Outage probability analysis of EH relay-assisted non-orthogonal multiple access (NOMA) systems over block rayleigh fading channel

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ABSTRACT

Non-orthogonal multiple access (NOMA) has been identified as a promising multiple access technique for the fifth generation (5G) mobile networks due to its superior spectral efficiency. In this paper, we introduce and investigate a Non-orthogonal multiple access (NOMA) of energy harvesting (EH) relay assisted system over Block Rayleigh Fading Channel. To evaluate the performance of the proposed system, the integral expression of the outage probability is analyzed and derived. Numerical results confirm that our derived analytical results match well with the Monte Carlo simulations in connection with all possible system parameter.

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1. INTRODUCTION

In the history of wireless communications from the first generation (1G) to 4G, the multiple access scheme has been the key technology to distinguish different wireless systems. It is well known that frequency-division multiple access (FDMA) for 1G, time-division multiple access (TDMA) mostly for 2G, code-division multiple access (CDMA) for 3G, and orthogonal frequency-division multiple access (OFDMA) for 4G are primarily orthogonal multiple access (OMA) schemes. In these conventional multiple access schemes, different users are allocated to orthogonal resources in either the time, frequency, or code domain in order to avoid or alleviate interfuse interference. In this way, multiplexing gain can be achieved with reasonable complexity. However, the fast growth of mobile Internet has propelled 1000-fold data traffic increase by 2020 for 5G. Hence, the spectral efficiency becomes one of the key challenges to handle such explosive data traffic. Moreover, due to the rapid development of the Internet of Things (IoT), 5G needs to support massive connectivity of users and/or devices to meet the demand for low latency, low-cost devices, and diverse service types. To satisfy these requirements, enhanced technologies are necessary. So far, some potential candidates have been proposed to address challenges of 5G, such as massive MIMO, millimeter wave communications, ultra-dense network, and non-orthogonal multiple access (NOMA). From that analysis, Non-orthogonal multiple access (NOMA) has been identified as a promising multiple access technique for the fifth generation (5G) mobile networks due to its superior spectral efficiency [1-6]. In contrast to traditional water-filling power allocation strategy, NOMA allocates more power to the users with worse channel conditions, which results in a better tradeoff between the system throughput and user fairness. From the previous researches, the impact of user pairing on downlink NOMA systems has been characterized in [7], the work in [8] has studied the power allocation with max-min fairness criterion. An uplink NOMA scheme with joint power and subcarrier allocations has been proposed in [9], where the performance of both link-level and system level has been investigated. In [10], a cooperation-based NOMA scheme for coordinated direct and relay transmissions has been introduced. A diversity-oriented detection mechanism for the cooperative relaying system using NOMA has been proposed in [11]. The performance of transmit antenna selection for NOMA assisted multiple-input-multiple-output (MIMO) relay networks have been examined in [12]. Inspired by user collaboration, a cooperative NOMA transmission scheme has been proposed in [13].

The main objective of this article is to propose and investigate a Non-Orthogonal Multiple Access (NOMA) EH relay assisted system over Block Rayleigh Fading Channel. Firstly, we proposed and investigated a Non-Orthogonal Multiple Access (NOMA) EH relay-assisted system over Block Rayleigh Fading Channel. In the analysis process, we analyze and derive the integral expression of the outage probability. Finally, the Monte Carlo Simulation is used for validating the analytical analysis in connection with all possible system parameters. The results show that the analytical and simulation results agree well with each other in contact with all possible system parameters. The main contributions of this research can be focused on as the followings:

- We propose and investigate a Non-Orthogonal Multiple Access (NOMA) EH relay assisted system over Block Rayleigh Fading Channel.
- The integral form expression of the outage probability is analyzed and derived.
- The influence of all possible system parameters on the outage probability is investigated and discussed.
- All results are verified by the Monte Carlo simulation.

The rest of this manuscript is organized as follows. In section 2, we present the proposed system model and analysis of the outage probability of the proposed system model. Numerical results and some discussion are drawn in section 3. Section 4 concludes this manuscript.

2. SYSTEM MODEL AND OUTAGE PROBABILITY ANALYSIS

As shown in Figure 1, we proposed a simple cooperative network where a source node, communicates with a destination node, D, via the helping of a decode-and-forward (DF) relay node, R. Moreover, the source S can also directly communicate the destination D. Here, we assume that the systems operate in half-duplex mode, i.e,.., the relay cannot transmit and receive a symbol at the same time. We denote the channel coefficients h_{SR}, h_{SD}, h_{RD} of the link between S, R, and D, respectively.

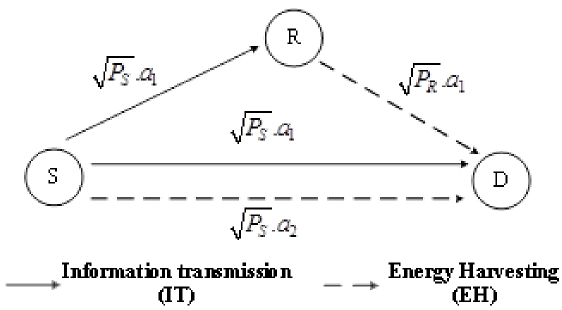

Figure 1. System model

The fading gains in all involved links are assumed to follow the Rayleigh distribution with the probability density function (PDF) as in [14].

$$f_{|h_k|^2}(x) = \frac{1}{\lambda_k}\exp(-\frac{x}{\lambda_k}) \quad (1)$$

Where $k \in \{SR, SD, RD\}$.

From (1) the cumulative distribution function (CDF) can be obtained as $F_{|h_k|^2}(x) = 1-\exp(-\frac{x}{\lambda_k})$, λ_k is the mean of the random variable $|h_k|^2$.

As in many previous publications, we assume that the source and destination, as well as the relay, know the channel gains. The energy harvesting and information processing for this proposed model system as shown in Figure 2. In this protocol, the transmission is divided into blocks of length T, which consists of three time slots. In the first time slot αT (α is the time switching factor, $0<\alpha<1$), the relay harvests energy from the source node S_n. In the second interval time (1-α) T/2, the source S transfers the information to R and D at the same time. Finally, the remaining time slot (1-α) T/2 is used for information transferring from the relay node to the destination.

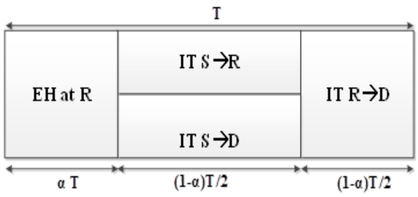

Figure 2. EH and IT processes

The harvested energy at the relay can be expressed as in [14]

$$E_h = \eta\alpha T P_s |h_{SR}|^2 \quad (2)$$

Where $0<\eta\le 1$ is energy conversion efficiency, and $0<\alpha<1$ is a time-switching factor.

The average transmit power at the relay can be given by

$$P_R = \frac{E_h}{(1-\alpha)T/2} = \beta P_s |h_{SR}|^2 \quad (3)$$

Where $\beta = \frac{2\eta\alpha}{1-\alpha}$

The communication process for cooperative relay systems consists of the remaining two consecutive time slots. During the second time slot, the source S will transmit a symbol a_1 with the power P_s to both the relay R and destination D. Therefore, the received signal at R and D can be expressed as, respectively.

$$\begin{aligned} y_{R,a_1} &= \sqrt{P_S} h_{SR} a_1 + n_R, \\ y_{D,a_1} &= \sqrt{P_S} h_{SD} a_1 + n_D \end{aligned} \quad (4)$$

Where n_R, n_D are the additive white Gaussian noise (AWGN) with zero mean and variance N_0, and $\mathrm{E}\{|a_1|^2\} = 1$, $\mathrm{E}\{\bullet\}$ is expectation operator.

The received signal to noise ratio (SNR) for the symbol a_1 at R and D is given by, respectively.

$$\begin{aligned} \gamma_{SR,a_1} &= \frac{P_S |h_{SR}|^2}{N_0} = \gamma_0 |h_{SR}|^2, \\ \gamma_{SD,a_1} &= \frac{P_S |h_{SD}|^2}{N_0} = \gamma_0 |h_{SD}|^2 \end{aligned} \quad (5)$$

Where $\gamma_0 = \frac{P_s}{N_0}$.

In the third time slot, R will forward the decoded symbol a_1 with the power P_R to D, and S will transmit another symbol a_2 with $\mathrm{E}\left\{|a_2|^2\right\}=1$ and the power P_s to D. Hence, the received signal at D is given by

$$y_D = \sqrt{P_R} h_{RD} a_1 + \sqrt{P_s} h_{SD} a_2 + n_D \quad (6)$$

Apply successive interference cancellation (SIC)-based NOMA scheme, D firstly decodes the symbol a_1 by disposing of the symbol a_2 as a noise term. Also, a_1 is rejected from y_D by using SIC to decode a_2 . So, the received SNRs for symbol a_1 and a_2 are respectively obtained as

$$\gamma_{D,a_1} = \frac{P_R |h_{RD}|^2}{P_s |h_{SD}|^2 + N_0} = \frac{\beta\gamma_0 |h_{SR}|^2 |h_{RD}|^2}{\gamma_0 |h_{SD}|^2 + 1} \quad (7)$$

$$\gamma_{D,a_2} = \gamma_0 |h_{SD}|^2 \quad (8)$$

Finally, we can obtain the end to end SNR for the transmitted symbol a_1 as the following

$$\gamma_{e2e,a_1} = \min\left(\gamma_{D,a_1}, \gamma_{SR,a_1}\right) \quad (9)$$

Using the selecting combining (SC) technique at the receiver, so the total outage probability of a_1 is given by

$$\begin{aligned}
OP_{a_1} &= \Pr\left[\max\left\{\min\left(\gamma_{D,a_1},\gamma_{SR,a_1}\right),\gamma_{SD,a_1}\right\} < \gamma_{th}\right] \\
&= \Pr\left[\max\left\{\min\left(\frac{\beta\gamma_0 |h_{SR}|^2 |h_{RD}|^2}{\gamma_0 |h_{SD}|^2 + 1}, \gamma_0 |h_{SR}|^2\right), \gamma_0 |h_{SD}|^2\right\} < \gamma_{th}\right] \\
&= \Pr\left[\max\left\{\min\left(\frac{\beta\gamma_0 XY}{\gamma_0 Z + 1}, \gamma_0 X\right), \gamma_0 Z\right\} < \gamma_{th}\right] \\
&= \Pr\left[\min\left(\frac{\beta\gamma_0 XY}{\gamma_0 Z + 1}, \gamma_0 X\right) < \gamma_{th}, \gamma_0 Z < \gamma_{th}\right] \\
&= \Pr\left[\left(\frac{\beta\gamma_0 XY}{\gamma_0 Z + 1} < \gamma_{th} \text{ or } \gamma_0 X < \gamma_{th}\right) and \left(\gamma_0 Z < \gamma_{th}\right)\right] \\
&= \Pr\left[\left(\frac{\beta\gamma_0 XY}{\gamma_0 Z + 1} < \gamma_{th} \; and \; \gamma_0 Z < \gamma_{th}\right) \text{or} \left(\gamma_0 X < \gamma_{th} \; and \; \gamma_0 Z < \gamma_{th}\right)\right] \\
&= \Pr\left(\frac{\beta\gamma_0 XY}{\gamma_0 Z + 1} < \gamma_{th}, \gamma_0 Z < \gamma_{th}\right) + \Pr\left(\gamma_0 X < \gamma_{th}, \gamma_0 Z < \gamma_{th}\right) \\
&- \Pr\left(\frac{\beta\gamma_0 XY}{\gamma_0 Z + 1} < \gamma_{th} \; and \; \gamma_0 X < \gamma_{th} \; and \; \gamma_0 Z < \gamma_{th}\right) \\
&= \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty} f_X(x)dx \int_0^{\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 X}} f_Y(y)dy + F_X\left(\frac{\gamma_{th}}{\gamma_0}\right) F_Z\left(\frac{\gamma_{th}}{\gamma_0}\right) \\
&- \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_X(x)dx \int_0^{\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 X}} f_Y(y)dy
\end{aligned} \quad (10)$$

Where we denote $X = |h_{SR}|^2, Y = |h_{RD}|^2, Z = |h_{SD}|^2, \gamma_{th} = 2^{2R} - 1$, and R is the source rate. Let's us to denote

$$\begin{aligned} P_1 &= \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty} f_X(x)dx \int_0^{\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 X}} f_Y(y)dy = \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty} F_Y\left[\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 X}\right] f_X(x)dx \\ &= \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty}\left(1-\exp\left[-\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 X\lambda_{RD}}\right]\right) f_X(x)dx \\ &= \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty} f_X(x)dx - \frac{1}{\lambda_{SR}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty} \exp\left[-\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 x\lambda_{RD}} - \frac{x}{\lambda_{SR}}\right]dx \\ &= F_Z\left(\frac{\gamma_{th}}{\gamma_0}\right) - \frac{1}{\lambda_{SR}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\infty} \exp\left[-\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 x\lambda_{RD}} - \frac{x}{\lambda_{SR}}\right]dx \end{aligned} \quad (11)$$

Apply eq (3.324, 1) of the table of integral [15], (11) can be rewritten as the following

$$\begin{aligned} P_1 &= F_Z\left(\frac{\gamma_{th}}{\gamma_0}\right) - \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)\sqrt{4\frac{\gamma_{th}(\gamma_0 z+1)}{\beta\gamma_0\lambda_{RD}\lambda_{SR}}} K_1\left(2\sqrt{\frac{\gamma_{th}(\gamma_0 z+1)}{\beta\gamma_0\lambda_{RD}\lambda_{SR}}}\right)dz \\ &= F_Z\left(\frac{\gamma_{th}}{\gamma_0}\right) - \frac{1}{\lambda_{SD}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} 2\sqrt{\frac{\gamma_{th}(\gamma_0 z+1)}{\beta\gamma_0\lambda_{RD}\lambda_{SR}}} \exp\left(-\frac{z}{\lambda_{SD}}\right) K_1\left(2\sqrt{\frac{\gamma_{th}(\gamma_0 z+1)}{\beta\gamma_0\lambda_{RD}\lambda_{SR}}}\right)dz \end{aligned} \quad (12)$$

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

$$\begin{aligned} P_2 &= \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_X(x)dx \int_0^{\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 X}} f_Y(y)dy \\ &= \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_X(x)dx - \frac{1}{\lambda_{SR}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\frac{\gamma_{th}}{\gamma_0}} \exp\left[-\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 x\lambda_{RD}} - \frac{x}{\lambda_{SR}}\right]dx \\ &= F_Z\left(\frac{\gamma_{th}}{\gamma_0}\right) F_X\left(\frac{\gamma_{th}}{\gamma_0}\right) - \frac{1}{\lambda_{SR}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} f_Z(z)dz \int_0^{\frac{\gamma_{th}}{\gamma_0}} \exp\left[-\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 x\lambda_{RD}} - \frac{x}{\lambda_{SR}}\right]dx \end{aligned} \quad (13)$$

Replace (12), (13) into (10), we have

$$\begin{aligned} OP_{a_1} &= 1 - e^{-\frac{\gamma_{th}}{\gamma_0\lambda_{SD}}} - \frac{1}{\lambda_{SD}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} 2\sqrt{\frac{\gamma_{th}(\gamma_0 z+1)}{\beta\gamma_0\lambda_{RD}\lambda_{SR}}} \exp\left(-\frac{z}{\lambda_{SD}}\right) K_1\left(2\sqrt{\frac{\gamma_{th}(\gamma_0 z+1)}{\beta\gamma_0\lambda_{RD}\lambda_{SR}}}\right)dz \\ &+ \frac{1}{\lambda_{SR}\lambda_{SD}} \int_0^{\frac{\gamma_{th}}{\gamma_0}} \exp\left(-\frac{z}{\lambda_{SD}}\right)dz \int_0^{\frac{\gamma_{th}}{\gamma_0}} \exp\left[-\frac{\gamma_{th}(\gamma_0 Z+1)}{\beta\gamma_0 x\lambda_{RD}} - \frac{x}{\lambda_{SR}}\right]dx \end{aligned} \quad (14)$$

Similarity, the end to end SNR for the transmitted symbol a_2 can be calculated as

$$\gamma_{e2e,a_2} = \min\left(\gamma_{D,a_1}, \gamma_{D,a_2}\right) \quad (15)$$

Therefore, the total outage probability of a_2 can be computed as

$$\begin{aligned} OP_{a_2} &= \Pr\left(\gamma_{e2e,a_2} < \gamma_{th}\right) = \Pr\left(\min\left\{\gamma_{D,a_1}, \gamma_{D,a_2}\right\} < \gamma_{th}\right) = 1 - \Pr\left(\gamma_{D,a_1} \ge \gamma_{th}, \gamma_{D,a_2} \ge \gamma_{th}\right) \\ &= 1 - \Pr\left(\frac{\beta\gamma_0 |h_{SR}|^2 |h_{RD}|^2}{\gamma_0 |h_{SD}|^2 + 1} \ge \gamma_{th}, \gamma_0 |h_{SD}|^2\right) \end{aligned} \quad (16)$$

In order to find the total outage probability of a_2, we denote that $V = |h_{SR}|^2 |h_{RD}|^2, W = |h_{SD}|^2$, (16) can be rewritten as

$$OP_{a_2} = 1 - \Pr\left(\frac{\beta\gamma_0 V}{\gamma_0 W + 1} \ge \gamma_{th}, \gamma_0 W \ge \gamma_{th}\right) = 1 - \Pr\left(V \ge \frac{\gamma_{th}\left[\gamma_0 W + 1\right]}{\beta\gamma_0}, W \ge \frac{\gamma_{th}}{\gamma_0}\right)$$
$$= 1 - \int_{\frac{\gamma_{th}}{\gamma_0}}^{\infty} f_W(w)dw \int_{\frac{\gamma_{th}[\gamma_0 w+1]}{\beta\gamma_0}}^{\infty} f_V(v)dv \quad (17)$$

Utilizing the result in [16], the CDF of V can be shown as the (18):

$$F_V(v) = 1 - 2\sqrt{\frac{v}{\lambda_{SR}\lambda_{RD}}} K_1\left(2\sqrt{\frac{v}{\lambda_{SR}\lambda_{RD}}}\right) \quad (18)$$

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

From (17), (18), we have:

$$OP_{a_2} = 1 - \frac{2}{\lambda_{SD}} \int_{\frac{\gamma_{th}}{\gamma_0}}^{\infty} e^{-\frac{w}{\lambda_{SD}}} \sqrt{\frac{\gamma_{th}[\gamma_0 w + 1]}{\beta\gamma_0\lambda_{SR}\lambda_{RD}}} K_1\left\{2\sqrt{\frac{\gamma_{th}[\gamma_0 w + 1]}{\beta\gamma_0\lambda_{SR}\lambda_{RD}}}\right\} dw \quad (19)$$

3. RESULTS AND DISCUSSION

For validation, the correctness of the derived system performance expressions, as well as investigation of the effect of various parameters on the system performance, a set of Monte Carlo simulations are conducted and presented in this section [17-21]. For each simulation, we first provide the graphs from the analytical formulas. Secondly, we plot the same curves that result from the Monte Carlo simulation. For this purpose, we generate 106 random samples of each channel gain, which are Rayleigh distributed. Finally, the analytical curve and the simulation one should match together to verify the correctness of our analysis.

The outage probability of the proposed system versus transmitting SNR γ_0 is plotted in Figure 3 with basic system parameters as R=0.5 bps, η=0.8, α=0.45 and 0.85. In this analysis, the transmit SNR γ_0 varies from -10 dB to 20 dB continuously. From the research results, we see that the outage probability of the proposed system decreases significantly with the increasing the transmit SNR γ_0. It can be observed that the higher transmit SNR γ_0 causes a higher throughput of the proposed system. All the simulation and analytical curves matched well with each other.

Furthermore, Figure 4 shows the connection between the system outage probability and time switching factor α with the main system parameters as R=0.5 bps, γ_0= 10 dB and η=0.4, 0.8. As shown in Figure 4, we can see that the outage probability of the system model has a decrease when the time switching factor α varies from 0 to 1 in the connection with the fact that more power is used for harvesting energy at R than power is used for information transmission between D, R and S. Again all simulation and analytical results agree well with each other.

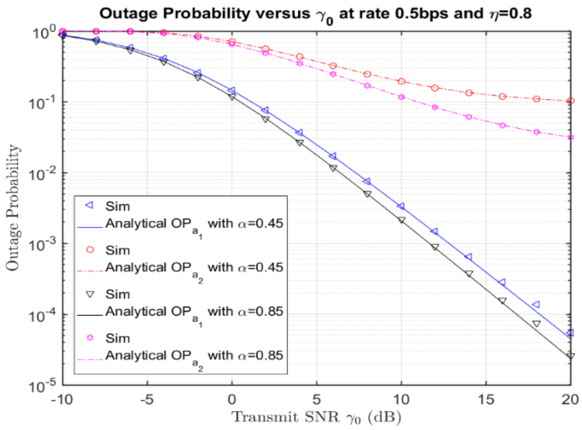

Figure 3. OP versus transmit SNR γ_0

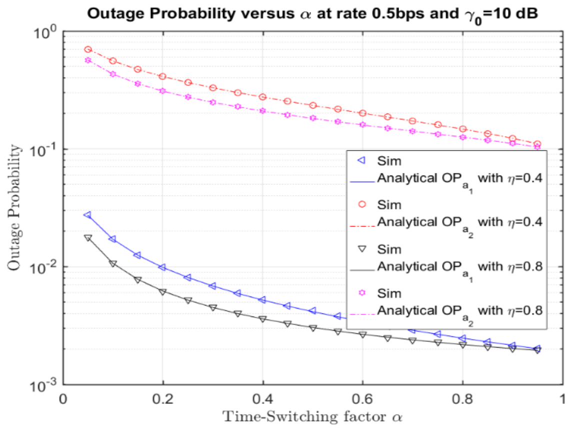

Figure 4. OP versus α

Moreover, the function of the outage probability on the energy conversion efficiency η as shown in Figure 5. Here we set the main system parameters as R-0.5 bps, α=0.5 and γ_0= 5, 10 dB. Similar to the above cases, the outage probability of the model system increases crucially while the energy conversion efficiency varies from 0 to 1. It can be observed that the more efficient energy conversion of the system the less outage probability. In addition, the analytical curve is the same as the simulation curve as shown in Figure 5.

Finally, the outage probability versus the source rate R as shown in Figure 6 with α=0.5, η=0.8 and γ_0= 5, 10 dB. From the results, the outage probability increases significantly when the source rate increases from 0 to 7. We can see that the simulation and the analytical result are the same with all values of the source rate R.

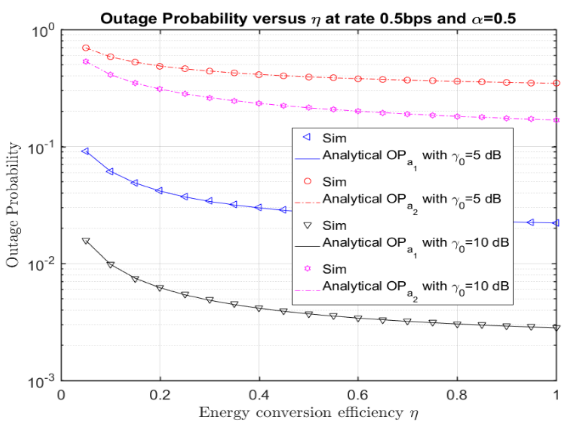

Figure 5. OP versus η

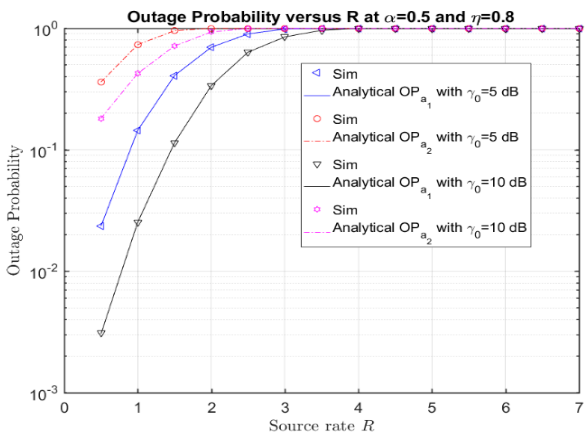

Figure 6. OP versus R

4. CONCLUSION

In this paper, we introduce and investigate a Non-Orthogonal Multiple Access (NOMA) EH relay assisted system over Block Rayleigh Fading Channel. Firstly, we proposed and investigated a Non-Orthogonal Multiple Access (NOMA) EH relay-assisted system over Block Rayleigh Fading Channel. In the analysis process, we analyze and derive the integral expression of the outage probability. Finally, the Monte Carlo Simulation is used for validating the analytical analysis in connection with all possible system parameters. The results show that the analytical and simulation results agree well with each other in contact with all possible system parameters.

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