Outage probability analysis of EH NOMA system network over Rayleigh fading channel using selection combining at the receiver

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ABSTRACT

Non-orthogonal multiple access (NOMA) with advantages such as superior spectral efficiency has been considered as a promising multiple access technique for the fifth-generation (5G) mobile networks. In this research, we propose energy harvesting (EH) NOMA system relaying network over Rayleigh fading channel using selection combining at the receiver. Firstly, we investigate the system performance in terms of the closed-form expression of the outage probability (OP). Here we compare the OP of two destination users of the proposed system. Finally, all the results is convinced by the Monte Carlo simulation. From the results, we can confirm that all the analytical and simulation results are the same in connection with the primary system parameters.

Keywords:
Energy harvesting (EH)
Monte carlo
Outage probability (OP)
Power beacon
Relaying network

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1. INTRODUCTION

Non-orthogonal multiple access (NOMA) with advantages such as superior spectral efficiency has been considered as a promising multiple access technique for the fifth-generation (5G) mobile networks [1-6]. In comparison with the traditional water-filling power allocation strategy, NOMA can transfer more power to the users in the worse channel conditions. It leads to a better trade-off between system throughput and user fairness. From the previous researches, authors investigated the impact of user pairing on downlink NOMA systems as in [7], the authors in [8] have considered the power allocation with the max-min fairness criterion of the model system. An uplink NOMA scheme with joint power and subcarrier allocations has been proposed and investigated in [9]. In [10], a cooperation-based NOMA scheme for coordinated direct and relay transmissions is studied. Furthermore, a diversity-oriented detection mechanism for the cooperative relaying system using NOMA is considered by authors in [11]. The performance of transmit antenna selection for NOMA assisted multiple-input-multiple-output (MIMO) relay networks is presented in [12]. Then inspired by user collaboration, a cooperative NOMA transmission scheme is presented in [13].

In this research, we propose energy harvesting (EH) NOMA network system over the Rayleigh fading channel using selection combining at the receiver. In the first stage, we investigate and derive...
the closed-form expression of the outage probability (OP) of the model system by Monte Carlo simulation. Then the comparison of the OP of two destination users is investigated in connection with the primary system parameters. Finally, all the results are convinced by the Monte Carlo simulation. From the results, we can convince that all the analytical and simulation results are the same in connection with the primary system parameters. The main contributions of this research are listed as:

- The EH NOMA network system over the Rayleigh fading channel using selection combining at the receiver is proposed.
- The closed-form expression of the system OP is investigated and derived.
- The comparison of the OP of two destination users is investigated.
- All the results are convinced by the Monte Carlo simulation.

2. SYSTEM MODEL

The EH NOMA network system over the Rayleigh fading channel using selection combining at the receiver is drawn in Figure 1. In this system model, we denote Source is $S$, Relay is $R$, $D_1$ and $D_2$ are two Destination nodes. We assume that all links between them (i.e., $S$-to-$D_1$, $S$-to-$R$, and $R$-to-$D_2$) are available. The Rayleigh fading channel coefficients of $S$-to-$D_1$, $S$-to-$R$, and $R$-to-$D_2$ links are denoted as $h_{SD_1,2}$, $h_{SR}$, and $h_{RD_1,2}$, respectively as shown in Figure 1. The energy harvesting and information processing (IT) are illustrated in Figure 2. In this protocol, the transmission block time $T$, which consists of three-time slots. In the first-time slot $\alpha T$ (where $\alpha$ is the time switching factor, $0<\alpha<1$), the relay harvests energy from the source node $S$. In the second interval time $(1-\alpha)T/2$, the source $S$ transfers the information to $R$ and $D_1$, $D_2$ at the same time. Finally, the relay node $R$ transfers the information to the destination nodes $D_1, D_2$ in the remaining time slot $(1-\alpha)T/2$.

![Figure 1. System model](image)

![Figure 2. The time switching protocol](image)

Energy harvesting phase
In the first slot time $\alpha T$, we formulate the received signal as:

$$y_r = h_{sr} \sqrt{P_s} x_s + n_r$$

The received energy can be computed as:

$$E_r = \eta \alpha T |h_{sr}|^2 P_s$$

Where $0 < \eta < 1$ is the energy conversion efficiency.

The average transmit power at the $R$ node can be calculated as:

$$P_r = \frac{E_r}{(1-\alpha)T/2} = \kappa |h_{sr}|^2 P_s$$

Where we denote $\kappa = \frac{2\eta \alpha}{1-\alpha}$.
Information transmission

In the second slot time, S transmits the superposed signal $\sqrt{a_1P_1}x_1 + \sqrt{a_2P_2}x_2$ to relay, $D_1$ and $D_2$ according to the NOMA scheme [1]. $a_1$, $a_2$ are the power allocation coefficients for $D_1$ and $D_2$, where we assume $a_1 + a_2 = 1$, $a_2 > a_1$, $x_1$ and $x_2$ are the transmit signal for $D_1$ and $D_2$, respectively. Hence, the received signal at the R node, $D_1$ and $D_2$ can be expressed as respectively [14].

$$y_s = h_r \left( \sqrt{a_1P_1}x_1 + \sqrt{a_2P_2}x_2 \right) + n_s$$  \hspace{1cm} (4)

$$y_{d_1} = h_{d_1} \left( \sqrt{a_1P_1}x_1 + \sqrt{a_2P_2}x_2 \right) + n_{d_1}$$  \hspace{1cm} (5)

$$y_{d_2} = h_{d_2} \left( \sqrt{a_1P_1}x_1 + \sqrt{a_2P_2}x_2 \right) + n_{d_2}$$  \hspace{1cm} (6)

Where $n_{d_1}, n_{d_2}$ are the additive white Gaussian noise (AWGN) at the $D_1$ and $D_2$ with zero-mean and variance $N_0$, respectively. From (6), we separate the received signal at the $D_2$ into two parts included signal and noise part for $D_2$ to detect $x_1$.

$$y_{d_2} = h_{d_1} \sqrt{a_2P_1}x_2 + h_{d_1} \sqrt{a_1P_1}x_1 + n_{d_1}$$  \hspace{1cm} (7)

Hence, the received signal to interference and noise ratio (SINR) for $D_2$ to detect $x_1$ is given as:

$$\gamma_{sd_2} = \frac{E[\text{signal}^2]}{E[\text{noise}^2]} = \frac{|h_{d_1}|^2 a_2P_1}{|h_{d_1}|^2 a_1P_1 + N_0} = \frac{|h_{d_1}|^2 a_2\psi}{|h_{d_1}|^2 a_1\psi + 1}$$  \hspace{1cm} (8)

Where $\psi = \frac{P_2}{N_0}$ is the transmit signal to noise ratio (SNR).

From (5), SIC is first used for $D_1$ by detecting and decoding the information of $D_2$. Hence, the received signal at the $D_1$ can be rewritten as:

$$y_{d_1} = h_{d_1} \sqrt{a_2P_1}x_2 + h_{d_1} \sqrt{a_1P_1}x_1 + n_{d_1}$$  \hspace{1cm} (9)

Then, the received SINR at $D_1$ is given by:

$$\gamma_{sd_1} = \frac{|h_{d_1}|^2 a_2\psi}{|h_{d_1}|^2 a_1\psi + 1}$$  \hspace{1cm} (10)

After the far user message is decoded, $D_1$ can decode its own information with the SINR as following

$$\gamma_{sd_1} = |h_{d_1}|^2 a_2\psi$$  \hspace{1cm} (11)

During the third slot time, the relaying node will amplify the received signal and forward to $D_1$ and $D_2$ with the amplifying factor

$$\beta = \frac{x_1}{y_s} = \sqrt{\frac{P_1}{|h_{d_1}|^2 + N_0}}.$$ The received signals at the $D_1$ and $D_2$ are expressed as, respectively.
Substituting (4) into (12)

\[ y_{sd} = h_{sd}x + n_{sd} = h_{sd}\beta y + n_{sd} \]  

(13)

And

\[ y_{sd} = h_{sd}x + n_{sd} = h_{sd}\beta y + n_{sd} \]

(14)

Where \( n_{sd}, n_{dj} \) was denoted the AWGN at \( D_1 \) and \( D_2 \), respectively. From (14), the received SINR for \( D_2 \) to detect \( x_2 \) is given as:

\[
\gamma_{sd} = \frac{E[|signal|^2]}{E[|noise|^2]} = \frac{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma}{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma + |h_{sd}|^2 + 1/\beta^2}
\]  

(15)

Using the fact that \( N_0 < P_r \), hence, (15) can be rewritten as:

\[
\gamma_{sd} = \frac{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma}{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma + |h_{sd}|^2 + 1/\kappa}
\]  

(16)

The received SINR when \( D_1 \) first detect \( D_2 \)’s information is given by:

\[
\gamma_{sd} \approx \frac{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma}{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma + |h_{sd}|^2 + 1/\kappa}
\]  

(17)

Applying SIC operation, the received SINR for \( D_1 \) is given by:

\[
\gamma_{sd} \approx \frac{|h_{sd}|^2|h_{sd}|^2a_\nu^\sigma}{|h_{sd}|^2 + 1/\kappa}
\]  

(18)

3. SYSTEM PERFORMANCE ANALYSIS

The outage probability (OP) of the destination node \( D_2 \) can be given by:

\[
OP_{D_2} = \Pr \left[ \max (\gamma_{sd}, \gamma_{sd}) \leq \gamma_{\alpha} \right]
\]

(19)

Where \( \gamma_{\alpha} = 2^{R_2} - 1 \) with \( R_2 \) being the target rate at the \( D_2 \). From (8), we have:
\[ \text{Pr}(\gamma_{sd} < \gamma_{d}) = \Pr \left( \left| \frac{h_{sd}}{\kappa} \right|^2 + \frac{a_{sd}}{\kappa} < \gamma_{sd} \right) = \Pr \left( \left| \frac{h_{sd}}{\kappa} \right|^2 + \frac{a_{sd}}{\kappa} < \gamma_{d} \right) \]
\[ = \left\{ \begin{array}{l l} \frac{1}{1} - \exp \left( -\frac{\gamma_{d} \lambda_{sd}}{\kappa} \right) & \text{if } a_{d} > \gamma_{d} \lambda_{d} \\ 1 & \text{if } a_{d} \leq \gamma_{d} \lambda_{d} \end{array} \right. \] 

Where \( \lambda_{sd} \) is the mean of the random variable (RV) \( \left| h_{sd} \right|^2 \). From (16), we can calculate the second probability of (19):

\[ \text{Pr}(\gamma_{sd} < \gamma_{d}) = \Pr \left( \left| \frac{h_{sd}}{\kappa} \right|^2 + \frac{a_{sd}}{\kappa} < \gamma_{d} \right) = \Pr \left( \frac{\phi_{sd}}{\phi_{sd} \psi_{sd} + \phi_{d} + \gamma_{d} \lambda_{d}} < \gamma_{d} \right) \]
\[ = \left\{ \begin{array}{l l} \frac{1}{1} - \exp \left( -\frac{\gamma_{d} \lambda_{sd}}{\kappa} \right) & \text{if } a_{d} > \gamma_{d} \lambda_{d} \\ 1 & \text{if } a_{d} \leq \gamma_{d} \lambda_{d} \end{array} \right. \] 

By changing a variable \( x = \phi_{sd} \psi_{sd} - \gamma_{d} \phi_{sd} \psi_{sd} - \gamma_{d} \Rightarrow \phi_{d} = \frac{\partial x}{\gamma_{d}} \), (21) can be rewritten as:

\[ \text{Pr}(\gamma_{sd} < \gamma_{d}) = 1 - \frac{\lambda_{sd} \phi_{d}}{\gamma_{d}} \exp \left( -\frac{\lambda_{sd} \phi_{d}}{\gamma_{d}} \right) \]
\[ = \frac{1}{1} - \exp \left( -\frac{\gamma_{d} \lambda_{sd}}{\kappa} \right) \]

Apply eq (3.324,1) of [15], (22) can be reformulated as:

\[ \text{Pr}(\gamma_{sd} < \gamma_{d}) = 1 - 2 \exp \left( -\frac{\lambda_{sd} \phi_{d}}{\gamma_{d}} \right) \]
\[ \times \sqrt{\frac{\lambda_{sd} \phi_{d}}{\kappa} \times K \left( \frac{\lambda_{sd} \phi_{d}}{\kappa} \right)} \]

Where \( K(\bullet) \) is the modified Bessel function of the second kind and \( v^{th} \) order. Substituting (20) and (23) into (19), finally, we can obtain:

\[ OP_{sd} = \begin{cases} 1 - \exp \left( -\frac{\lambda_{sd} \phi_{d}}{\gamma_{d}} \right) \\ 1 - 2 \exp \left( -\frac{\lambda_{sd} \phi_{d}}{\gamma_{d}} \right) \times \sqrt{\frac{\lambda_{sd} \phi_{d}}{\kappa} \times K \left( \frac{\lambda_{sd} \phi_{d}}{\kappa} \right)} \end{cases} \]
Hence, the outage probability (OP) of the destination $D_1$ can be given by:

$$
\text{OP}_{D_1} = \Pr \left( \gamma_{sd_1} < \gamma_{a_1} \text{ and } \gamma_{rd_1} < \gamma_{a_1} \right) \\
\times \Pr \left( \gamma_{sd_1} < \gamma_{a_1} \text{ and } \gamma_{rd_1} < \gamma_{a_1} \right)
$$

$$
= \left[ 1 - \Pr \left( \gamma_{sd_1} \geq \gamma_{a_1} \text{ and } \gamma_{rd_1} \geq \gamma_{a_1} \right) \right] \times

\left[ 1 - \Pr \left( \gamma_{sd_1} \geq \gamma_{a_1} \text{ and } \gamma_{rd_1} \geq \gamma_{a_1} \right) \right] = P_1 \times P_2
$$

(25)

Where $P_1 = \left[ 1 - \Pr \left( \gamma_{sd_1} \geq \gamma_{a_1} \text{ and } \gamma_{rd_1} \geq \gamma_{a_1} \right) \right]$. $P_2 = \left[ 1 - \Pr \left( \gamma_{sd_1} \geq \gamma_{a_1} \text{ and } \gamma_{rd_1} \geq \gamma_{a_1} \right) \right]$. And $\gamma_{a_1} = 2^{R_1} - 1$ with $R_1$ being the target rate at the $D_1$. From (10) and (11), $P_1$ can be calculated as:

$$
P_1 = \left[ 1 - \Pr \left( \frac{h_{sd_1}^2}{a_{1,\nu}} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \text{ and } \frac{h_{sd_1}^2}{a_{1,\nu} + 1} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \right) \right]
$$

$$
= \left[ 1 - \Pr \left( \frac{h_{sd_1}^2}{a_{1,\nu}} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \text{ or } \frac{h_{sd_1}^2}{a_{1,\nu} + 1} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \right) \right]
$$

$$
= \left[ 1 - \Pr \left( \frac{h_{sd_1}^2}{a_{1,\nu}} \geq \max \left( \frac{\gamma_{a_1}}{a_{1,\nu}}, \frac{\gamma_{a_1}}{a_{1,\nu} + 1} \right) \right) \right]
$$

$$
= \Pr \left( h_{sd_1}^2 < \Xi \right) = 1 - \exp \left( - \lambda_{sd_1} \Xi \right)
$$

Where $\lambda_{sd_1}$ is the mean of RV $h_{sd_1}^2$ and $\Xi = \max \left( \frac{\gamma_{a_1}}{a_{1,\nu}}, \frac{\gamma_{a_1}}{a_{1,\nu} + 1} \right)$. From (17) and (18), $P_2$ can be calculated as:

$$
P_2 = \left[ 1 - \Pr \left( \frac{|h_{sr_1}|^2}{|h_{sd_1}|^2 a_{1,\nu}} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \text{ and } \frac{|h_{sr_1}|^2}{|h_{sd_1}|^2 a_{1,\nu} + 1/\kappa} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \right) \right]
$$

$$
= \left[ 1 - \Pr \left( \frac{|h_{sr_1}|^2}{|h_{sd_1}|^2 a_{1,\nu}} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \text{ or } \frac{|h_{sr_1}|^2}{|h_{sd_1}|^2 a_{1,\nu} + 1/\kappa} \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \right) \right]
$$

$$
= \left[ 1 - \Pr \left( \phi_1 \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \text{ and } \phi_1 \geq \frac{\gamma_{a_1}}{a_{1,\nu} + 1/\kappa} \right) \right]
$$

$$
= \left[ 1 - \Pr \left( \phi_1 \geq \frac{\gamma_{a_1}}{a_{1,\nu}} \text{ or } \phi_1 \geq \frac{\gamma_{a_1}}{a_{1,\nu} + 1/\kappa} \right) \right]
$$

$$
= 1 - \int_{\Xi}^{\infty} f_{\phi_1}(\phi_1) d\phi_1 \int_{\Xi}^{\infty} f_{\phi_1}(\phi_1) d\phi_1
$$

$$
= 1 - \int_{\Xi}^{\infty} \left[ 1 - F_{\phi_1}\left( \frac{\gamma_{a_1}}{a_{1,\nu}}, \frac{\gamma_{a_1}}{a_{1,\nu} + 1/\kappa} \right) \right] f_{\phi_1}(\phi_1) d\phi_1
$$

$$
= 1 - \int_{\Xi}^{\infty} \exp \left( - \lambda_{sd_1} \frac{\Xi}{\phi_1} \right) \exp(-\lambda_{sd_1} \phi_1) d\phi_1
$$

Outage probability analysis of eh noma system network over rayleigh fading channel... (Phu Tran Tin)
Where $A = \frac{\gamma_{11}}{a_{11}B - \gamma_{11}a_{11}}$, $B = \frac{\gamma_{11}}{a_{11}B - \gamma_{11}a_{11}}$, $\Xi = \max (A, B)$, respectively changing variable $y = \varphi - \Xi$, (27) can be rewritten as:

$$P_2 = 1 - \lambda_{a_2} \int_0^\infty \exp \left( -\frac{\lambda_{a_2}}{\kappa y} \right) \exp \left[ -\lambda_{a_2} (y + \Xi) \right] dy$$

$$= 1 - \lambda_{a_2} \exp (-\lambda_{a_2} \Xi) \int_0^\infty \exp \left( -\frac{\lambda_{a_2}}{\kappa y} - \lambda_{a_2} y \right) dy$$

Applying equation (3.324,1) of [table of integral], (22) can be reformulated as:

$$P_2 = 1 - 2 \exp (-\lambda_{a_2} \Xi) \times \sqrt{\frac{\lambda_{a_2} \lambda_{a_2} \Xi}{\kappa}} \times K_1 \left( 2 \sqrt{\frac{\lambda_{a_2} \lambda_{a_2} \Xi}{\kappa}} \right)$$

where $K_1(\cdot)$ is the modified Bessel function of the second kind and $v^{th}$ order. Substituting (26) and (29) into (25), finally, the outage probability of $D_1$ can be claimed as:

$$\text{OP}_{D_1} = \left[ 1 - \exp (-\lambda_{a_2} \Xi) \right] \left[ 1 - 2 \exp (-\lambda_{a_2} \Xi) \times \sqrt{\frac{\lambda_{a_2} \lambda_{a_2} \Xi}{\kappa}} \times K_1 \left( 2 \sqrt{\frac{\lambda_{a_2} \lambda_{a_2} \Xi}{\kappa}} \right) \right]$$

4. NUMERICAL RESULTS AND DISCUSSION

In this section, we investigate the OP of the model system using Monte Carlo simulation in connection with the primary system parameters [16-26]. In Figure 3, the effect of $a_2$ on the system OP is plotted with the primary system parameters as $\eta=0.8$, $R_1=R_2=0.25$, 0.5 bps/Hz, $\alpha=0.5$. From the results, we can see that the OP of the destination $D_1$ significantly decreases with the rising of $a_2$. However, the OP of the $D_2$ decreases when $a_2$ increases from 0.55 to 0.7 and after that has a massive increase with the remaining values of $a_2$. In the same way, the system OP versus $\alpha$ is drawn in Figure 4. In this simulation, we set $\eta=0.8$, $R_1=R_2=0.5$ bps/Hz, $P_S/N_0=0.5$, and $a_2=0.7, 0.9$. As shown in Figure 4, we can state that the OP of the model system has a slight decrease when $\alpha$ varies from 0 to 1. In both Figures 3 and 4, the simulation and analytical results are the same with all values of $\alpha$ and $a_2$.
Furthermore, we investigate the effect of $\eta$ and $\psi$ on the OP of the model system as plotted in Figures 5 and 6. In these Figures, we set the primary parameters as $\alpha = 0.7$, 0.9, $R_1=0.5$ bps/Hz, $P_s/N_0=0.5$. From Figures 5 and 6, it can be observed that the system OP has a slight decrease when $\eta$ varies from 0 to 1 and the system OP crucially decreases with the rising of $\psi$ from 0 to 25. In all two Figures, the analytical and simulation results agree well with each other. On another hand, the comparison of the system OP of two destination nodes is demonstrated in all Figures. From the results, we can state that the system OP of the destination node $D_2$ is better than the destination node $D_1$.

![Figure 5. OP versus $\eta$](image1)

![Figure 6. OP versus $\psi$](image2)

5. CONCLUSION

In this research, we propose EH NOMA network system over the Rayleigh fading channel using selection combining at the receiver. The closed-form expression of the OP of the model system by Monte Carlo simulation is derived. Moreover, the comparison of the OP of two destination users is investigated in connection with the primary system parameters. From the results, we can see that all the analytical and simulation results are the same with the primary system parameters using Monte Carlo simulation. These results can be provided a novel recommendation for improving the performance of the EH NOMA communication network system.

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