}) = \int_0^{\gamma_{th}} F_X(\gamma_{th} - y) f_Y(y) dy \tag{18}$$

where γ_{th} is the predetermined threshold of the system. To find the probability in (18), we have to calculate the cumulative distribution function (CDF) of X. So, the CDF of X can be found as;

$$F_X(x) = Pr(X < x) = Pr\left(\frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1 + (1-\rho)} < x\right)$$

$$= Pr\left[\varphi_2 < \frac{x(\eta\rho\varphi_1+(1-\rho))}{\varphi_1\Psi\eta\rho(1-\rho)}\right] = Pr\left[\varphi_2 < \frac{x}{\Psi(1-\rho)} + \frac{x}{\varphi_1\Psi\eta\rho}\right] \tag{19}$$

$$= \int_0^{\infty} F_{\varphi_2}\left[\left(\frac{x}{\Psi(1-\rho)} + \frac{x}{\varphi\Psi\eta\rho}\right)|\varphi_1 = \varphi\right] \times f_{\varphi_1}(\varphi) d\varphi$$

$$= 1 - \lambda_1\, exp\left[-\frac{x\lambda_2}{\Psi(1-\rho)}\right] \int_0^{\infty \int \left(-\frac{x\lambda_2}{\varphi\Psi\eta\rho} - \lambda_1\varphi\right)} exp$$

where λ_1, λ_2 are the mean of random variables (RVs) φ_1, φ_2, respectively. Applying as shown in (3.324,1) of [ref: table of…], in (19) can be reformulated by;

$$F_X(x) = 1 - 2\, exp\left[-\frac{x\lambda_2}{\Psi(1-\rho)}\right] \times \sqrt{\frac{x\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(2\sqrt{\frac{x\lambda_1\lambda_2}{\Psi\eta\rho}}\right) \tag{20}$$

Substituting (20) into (18), we can obtain;

$$OP = 1 - exp\left(-\frac{\gamma_{th}\lambda_3}{\Psi}\right) - \frac{2\lambda_3}{\Psi}\int_0^{\gamma_{th}} \begin{matrix} exp\left[-\frac{(\gamma_{th}-y)\lambda_2}{\Psi(1-\rho)} - \frac{y\lambda_3}{\Psi}\right] \\ \times \sqrt{\frac{(\gamma_{th}-y)\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(2\sqrt{\frac{(\gamma_{th}-y)\lambda_1\lambda_2}{\Psi\eta\rho}}\right) dy \end{matrix} \tag{21}$$

where λ_3 is the mean of RV φ_3

3.2. Lower and upper bound analysis

We will perform the OP of the system in terms of lower and upper bound form. From (17), we can compute as (22).

$$2\, min(X, Y) \le X + Y \le 2\, max(X, Y) \tag{22}$$

Therefore, the OP of the system in lower bound form can be given by;

$$OP_{LB} = Pr\left[min(X, Y) < \frac{\gamma_{th}}{2}\right] = 1 - \underbrace{Pr\left(X \ge \frac{\gamma_{th}}{2}\right)}_{P_1}\underbrace{Pr\left(Y \ge \frac{\gamma_{th}}{2}\right)}_{P_2} \tag{23}$$

From (20), P_1 can be calculated as (24).

$$P_1 = 1 - Pr\left(X < \frac{\gamma_{th}}{2}\right) = exp\left[-\frac{\gamma_{th}\lambda_2}{2\Psi(1-\rho)}\right] \times \sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(\sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}}\right) \quad (24)$$

Next, P2 can be found as;

$$P_2 = 1 - Pr\left(Y < \frac{\gamma_{th}}{2}\right) = 1 - Pr\left(\Psi\varphi_3 < \frac{\gamma_{th}}{2}\right)$$
$$= 1 - Pr\left(\varphi_3 < \frac{\gamma_{th}}{2\Psi}\right) = exp\left(-\frac{\lambda_3\gamma_{th}}{2\Psi}\right) \quad (25)$$

From (24), (25) and (23), we have;

$$OP_{LB} = 1 - exp\left[-\frac{\gamma_{th}\lambda_2}{2\Psi(1-\rho)} - \frac{\lambda_3\gamma_{th}}{2\Psi}\right] \times \sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(\sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}}\right) \quad (26)$$

Similar as above, the upper bound OP of system can be computed as;

$$OP_{UB} = Pr\left[max(X,Y) < \frac{\gamma_{th}}{2}\right] = Pr\left(X < \frac{\gamma_{th}}{2}\right) Pr\left(Y < \frac{\gamma_{th}}{2}\right)$$
$$= \left\{1 - exp\left[-\frac{\gamma_{th}\lambda_2}{2\Psi(1-\rho)}\right] \times \sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(\sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}}\right)\right\} \times \left\{1 - exp\left(-\frac{\lambda_3\gamma_{th}}{2\Psi}\right)\right\} \quad (27)$$

4. NUMERICAL RESULTS AND DISCUSSION

The system performance of the model system is investigated as in [21-27]. The OP as a function of the energy coefficient η is drawn in Figure 3 with the main system parameters as $\gamma_{th} = 1, \psi = 5\ dB$, and $\rho = 0.5$. In this figure, we considered the exact, upper, and lower bound analysis of the system OP. The results show that the system OP decrease with the increasing of the energy coefficient. In the same way, the system Op versus γ_{th} is illustrated in Figure 4, and we set $\eta = 1$, $\psi = 10\ dB$, and $\rho = 0.5$. The system OP has a significant rise while γ_{th} varies from 0 to 6 as shown in Figure 4 for all cases with lower and upper bound. From Figures 3 and 4, the simulation and the analytical values agree well. Moreover, the system OP versus ψ and ρ are presented in Figures 5 and 6, respectively. We set $\gamma_{th} = 1$, $\eta = 1$, and $\rho - 0.85$ for Figure 4, $\psi = 5\ dB$ for Figure 5, respectively. From Figure 5, it can be stated that the system OP falls while ψ rises from -5 dB to 15 dB. The system OP has a slight fall with ρ varies from 0 to 0.5 and then has a rise with the remaining values of ρ. The maximum value of the system OP can be obtained with $\rho = 0.5$, as shown in Figure 6. Once again, the simulation results have an agreement with the mathematical, analytical results, as in Figures 5 and 6.

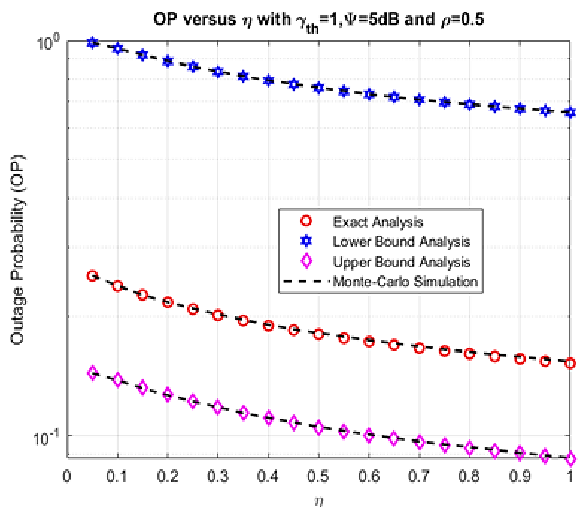

Figure 3. OP versus η

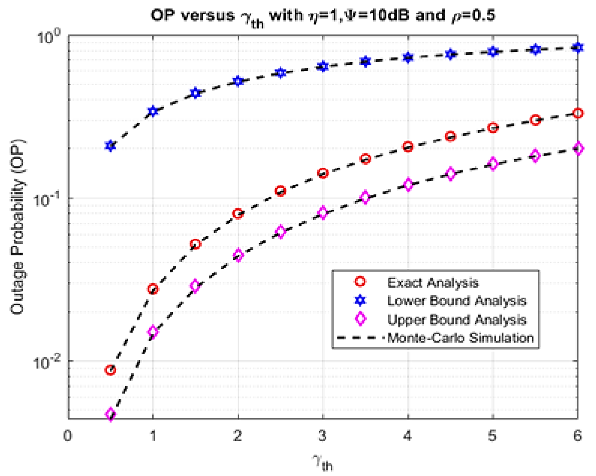

Figure 4. OP versus γ_{th}

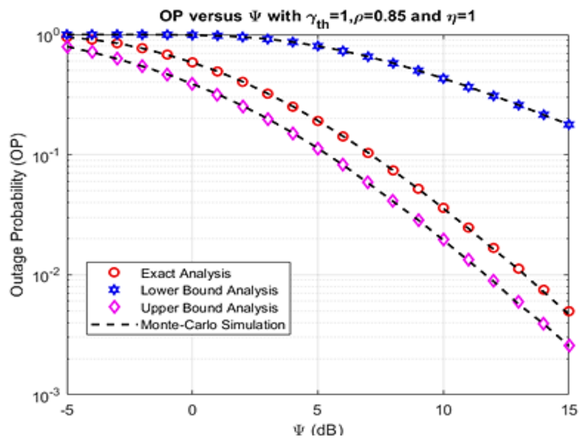

Figure 5. OP versus ψ

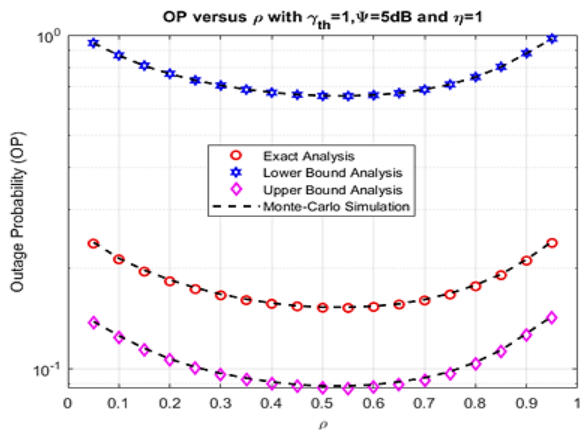

Figure 6. OP versus ρ

5. CONCLUSION

In this paper, the system performance of the two-way of HD relaying network under the impact of the direct link is studied. The model system has two S and one D communicate by direct link and via R. For system performance analysis, we derived the lower and upper bound for OP. Furthermore, the analytical expressions of the system performance are verified by using the Monte Carlo simulation in the effect of main parameters. As shown in the results, we can the simulation and analytical results have a good agreement.

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