

# Outage probability analysis of dual energy harvesting relay network over rayleigh fading channel using SC and MRC technique

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## ABSTRACT

In this paper, the system model of dual-energy harvesting relay network over Rayleigh fading channel and the comparison between Selecting Combining (SC) and Maximal Ratio Combining (MRC) technique cases are proposed and investigated. The closed-form expression of the outage probability for the SC case and the integral-form expression of the outage probability for MRC case is derived. Moreover, the influence of the main parameters on the system performance is demonstrated entirely by the Monte Carlo simulation. From the results, we can see that all simulation and analytical results match well with each other.

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## 1. INTRODUCTION

Nowadays, the fifth generation (5G) network technology is the best solution for the near future communication network. However, increase the energy efficiency of wireless communication networks is the critical problem, on which are strongly depended the economic and ecological aspects of 5G networks. For this target, two solutions are proposed and demonstrated. Firstly, the overall energy consumption of future 5G network shall not exceed 10 percent of the current usage. Secondly, much longer battery life for mobile devices is expected [1-7]. Significant technological steps would have to be taken shortly for this goal to become a reality. Several candidate solutions have been proposed lately to meet the goals above. Technologies based on radio frequency (RF) energy harvesting (EH) and transfer have recently been gaining momentum. With these approaches, future wireless devices would have the capability of harvesting energy from signals emitted either by ambient or dedicated sources [1-7]. In the last few years, radio frequency (RF) energy harvesting (EH) as one of the promising techniques, has received much attention, since it can provide unlimited power to the sensor nodes which scavenge energy from the environment (i.e., solar, wind, etc.). Among these, RF energy radiated by ambient transmitters is almost ubiquitous, which can be harvested more effectively from wireless RF signals. Since RF signal can carry energy and information simultaneously, energy harvesting (EH) and simultaneous wireless information and power transfer (SWIPT) are becoming a

more and more promising research direction [1-7]. In the last few years, the system performance of the energy harvesting relay network has been considered in many studies. [8] investigated the full-duplex energy harvesting relay network with simultaneous energy harvesting and information transmission. Moreover, the development of cooperative protocols for energy harvesting relay network is deeply studied in [9-10]. Furthermore, [11-12] proposed a “harvest-then-transmit” protocol for a multi-user relay network.

In this work, the outage probability analysis of dual-energy harvesting relay network over Rayleigh fading channel using Selection Combining (SC) and Maximal Ratio Combining (MRC) technique is presented and investigated. For details on this analysis, the energy, and information are transferred from the source to the relay nodes, and all channels are considered as the Rayleigh fading channels. The main contributions of the paper are summarized as follows:

- a) The system model of dual-energy harvesting relay network over Rayleigh fading channel and the comparison between Selection Combining (SC) and Maximal Ratio Combining (MRC) technique cases are proposed and investigated.
- b) The closed-form expression of the outage probability for the SC case and the integral-form expression of the outage probability for the MRC case is derived.
- c) The influence of the main parameters on the system performance is demonstrated entirely by the Monte Carlo simulation.

The structure of this paper is proposed as follows. Sections 2 presents the system model of the relaying network. Sections 3 derives the system performance of the model system. Section 4 provides numerical results and some discussions. Finally, Section 5 concludes the paper.

**2. SYSTEM MODEL**

In this section, Figure 1 plots the system model of the dual energy harvesting (EH) relaying network over a Rayleigh fading channel with one Source (S), one Destination (D) and two helping Relay (R<sub>1</sub> and R<sub>2</sub>). Moreover, Figure 2 illustrates the EH and Information Transmission (IT) phases of the model system with the block time T. In the first interval time (αT), the R<sub>1</sub> and R<sub>2</sub> harvest energy from the source signal, where α is the time switching factor α ∈ (0, 1). After that, in the (1-α)T/2 interval time, The S transfers information to the R<sub>1</sub> and R<sub>2</sub>. In the remaining interval time (1-α)T/2, the R<sub>1</sub> and R<sub>2</sub> node transfer information to the D. All the fading channels from S to R and R to D are proposed as the Rayleigh fading channels. More details of the analytical mathematical model of the outage probability and throughput of the system model is presented and analyzed in the following sections [13-25].

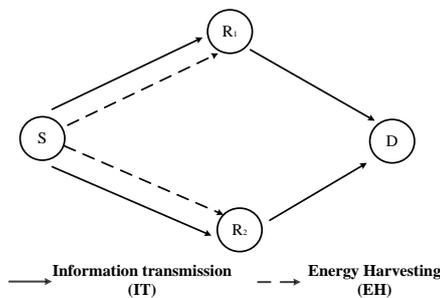


Figure1. System model

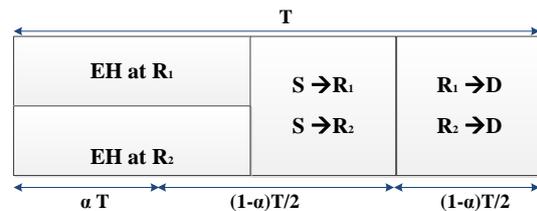


Figure 2. The power splitting protocol

**2.1. Energy Harvesting Phase**

The received signal at R<sub>1</sub> can be expressed as

$$y_{r_1} = h_{sr_1} x_s + n_{r_1} \tag{1}$$

Where  $x_s$  is the transmit signal at the source and  $E\{|x_s|^2\} = P_s$ ,  $E\{\bullet\}$ : expectation operator,  $P_s$  is transmitting power of the source,  $n_{r_1}$ : the additive white Gaussian noise (AWGN) at the relay R<sub>1</sub> with zero-mean and variance  $N_0$ .

The harvested energy at R<sub>1</sub> can be given by

$$E_{r_1} = \alpha T \eta P_s |h_{sr_1}|^2 \tag{2}$$

From (2), the average transmit power at R<sub>1</sub> can be obtained as

$$P_{r_1} = \frac{E_{r_1}}{(1-\alpha)T/2} = \mu P_s |h_{sr_1}|^2 \tag{3}$$

Where we denote  $\mu = \frac{2\eta\alpha}{1-\alpha}$ ,  $0 < \eta \leq 1$  is the energy conversion efficiency and  $0 < \alpha < 1$  is the time switching factor.

Similarity, the received signal at R<sub>2</sub> can be expressed as

$$y_{r_2} = h_{sr_2} x_s + n_{r_2} \tag{4}$$

Where  $n_{r_2}$  is the AWGN at the relay R<sub>2</sub> with zero-mean and variance N<sub>0</sub>.

The average transmit power at R<sub>2</sub> can be claimed as

$$P_{r_2} = \frac{E_{r_2}}{(1-\alpha)T/2} = \mu P_s |h_{sr_2}|^2 \tag{5}$$

**2.2. Information transmission phase**

The received signal at D from the transmitted signal of R<sub>1</sub> and R<sub>2</sub> can be expressed as the followings, respectively.

$$\begin{aligned} y_{d_1} &= h_{r_1d} x_{r_1} + n_d \\ y_{d_2} &= h_{r_2d} x_{r_2} + n_d \end{aligned} \tag{6}$$

Where  $x_{r_1}, x_{r_2}$  are the transmit signal at the relay R<sub>1</sub> and R<sub>2</sub>, respectively.  $E\{|x_{r_1}|^2\} = P_{r_1}$  and  $n_d$  is the AWGN at the destination with zero-mean and variance N<sub>0</sub>.

After received the signal from S, the signal at the relay R<sub>1</sub> will be amplified by amplifying factor as

$$\beta_{r_1} = \frac{x_{r_1}}{y_{r_1}} = \sqrt{\frac{P_{r_1}}{P_s |h_{sr_1}|^2 + N_0}} \tag{7}$$

Substituting (1) and (7) into (6), the received signal at the destination from R<sub>1</sub> can be obtained as

$$\begin{aligned} y_{d_1} &= h_{r_1d} \beta_{r_1} y_{r_1} + n_d = h_{r_1d} \beta_{r_1} [h_{sr_1} x_s + n_{r_1}] + n_d \\ &= \underbrace{h_{r_1d} h_{sr_1} x_s \beta_{r_1}}_{\text{signal}} + \underbrace{h_{r_1d} \beta_{r_1} n_{r_1} + n_d}_{\text{noise}} \end{aligned} \tag{8}$$

The end to end signal to noise (SNR) ratio of S-R<sub>1</sub>-D link can be claimed as

$$\gamma_1 = \frac{E\{|signal|^2\}}{E\{|noise|^2\}} = \frac{|h_{sr_1}|^2 |h_{r_1d}|^2 P_s \beta_{r_1}^2}{|h_{r_1d}|^2 \beta_{r_1}^2 N_0 + N_0} \tag{9}$$

Using the fact that  $N_0 \ll P_{r_1}$ , then, substituting (3) and (7) into (9), the (9) can be rewritten as

$$\gamma_1 \approx \frac{\mu |h_{sr_1}|^2 |h_{r_1d}|^2 \Delta}{\mu |h_{r_1d}|^2 + 1} \quad (10)$$

Where we denote  $\Delta = \frac{P_s}{N_0}$

Similarity, the SNR of S-R<sub>2</sub>-D link can be obtained as

$$\gamma_2 \approx \frac{\mu |h_{sr_2}|^2 |h_{r_2d}|^2 \Delta}{\mu |h_{r_2d}|^2 + 1} \quad (11)$$

### 3. THE SYSTEM PERFORMANCE

#### 3.1. Selection Combining (SC)

In this section, we consider the diversity technique SC at the receiver. In this technique, the destination will choose the best SNR between S-R<sub>1</sub>-D and S-R<sub>2</sub>-D link

Hence, the end to end SNR can be given by

$$\gamma_{e2e}^{SC} = \max(\gamma_1, \gamma_2) \quad (12)$$

Substituting (10) and (11) into (12), finally, the end to end SNR at D can be rewritten as

$$\gamma_{e2e}^{SC} = \max \left( \frac{\mu |h_{sr_1}|^2 |h_{r_1d}|^2 \Delta}{\mu |h_{r_1d}|^2 + 1}, \frac{\mu |h_{sr_2}|^2 |h_{r_2d}|^2 \Delta}{\mu |h_{r_2d}|^2 + 1} \right) \quad (13)$$

Outage probability (OP) analysis

$$\begin{aligned} OP_{SC} &= \Pr(\gamma_{e2e}^{SC} < \gamma_{th}) = \Pr \left\{ \max \left( \frac{\mu |h_{sr_1}|^2 |h_{r_1d}|^2 \Delta}{\mu |h_{r_1d}|^2 + 1}, \frac{\mu |h_{sr_2}|^2 |h_{r_2d}|^2 \Delta}{\mu |h_{r_2d}|^2 + 1} \right) < \gamma_{th} \right\} \\ &= \Pr \left( \frac{\mu |h_{sr_1}|^2 |h_{r_1d}|^2 \Delta}{\mu |h_{r_1d}|^2 + 1} < \gamma_{th} \right) \times \Pr \left( \frac{\mu |h_{sr_2}|^2 |h_{r_2d}|^2 \Delta}{\mu |h_{r_2d}|^2 + 1} < \gamma_{th} \right) \\ &= P_1 \times P_2 \end{aligned} \quad (14)$$

Where  $\gamma_{th} = 2^{2R} - 1$  is the threshold and R is the target rate.

We denote as

$$\begin{aligned} P_1 &= \Pr \left( \frac{\mu |h_{sr_1}|^2 |h_{r_1d}|^2 \Delta}{\mu |h_{r_1d}|^2 + 1} < \gamma_{th} \right) = \Pr \left[ |h_{sr_1}|^2 < \frac{\gamma_{th}}{\Delta} + \frac{\gamma_{th}}{\mu \Delta |h_{r_1d}|^2} \right] \\ &= \int_0^\infty F_{|h_{sr_1}|^2} \left( \frac{\gamma_{th}}{\Delta} + \frac{\gamma_{th}}{\mu \Delta |h_{r_1d}|^2} \mid |h_{sr_1}|^2 \right) f_{|h_{r_1d}|^2} \left( |h_{r_1d}|^2 \right) d \left( |h_{r_1d}|^2 \right) \\ &= \int_0^\infty F_X \left( \frac{\gamma_{th}}{\Delta} + \frac{\gamma_{th}}{\mu \Delta Y} \mid X \right) f_Y(Y) dY \end{aligned} \quad (15)$$

Where we denote  $X = |h_{sr_1}|^2$ ,  $Y = |h_{r_1d}|^2$ .

Then the (15) can be obtained as

$$\begin{aligned}
 P_1 &= 1 - \lambda_{r_1d} \int_0^\infty \exp\left[-\lambda_{sr_1} \left(\frac{\gamma_{th}}{\Delta} + \frac{\gamma_{th}}{\mu\Delta Y}\right)\right] \times \exp(-\lambda_{r_1d} Y) dY \\
 &= 1 - \lambda_{r_1d} \exp\left(-\frac{\lambda_{sr_1} \gamma_{th}}{\Delta}\right) \int_0^\infty \exp\left(-\frac{\lambda_{sr_1} \gamma_{th}}{\mu\Delta Y}\right) \times \exp(-\lambda_{r_1d} Y) dY
 \end{aligned}
 \tag{16}$$

Where  $\lambda_{sr_1}, \lambda_{r_1d}$  are the mean of the random variable  $|h_{sr_1}|^2, |h_{r_1d}|^2$ , respectively.

Apply equation (3.324,1) of the table of integral [26], from(16) can be reformulated as

$$P_1 = 1 - 2 \exp\left(-\frac{\lambda_{sr_1} \gamma_{th}}{\Delta}\right) \times \sqrt{\frac{\lambda_{sr_1} \lambda_{r_1d} \gamma_{th}}{\mu\Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sr_1} \lambda_{r_1d} \gamma_{th}}{\mu\Delta}}\right)
 \tag{17}$$

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

Similarity,  $P_1, P_2$  can be claimed as

$$P_2 = 1 - 2 \exp\left(-\frac{\lambda_{sr_2} \gamma_{th}}{\Delta}\right) \times \sqrt{\frac{\lambda_{sr_2} \lambda_{r_2d} \gamma_{th}}{\mu\Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sr_2} \lambda_{r_2d} \gamma_{th}}{\mu\Delta}}\right)
 \tag{18}$$

Finally, substituting (17), (18) into (14), the OP by using SC technique can be obtained as the following

$$\begin{aligned}
 OP_{SC} &= \left\{ 1 - 2 \exp\left(-\frac{\lambda_{sr_1} \gamma_{th}}{\Delta}\right) \times \sqrt{\frac{\lambda_{sr_1} \lambda_{r_1d} \gamma_{th}}{\mu\Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sr_1} \lambda_{r_1d} \gamma_{th}}{\mu\Delta}}\right) \right\} \\
 &\times \left\{ 1 - 2 \exp\left(-\frac{\lambda_{sr_2} \gamma_{th}}{\Delta}\right) \times \sqrt{\frac{\lambda_{sr_2} \lambda_{r_2d} \gamma_{th}}{\mu\Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sr_2} \lambda_{r_2d} \gamma_{th}}{\mu\Delta}}\right) \right\}
 \end{aligned}
 \tag{19}$$

### 3.2. Maximal Ratio Combining (MRC)

In this technique, the signal at the destination from S-R<sub>1</sub>-D and S-R<sub>2</sub>-D link will be incorporated. Hence, the end to end SNR at the destination can be expressed as

$$\gamma_{e2e}^{MRC} = \gamma_1 + \gamma_2 = \frac{\mu |h_{sr_1}|^2 |h_{r_1d}|^2 \Delta}{\mu |h_{r_1d}|^2 + 1} + \frac{\mu |h_{sr_2}|^2 |h_{r_2d}|^2 \Delta}{\mu |h_{r_2d}|^2 + 1}
 \tag{20}$$

Outage probability analysis

$$\begin{aligned}
 OP_{MRC} &= \Pr(\gamma_{e2e}^{MRC} < \gamma_{th}) = \Pr(\gamma_1 + \gamma_2 < \gamma_{th}) \\
 &= \int_0^{\gamma_{th}} f_y(y) dy \int_0^{\gamma_{th}-y} f_x(x) dx \\
 &= \int_0^{\gamma_{th}} [F_x(\gamma_{th} - y) - F_x(0)] f_y(y) dy
 \end{aligned}
 \tag{21}$$

Where we denote  $x = \gamma_1, y = \gamma_2$ , and  $F_x(\gamma_{th}) = \Pr(x < \gamma_{th}) = \Pr(\gamma_1 < \gamma_{th})$ .

So, from (17), easily to observe that  $F_x(0) = 0$ .

Hence, (21) can be rewritten as the following

$$OP_{MRC} = \int_0^{\gamma_{th}} F_x(\gamma_{th} - y) f_y(y) dy \quad (22)$$

In order to calculate the OP in (22), we have to find  $f_y(y)$ . Based on the definition of probability density function (PDF) and cumulative distribution function (CDF),  $f_y(y)$  can be obtained as

$$f_y(y) = \frac{\partial F_y(y)}{\partial y} \quad (23)$$

Using (18), we have

$$F_y(y) = \Pr(\gamma_2 < y) = 1 - 2 \exp\left(-\frac{\lambda_{sf_2} y}{\Delta}\right) \times \sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}}\right) \quad (24)$$

Using the formula  $\frac{d}{dx}(x^v K_v(x)) = -x^v K_{v-1}(x)$ , from (23) can be reformulated as

$$f_y(y) = \frac{2\lambda_{sf_2}}{\Delta} \times \exp\left(-\frac{\lambda_{sf_2} y}{\Delta}\right) \times \sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}}\right) + \frac{2\lambda_{sf_2} \lambda_{r_2 d}}{\mu \Delta} \times \exp\left(-\frac{\lambda_{sf_2} y}{\Delta}\right) \times K_0\left(2\sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}}\right) \quad (25)$$

Combine (17) and substituting (25) into (22), the OP of the MRC technique can be claimed as

$$OP_{MRC} = \int_0^{\gamma_{th}} \left\{ \left[ 1 - 2 \exp\left(-\frac{\lambda_{sf_1} [\gamma_{th} - y]}{\Delta}\right) \times \sqrt{\frac{\lambda_{sf_1} \lambda_{r_1 d} [\gamma_{th} - y]}{\mu \Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sf_1} \lambda_{r_1 d} [\gamma_{th} - y]}{\mu \Delta}}\right) \right] \times \left[ \frac{2\lambda_{sf_2}}{\Delta} \times \exp\left(-\frac{\lambda_{sf_2} y}{\Delta}\right) \times \sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}} \times K_1\left(2\sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}}\right) + \frac{2\lambda_{sf_2} \lambda_{r_2 d}}{\mu \Delta} \times \exp\left(-\frac{\lambda_{sf_2} y}{\Delta}\right) \times K_0\left(2\sqrt{\frac{\lambda_{sf_2} \lambda_{r_2 d} y}{\mu \Delta}}\right) \right] \right\} dy \quad (26)$$

Throughput can be calculated as

$$\tau_{SC \text{ or } MRC} = (1 - OP_{SC \text{ or } MRC}) \times \frac{R(1-\alpha)T/2}{T} = (1 - OP_{SC \text{ or } MRC}) \times \frac{R(1-\alpha)}{2} \quad (27)$$

#### 4. NUMERICAL RESULTS AND DISCUSSION

In the simulation stage, we set that  $\lambda_{sf_1} = 0.5$ ,  $\lambda_{rd_1} = 1$ ,  $\lambda_{sf_2} = 1.5$ ,  $\lambda_{sd_2} = 2$ . The influence of the energy efficiency coefficient  $\eta$  on the OP and throughput of the model system are plotted in Figures 3 and 4, respectively. As shown in these Figures, we can say that the OP falls, but the throughput rises with the rising  $\eta$  from 0 to 1. In this simulation step, we set  $R=1$ , 2 bps/Hz,  $\Delta=5$  dB and  $\alpha=1$ . It can be seen that the performance of the proposed system with SC technique is better than with the MRC technique and the simulation results are the same as the analytical results. In a similar way, the OP and throughput versus the time splitting factor  $\alpha$  are shown in Figures 5 and 6 with  $\eta=0.8$ ,  $\Delta=1$ , 5 dB and  $\alpha=0.5$ . As shown in Figure 5, the OP has a considerable decrease. The throughput rises when  $\alpha$  varies from 0 to 0.5 and then fall crucially

with  $\alpha$  from 0.5 to 1 as plotted in Figure 6. The optimal value of the system throughput can be obtained at 0.5 of  $\alpha$  as shown in Figure 6. Once again, the simulation and analytical results are the same.

Moreover, the influence of  $\Delta$  on the Op and system throughput are illustrated in Figures 7 and 8 with  $\alpha=0.5, 0.85, \eta=0.8$  and  $\Delta$  varies from -5 dB to 25 dB. Here, we can see that the OP significant decreases and throughput rises with rising  $\Delta$ . Also, the OP and system throughput versus R is drawn in Figures 9 and 10. It can be observed that the OP increases and throughput decrease significantly when the R varies from 0.5 to 2.5 bit/s/Hz. After that, the OP and throughput have slight changes when R increases from 2.5 to 5 bit/s/Hz. In all the above Figs, the simulation and analytical results agree with each other.

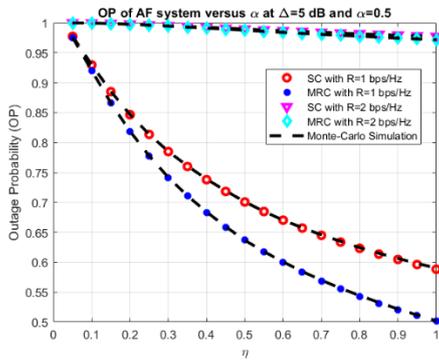


Figure 3. OP versus  $\eta$

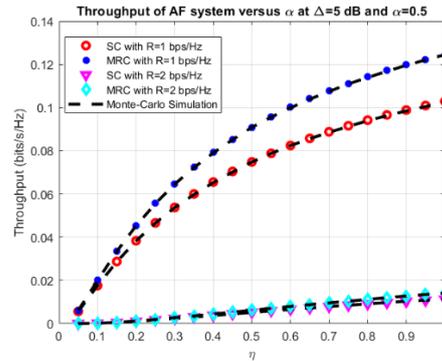


Figure 4. Throughput versus  $\eta$

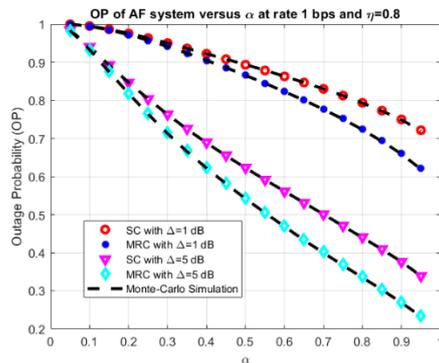


Figure 5. OP versus  $\alpha$

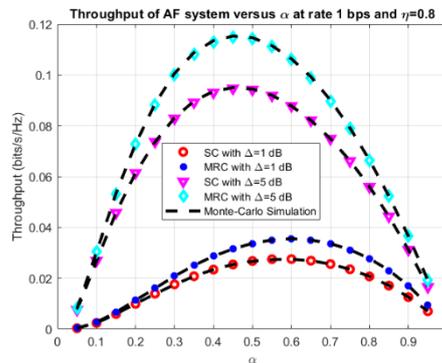


Figure 6. Throughput versus  $\alpha$

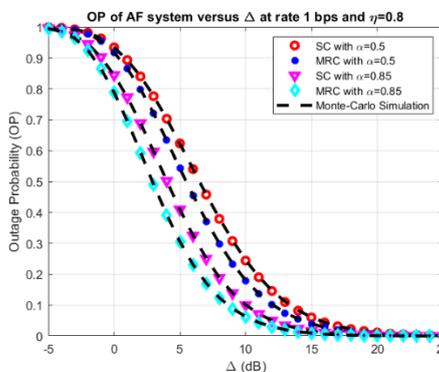


Figure 7. OP versus  $\Delta$

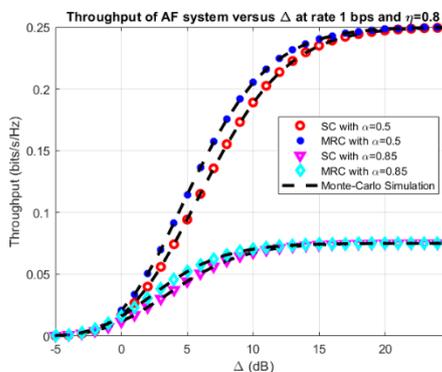


Figure 8. Throughput versus  $\Delta$

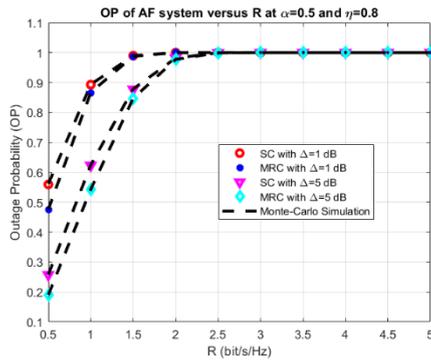


Figure 9. OP versus R

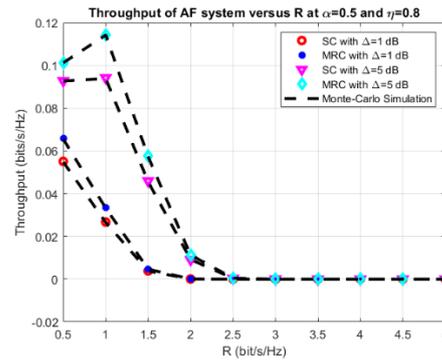


Figure 10. Throughput versus R

## 5. CONCLUSION

In this paper, the system model of dual-energy harvesting relay network over Rayleigh fading channel and the comparison between SC and MRC techniques cases are proposed and investigated. The closed-form expression of the outage probability for the SC case and the integral-form expressions of the outage probability for MRC case is derived. Moreover, the influence of the main parameters on the system performance is demonstrated entirely by the Monte Carlo simulation. From the results, we can see that all simulation and analytical results match well with each other. This paper provides a novel recommendation for the communication relaying network shortly.

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