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Performance analysis for three cases of outage probability in one-way DF full-duplex relaying network with presence of direct link

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ABSTRACT

In this paper, the one-way decode-and-forward (DF) full-duplex relaying network system with presence of direct link is investigated. In the analysis section, we derived the exact, lower, and upper bound for outage probability (OP) with maximal ratio combining (MRC) at the receiver. Furthermore, the system performance's analytical expressions are verified by using the Monte Carlo simulation. In addition, we investigated the effect of the main parameters on the OP of the proposed system. Finally, we can sate that the simulation curves overlap the analytical curves to convince the analysis section. This research can provide a novel recommendation for the communication network.

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1. INTRODUCTION

Nowadays, wireless-powered communication networks (WPCN) is the best solution for overcoming energy harvesting limitations in wireless-powered communication with the considerable demand for energy in energy-constrained wireless networks. Because human-made radio frequency (RF) can carry both energy and information, WPCN is considered the leading solution at our time [1]-[6]. In this time, many researched focus on the efficiency of the WPCN and its solution. Nguyen *et al.* 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, Liu *et al.* [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 them are proposed and investigated in [11]-[15].

In this paper, the one-way decode-and-forward (DF) full-duplex relaying network system with presence of direct link is investigated. In the analysis section, we derived the exact, lower, and upper bound

for outage probability (OP) with maximal ratio combining (MRC) at the receiver. Furthermore, the system performance's analytical expressions are verified by using the Monte Carlo simulation. In addition, we investigated the effect of the main parameters on the OP of the proposed system. Finally, we can sate that the simulation curves overlap the analytical curves to convince the analysis section.

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]. Assume that all of the channels are Rayleigh fading, hence the channel gains $|h_{\mathrm{SR}}|^2$, $|h_{\mathrm{RD}}|^2$ and $|h_{\mathrm{SD}}|^2$ are exponential random variables (RVs) whose cumulative distribution function (CDF) are given as;

$$\begin{aligned} F_{|h_{SR}|^2}(x) &= 1-\exp(-\lambda_{\mathrm{SR}}x), \\ F_{|h_{RD}|^2}(x) &= 1-\exp(-\lambda_{\mathrm{RD}}x), \\ F_{|h_{SD}|^2}(x) &= 1-\exp(-\lambda_{\mathrm{SD}}x) \end{aligned} \tag{1}$$

To take path-loss into account, we can model the parameters as follows:

$$\lambda_{\mathrm{SR}} = (d_{\mathrm{SR}})^{\chi}, \lambda_{\mathrm{RD}} = (d_{\mathrm{RD}})^{\chi}, \lambda_{\mathrm{SD}} = (d_{\mathrm{SD}})^{\chi} \tag{2}$$

The CDF is expressed as;

$$F_{|f|^2}(x) = 1 - exp(-\lambda_{RR}x). \tag{3}$$

Then, the PDFs of $|h_{SR}|^2$, $|h_{RD}|^2$, $|h_{SD}|^2$and $|f|^2$ are expressed, respectively as;

$$\begin{aligned} f_{|h_{SR}|^2}(x) &= \lambda_{\mathrm{SR}}\exp(-\lambda_{\mathrm{SR}}x), \\ f_{|h_{RD}|^2}(x) &= \lambda_{\mathrm{RD}}\exp(-\lambda_{\mathrm{RD}}x), \\ f_{|h_{SD}|^2}(x) &= \lambda_{\mathrm{SD}}\exp(-\lambda_{\mathrm{SD}}x), \\ f_{|f|^2}(x) &= \lambda_{RR}\exp(-\lambda_{RR}x) \end{aligned} \tag{4}$$

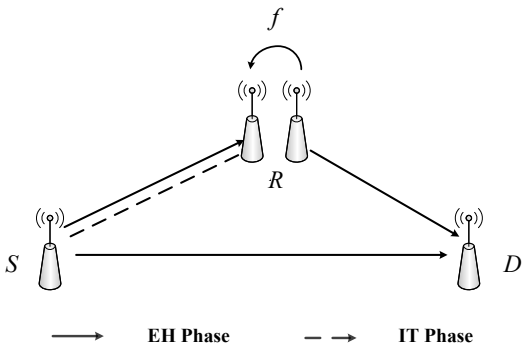

Figure 1. System model

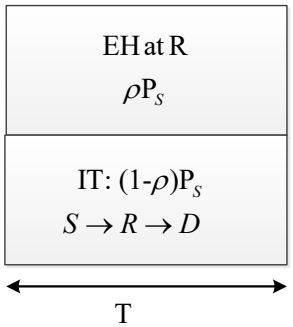

Figure 2. The EH and IT phases

The received signal at the relay can be expressed as;

$$y_R = \sqrt{1-\rho}h_{SR}x_s + fx_R + n_R \tag{5}$$

The average transmitted power at the relay can be given as;

$$P_R = \frac{E_h}{T} = \eta\rho P_s|h_{SR}|^2 \quad (6)$$

where $0 < \eta \leq 1$: energy conversion efficiency (which takes into account the energy loss by harvesting circuits and also by decoding and processing circuits). The received signal at the destination in the first phase can be given by;

$$y_D = h_{RD}x_R + n_D \quad (7)$$

where n_D is the AWGN with variance N_0.

Here, in our model, we adopt the decode-and-forward (DF) protocol. Hence, the signal to interference noise (SINR) at the relay node from (5) can be given by;

$$\gamma_R = \frac{(1-\rho)P_s|h_{SR}|^2}{|f|^2P_R+N_0} \quad (8)$$

Substituting (6) into (8) and using the fact that $N_0 << P_S$, we have:

$$\gamma_R = \frac{(1-\rho)P_s|h_{SR}|^2}{\eta\rho P_s|h_{SR}|^2|f|^2+N_0} \approx \frac{1-\rho}{\eta\rho|f|^2} \quad (9)$$

From (7), the SINR at the destination can be obtained by;

$$\gamma_D = \frac{|h_{RD}|^2P_R}{N_0} = \frac{\eta\rho P_s|h_{SR}|^2|h_{RD}|^2}{N_0} = \eta\rho\Phi|h_{SR}|^2|h_{RD}|^2 \quad (10)$$

where $\Phi = \frac{P_s}{N_0}$

Next, the destination will also receive the information directly from the source. Therefore, the SINR in this phase can be expressed by;

$$\gamma_{direct} = \Phi|h_{SD}|^2 \quad (11)$$

Finally, using the MRC technique at the receiver, the overall SINR of the system can be claimed as;

$$\gamma_{MRC}^{DF} = min(\gamma_R, \gamma_D) + \gamma_{direct} = min\left(\frac{1-\rho}{\eta\rho|f|^2}, \eta\rho\Phi|h_{SR}|^2|h_{RD}|^2\right) + \Phi|h_{SD}|^2 = X + Y \quad (12)$$

where $X = min\left(\frac{1-\rho}{\eta\rho|f|^2}, \eta\rho\Phi|h_{SR}|^2|h_{RD}|^2\right)$ and $Y = \Phi|h_{SD}|^2$

3. OUTAGE PROBABILITY (OP) ANALYSIS

3.1. Exact analysis

The OP of the system at the source destination can be defined as;

$$OP = Pr(\gamma_{MRC}^{DF} < \gamma_{th}) = Pr(X + Y < \gamma_{th}) = \int_0^{\gamma_{th}} F_X(\gamma_{th} - y)f_Y(y)dy \quad (13)$$

where γ_{th} is the predetermined threshold of the system. To find the probability in (13), we have to calculate the cumulative distribution function (CDF) of X and the probability density function (PDF) of Y. So, the CDF of X can be found as;

$$F_X(x) = Pr(X < x) = Pr\left(min\left(\frac{1-\rho}{\eta\rho|f|^2}, \eta\rho\Phi|h_{SR}|^2|h_{RD}|^2\right) < x\right) \quad (14)$$

By denoting $T = |h_{SR}|^2|h_{RD}|^2$ and $Z = |f|^2$, in (14) can be reformulated by;

$$F_X(x) = Pr\left(min\left(\frac{1-\rho}{\eta\rho|f|^2}, \eta\rho\Phi|h_{SR}|^2|h_{RD}|^2\right) < x\right)$$
$$= 1 - \underbrace{Pr\left(\frac{1-\rho}{\eta\rho Z} \geq x\right)}_{I_1} \underbrace{Pr(\eta\rho\Phi|h_{SR}|^2|h_{RD}|^2 \geq x)}_{I_2} \quad (15)$$

From (3), I_1 can be calculated as;

$$I_1 = Pr\left(\frac{1-\rho}{\eta\rho Z} \geq x\right) = Pr\left(Z \leq \frac{1-\rho}{\eta\rho x}\right) = 1 - exp\left(-\frac{\lambda_{RR}(1-\rho)}{\eta\rho x}\right) \quad (16)$$

Next, I_2 can be found by;

$$I_2 = \Pr\left(\eta\rho\Phi\left|h_{SR}\right|^2\left|h_{RD}\right|^2 \geq x\right) = 1 - \Pr\left(\eta\rho\Phi\left|h_{SR}\right|^2\left|h_{RD}\right|^2 < x\right)$$
$$= 1 - \Pr\left(\left|h_{SR}\right|^2 < \frac{x}{\eta\rho\Phi\left|h_{RD}\right|^2}\right) = 1 - \int_0^\infty F_{|h_{SR}|^2}\left(\frac{x}{\eta\rho\Phi\left|h_{RD}\right|^2} \middle| \left|h_{RD}\right|^2 = y\right) \times f_{|h_{RD}|^2}(y)dy \quad (17)$$
$$= \lambda_{RD}\int_0^\infty \exp\left(-\frac{\lambda_{SR}x}{\eta\rho\Phi y} - \lambda_{RD}y\right)dy$$

By applying equation (3.324,1) of [21], in (17) can be reformulated by;

$$I_2 = 2 \times \sqrt{\frac{\lambda_{SR}\lambda_{RD}x}{\eta\rho\Phi}} \times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RD}x}{\eta\rho\Phi}}\right) \quad (18)$$

where $K_v(\bullet)$ is the modified Bessel function of the second kind and v[th] order. Substituting (17) and (18) into (15), we obtain:

$$F_X(x) = 1 - 2\left\{1 - exp\left(-\frac{\lambda_{RR}(1-\rho)}{\eta\rho x}\right)\right\} \times \sqrt{\frac{\lambda_{SR}\lambda_{RD}x}{\eta\rho\Phi}} \times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RD}x}{\eta\rho\Phi}}\right) \quad (19)$$

Next, the CDF of Y can be found by;

$$F_Y(y) = \Pr(Y < y) = \Pr\left(\Phi\left|h_{SD}\right|^2 < y\right) = \Pr\left(\left|h_{SD}\right|^2 < \frac{y}{\Phi}\right)$$
$$= 1 - \exp\left(-\frac{\lambda_{SD}y}{\Phi}\right) \quad (20)$$

From (20), the PDF of Y can be obtained by;

$$f_Y(y) = \frac{\partial F_Y(y)}{\partial y} = \frac{\lambda_{SD}}{\Phi}\exp\left(-\frac{\lambda_{SD}y}{\Phi}\right) \quad (21)$$

Substituting (19) and (21) into (13), finally, the OP in exact form can be claimed as;

$$OP = \int_0^{\gamma_{th}} F_X(\gamma_{th} - y) f_Y(y)dy$$
$$= 1 - \exp\left(-\frac{\lambda_{SD}\gamma_{th}}{\Phi}\right) - \frac{2\lambda_{SD}}{\Phi}\int_0^{\gamma_{th}}\left\{1 - \exp\left(-\frac{\lambda_{RR}(1-\rho)}{\eta\rho(\gamma_{th}-y)}\right)\right\} \times \exp\left(-\frac{\lambda_{SD}y}{\Phi}\right)\Lambda(y) \times K_1\left(2\Lambda(y)\right)dy \quad (22)$$

where $\Lambda(y) = \sqrt{\frac{\lambda_{SR}\lambda_{RD}(\gamma_{th}-y)}{\eta\rho\Phi}}$

3.2. Lower and upper bound analysis

It is easy to observe that (22) is very difficult to calculate in a closed-form expression. Hence, in this section, we will perform the OP of the system in lower and upper bound forms. From (12), we can compute as;

$$2\min\left(X,Y\right) \le X+Y \le 2\max(X,Y) \tag{23}$$

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

$$OP_{LB} = Pr\left[min(X,Y) < \tfrac{\gamma_{th}}{2}\right] = 1 - \underbrace{Pr\left(X \ge \tfrac{\gamma_{th}}{2}\right)}_{P_1}\underbrace{Pr\left(Y \ge \tfrac{\gamma_{th}}{2}\right)}_{P_2} \tag{24}$$

From (19), P_1 can be calculated as;

$$P_1 = 1 - Pr\left(X < \tfrac{\gamma_{th}}{2}\right) = \left\{1 - exp\left(-\tfrac{2\lambda_{RR}(1-\rho)}{\eta\rho\gamma_{th}}\right)\right\} \times \sqrt{\tfrac{2\lambda_{SR}\lambda_{RD}\gamma_{th}}{\eta\rho\Phi}} \times K_1\left(\sqrt{\tfrac{2\lambda_{SR}\lambda_{RD}\gamma_{th}}{\eta\rho\Phi}}\right) \tag{25}$$

Next, P_2 can be found by;

$$P_2 = 1 - \Pr\left(Y < \frac{\gamma_{th}}{2}\right) = \exp\left(-\frac{\lambda_{SD}\gamma_{th}}{2\Phi}\right) \tag{26}$$

Substituting (25) and (26) into (24), we claim:

$$OP_{LB} = 1 - exp\left(-\tfrac{\lambda_{SD}\gamma_{th}}{2\Phi}\right)\left\{1 - exp\left(-\tfrac{2\lambda_{RR}(1-\rho)}{\eta\rho\gamma_{th}}\right)\right\} \times \sqrt{\tfrac{2\lambda_{SR}\lambda_{RD}\gamma_{th}}{\eta\rho\Phi}} \times K_1\left(\sqrt{\tfrac{2\lambda_{SR}\lambda_{RD}\gamma_{th}}{\eta\rho\Phi}}\right) \tag{27}$$

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

$$\begin{aligned} OP_{UB} &= \Pr\left[\max(X,Y) < \frac{\gamma_{th}}{2}\right] = \Pr\left(X < \frac{\gamma_{th}}{2}\right)\Pr\left(Y < \frac{\gamma_{th}}{2}\right) \\ &= \left\{1 - \left\{1 - \exp\left(-\frac{2\lambda_{RR}(1-\rho)}{\eta\rho\gamma_{th}}\right)\right\} \times \sqrt{\frac{2\lambda_{SR}\lambda_{RD}\gamma_{th}}{\eta\rho\Phi}} \times K_1\left(\sqrt{\frac{2\lambda_{SR}\lambda_{RD}\gamma_{th}}{\eta\rho\Phi}}\right)\right\} \\ &\times \left\{1 - \exp\left(-\frac{\lambda_{SD}\gamma_{th}}{2\Phi}\right)\right\} \end{aligned} \tag{28}$$

4. NUMERICAL RESULTS AND DISCUSSION

The model system's system performance is investigated using Monte Carlo simulation, as shown in [22]-[27]. The OP as a function of the energy coefficient η is drawn in Figure 3 with the main system parameters as γ_{th}=1, ψ= 3dB, and ρ=0.3. 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 increase of the energy coefficient. In the same way, the system OP versus γ_{th} is illustrated in Figure 4, and we set η=0.8, Φ=7dB, and ρ=0.8. The system OP has a significant rise while γ_{th} varies from 0 to 6 as shown in Figure 4 for all cases with exact, lower, and upper bound. From Figures 3 and 4, the simulation and the analytical values agree well. Moreover, the system OP versus Φ and ρ are presented in Figures 5 and 6, respectively. We set γ_{th}=1, η=1, and ρ-0.5 for Figure 4, Φ=5 dB for Figure 5, respectively. From Figure 6, it can be stated that the system OP falls while ψ rises from 0 dB to 20 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 ρ=0.5, as shown in Figure 6. Once again, the simulation results agree with the mathematical, analytical results, as in Figures 5 and 6.

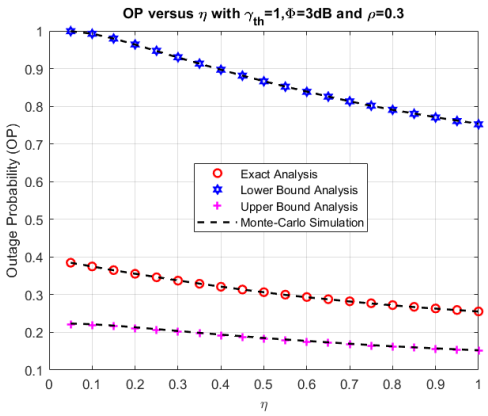

Figure 3. OP versus η

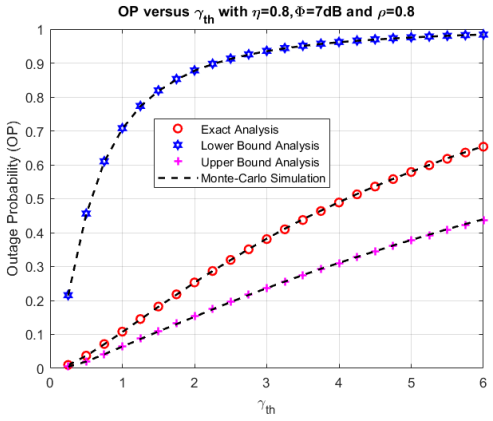

Figure 4. OP versus γ_{th}

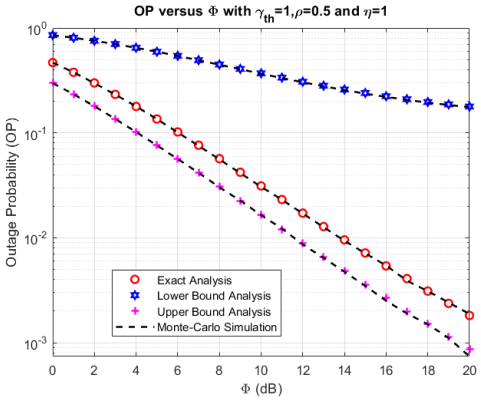

Figure 5. OP versus Φ

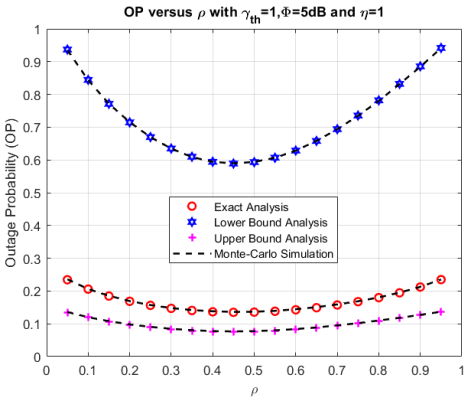

Figure 6. OP versus ρ

5. CONCLUSION

In this paper, the one-way DF full-duplex relaying network system with presence of direct link is investigated. In the analysis section, we derived the exact, lower, and upper bound for outage probability (OP) with maximal ratio combining (MRC) at the receiver. Furthermore, the system performance's analytical expressions are verified by using the Monte Carlo simulation. In addition, we investigated the effect of the main parameters on the OP of the proposed system. Finally, we can sate that the simulation curves overlap the analytical curves to convince the analysis section. This research can provide a novel recommendation for the communication network.

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