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Adaptive relaying protocol for wireless energy harvesting and information processing in NOMA systems: Outage probability analysis

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ABSTRACT

In order to satisfy the increasing data rate demands, the research in the fifth-generation (5G) wireless networks is ongoing, both in academia and industry. In this research, we propose and investigate adaptive relaying protocol (ARP) For wireless energy harvesting (EH) and information processing in NOMA systems. Firstly, we investigate and derive the closed-form and integral-form expressions of the outage probability (OP) of the model system. Then, all the results are convinced by the Monte Carlo simulation. The research results show that all the analytical and simulation results are the same in connection with the primary system parameters. This research can provide a recommendation for NOMA system network.

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94

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1. INTRODUCTION

In order to satisfy the increasing data rate demands, the research in the fifth-generation (5G) wireless networks is ongoing, both in academia and industry. The full-duplex (FD) is a popular technique in the relaying communication network, which allows the communication node to transmit and receive signals over the same frequency band at the same time slot. In comparison with the 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 [1-6]. From the previous researches, authors in [7] investigate the impact of user pairing on downlink NOMA systems. [8] has proposed power allocation with the max-min fairness criterion. An uplink NOMA scheme with joint power and subcarrier allocations has been considered in [9]. In [10], the authors introduced a cooperation-based NOMA scheme for coordinated direct and relay transmissions. A diversity-oriented detection mechanism for the cooperative relaying system using NOMA has been presented in [11]. The performance of transmit antenna selection for NOMA assisted multiple-input-multiple-output (MIMO) relay networks have been examined in [12]. Authors in [13] presented and investigated a cooperative NOMA transmission scheme.

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In this research, we propose adaptive relaying protocol (ARP) for wireless energy harvesting and information processing in NOMA Systems. Firstly, we investigate and derive the closed-form and integral form expression of the outage probability (OP) of the model system. Then, all the results are convinced by Monte Carlo simulation in connection with all primary system parameters. From the results, we can convince that all the analytical and simulation results are the same in connection with the primary system parameters. The research focuses on some contributions as;

- The ARP for wireless energy harvesting and information processing in NOMA systems is proposed.
- The closed-form and integral-form expressions of the system OP is investigated and derived.
- All the results are convinced by Monte Carlo simulation in connection with all primary system parameters.

2. SYSTEM MODEL

The ARP for wireless energy harvesting and information processing in NOMA systems is drawn in Figure 1. In this system model, we denote Source is S, D_1 and D_2 are two destination nodes. The energy harvesting (EH) and information processing (IT) for this proposed model system are illustrated in Figure 2. In this protocol, the transmission time T consists of three-time slots. In the first time slot αT (α is the time switching factor, $0 < \rho < 1$), the energy of the D_1 harvest from the source node S. In the second interval time $(1-\alpha)T/2$, the source S transfers the energy and information to D_1 at the same time. Finally, the remaining time slot $(1-\alpha)T/2$ is used for information transferring from the destination node D_1 to the destination node D_2 .

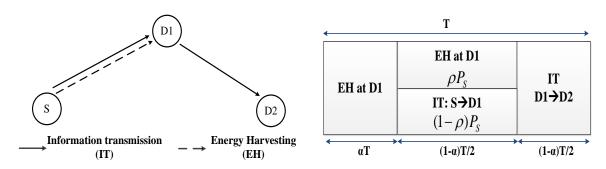


Figure 1. System model

Figure 2. The EH and IT

2.1. Energy harvesting phase

The received signal at the relay R in the first time slot αT can be formulated as;

$$y_{D_1}^1 = h\left(\sqrt{b_1 P_s} x_1 + \sqrt{b_2 P_s} x_2\right) + n_{D_1} \tag{1}$$

Where P_S is the transmitting power of source S, h is channel gain of S- D_1 link and n_{D1} denoted the additive white Gaussian noise (AWGN) at D_1 which has zero-mean and variance N_0 . b_1 and b_2 are power allocation coefficients for data symbols x_1 and x_2 that is wished to send from;

S to D₁ and D₂, respectively and satisfied
$$\begin{cases} b_2 > b_1 > 0 \\ b_1 + b_2 = 1 \end{cases}$$
.

We assume that $E\{|x_1|^2\} = E\{|x_2|^2\} = 1$ which $E\{\bullet\}$ is the expectation operator. Based on (1), the harvested energy in the first time slot αT can be calculated as;

$$E_{1} = \eta \alpha T P_{s} |h|^{2} (b_{2} + b_{1}) = \eta \alpha T P_{s} |h|^{2}$$
(2)

The received signal at D_1 in the second interval time $(1-\alpha)T/2$ can be expressed as;

$$y_{D_1}^2 = \sqrt{\rho} h \left(\sqrt{b_1 P_s} x_1 + \sqrt{b_1 P_s} x_2 \right) + n_{D_1}$$
 (3)

96 □ ISSN: 2302-9285

Therefore, the harvested energy in the second interval time $(1-\alpha)T/2$ can be given by;

$$E_2 = \eta \rho \left(\frac{1-\alpha}{2}\right) TP_s \left|h\right|^2 \left(b_1 + b_2\right) = \eta \rho \left(\frac{1-\alpha}{2}\right) TP_s \left|h\right|^2 \tag{4}$$

From (2) and (4), the total average transmitted power at the relay node R can be calculated as the following;

$$P_{D_{1}} = \frac{E_{D_{1}}}{(1-\alpha)T/2} = \frac{E_{1} + E_{2}}{(1-\alpha)T/2} = \kappa \eta P_{s} |h|^{2}$$
(5)

Where
$$\kappa = \frac{2\alpha + (1-\alpha)\rho}{1-\alpha}$$

2.2. Information transmission phase

In the second interval time $(1-\alpha)T/2$, the received signal at the destination node D_1 can be expressed as;

$$y_{D_1} = \sqrt{(1-\rho)P_s} h\left(\sqrt{b_1}x_1 + \sqrt{b_2}x_1\right) + n_{D_1}$$
(6)

After receiving the signal from S, D_1 will decode the signal and decode its own signal by using successive interference cancellation (SIC) [14]. From (6) the received signal to interference plus noise ratio (SINR) at the destination node D_1 to detect of the destination node D_2 is given by;

$$SINR_{2,D_{1}} = \frac{(1-\rho)|h|^{2}b_{2}\Psi}{(1-\rho)\Psi|h|^{2}b_{1}+1}$$
(7)

Where $\Psi = \frac{P_s}{N_0}$ represents the transmit signal-to-noise ratio (SNR).

After applying SIC, there is no interference remaining in the received signal at the destination node D_1 . Therefore, the received SNR at the destination node D_1 to detect its own signal x_1 is obtained by;

$$SNR_{l,D_i} = (1 - \rho)|h|^2 b_l \Psi \tag{8}$$

In the third interval time $(1-\alpha)T/2$, the decoded signal x_2 at D_1 is forwarded to D_2 . Hence, the received signal at the destination node D_2 can be given as;

$$y_{D_1} = \sqrt{P_{D_1}} g x_2 + n_{D_2} \tag{9}$$

Where g is channel gain of D_1 - D_2 link and n_{D_2} is AWGN at D_2 which has zero-mean and variance N_0 . Hence, the received SNR at D_2 is given by;

$$SNR_{2,D_2} = \frac{P_{D_1} |g|^2}{N_0}$$
 (10)

Substituting (5) into (10), we have:

$$SNR_{2,D_2} = \frac{\kappa \eta P_s |h|^2 |g|^2}{N_0} = \kappa \eta \Psi |h|^2 |g|^2$$
 (11)

3. SYSTEM PERFORMANCE ANALYSIS

3.1. Outage probability (OP) at D₁

In the NOMA protocol, D_1 is not in an outage when it can decode both x_1 and x_2 received from S. So, the OP at D_1 can be expressed as;

$$OP_{D_1} = 1 - \Pr(SINR_{2,D_1} > \gamma_{th}^2, SNR_{1,D_1} > \gamma_{th}^1)$$
 (12)

Where $\gamma_{th}^1 = 2^{2R_1} - 1$ and $\gamma_{th}^2 = 2^{2R_2} - 1$ in which R_1 and R_2 are the source rates to detect x_1 and x_2 at D_1 , respectively. Substituting (7) and (8) into (12), the OP at D_1 can be rewritten as;

$$OP_{D_{1}} = 1 - \Pr\left(\frac{(1-\rho)|h|^{2} b_{2} \Psi}{(1-\rho)\Psi|h|^{2} b_{1} + 1} > \gamma_{th}^{2}, (1-\rho)|h|^{2} b_{1} \Psi > \gamma_{th}^{1}\right)$$

$$= 1 - \Pr\left[|h|^{2} > \frac{\gamma_{th}^{2}}{(1-\rho)\Psi(b_{2} - \gamma_{th}^{2} b_{1})}, |h|^{2} > \frac{\gamma_{th}^{1}}{(1-\rho)b_{1} \Psi}\right]$$

$$= 1 - \Pr\left[|h|^{2} > \Theta\right]$$

$$= 1 - \int_{\Theta}^{\infty} f_{|h|^{2}}(x) dx = 1 - \exp\left(-\lambda_{h}\Theta\right)$$
(13)

Where $\Theta = \max \left[\frac{\gamma_{th}^2}{(1-\rho)\Psi(b_2 - \gamma_{th}^2 b_1)}, \frac{\gamma_{th}^1}{(1-\rho)b_1\Psi} \right]$ and λ_h is mean of the random variable (RV) $|h|^2$

3.2. Outage probability (OP) at D₂

 D_2 is in an outage when either D_1 can not detect x_2 or D_2 can not recover the forwarded signal from D_1 . Hence, the OP at D_2 can be obtained as;

$$OP_{D_{2}} = \Pr(SINR_{2,D_{1}} < \gamma_{th}^{2}) + \Pr(SNR_{2,D_{2}} < \gamma_{th}^{2}, SINR_{2,D_{1}} > \gamma_{th}^{2})$$
(14)

The first term of (14) can be derived as;

$$\Pr\left(SINR_{2,D_{1}} < \gamma_{th}^{2}\right) = \Pr\left[\frac{(1-\rho)|h|^{2} b_{2}\Psi}{(1-\rho)\Psi|h|^{2} b_{1} + 1} < \gamma_{th}^{2}\right] \\
= \begin{cases}
\Pr\left[|h|^{2} < \frac{\gamma_{th}^{2}}{(1-\rho)\Psi\left(b_{2} - \gamma_{th}^{2}b_{1}\right)}\right], b_{2} - \gamma_{th}^{2}b_{1} > 0 \\
1, b_{2} - \gamma_{th}^{2}b_{1} \leq 0
\end{cases} \\
= \begin{cases}
1 - \exp\left[-\frac{\gamma_{th}^{2}\lambda_{h}}{(1-\rho)\Psi\left(b_{2} - \gamma_{th}^{2}b_{1}\right)}\right], b_{2} - \gamma_{th}^{2}b_{1} \leq 0 \\
1, b_{2} - \gamma_{th}^{2}b_{1} \leq 0
\end{cases}$$

$$(15)$$

98 ISSN: 2302-9285

The second term of (14) can be rewritten as;

$$\Pr\left(SNR_{2,D_{2}} < \gamma_{th}^{2}, SINR_{2,D_{1}} > \gamma_{th}^{2}\right) = \Pr\left[\kappa\eta\Psi|h|^{2}|g|^{2} < \gamma_{th}^{2}, \frac{(1-\rho)|h|^{2}|b_{2}\Psi|}{(1-\rho)\Psi|h|^{2}|b_{1}+1} > \gamma_{th}^{2}\right] \\
= \Pr\left[|g|^{2} < \frac{\gamma_{th}^{2}}{\kappa\eta\Psi|h|^{2}}, |h|^{2} > \frac{\gamma_{th}^{2}}{(1-\rho)\Psi(b_{2}-\gamma_{th}^{2}b_{1})}\right] \\
= \int_{\frac{\gamma_{th}^{2}}{(1-\rho)\Psi(b_{2}-\gamma_{th}^{2}b_{1})}}^{\frac{\gamma_{th}^{2}}{\kappa\eta\Psi|h|^{2}}} \int_{0}^{1} f_{|h|^{2}}(x) f_{|g|^{2}}(y) dx dy \\
= \lambda_{h} \int_{\Xi}^{\infty} \left[1 - \exp\left(-\frac{\gamma_{th}^{2}\lambda_{g}}{\kappa\eta\Psi x}\right)\right] \exp\left(-x\lambda_{h}\right) dx \tag{16}$$

Where $\Xi = \frac{\gamma_{th}^2}{(1-\rho)\Psi(b_2-\gamma_{th}^2b_1)}$. Substituting (15), (16) into (14), finally, the OP at D₂ can be claimed as;

$$OP_{D_2} = 1 - \exp(-\lambda_h \Xi) + \lambda_h \int_{\Xi}^{\infty} \left[1 - \exp\left(-\frac{\gamma_{th}^2 \lambda_g}{\kappa \eta \Psi x}\right) \right] \exp(-x\lambda_h) dx$$
(17)

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 [15-26]. In Figure 3, the effect of b_2 on the system OP is plotted with the primary system parameters as η =0.8, R_1 = R_2 =0.5 bps/Hz, α = ρ =0.5. From the results, we can see that the system OP of the destination node D_1 significantly decreases with the rising of b_2 . However, the system OP of the destination node 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 b_2 . In the same way, the system OP versus α is drawn in Figure 4. In this simulation, we set η =0.8, ψ =7 dB, ρ =0.5, and b_2 =0.9, b_1 =0.1. As shown in Figure 4, we can state that the OP of the model system has a slight decrease when α varies from 0 to 1. In both Figure 3 and Figure 4, the simulation and analytical results are the same with hall values of α and b_2 .

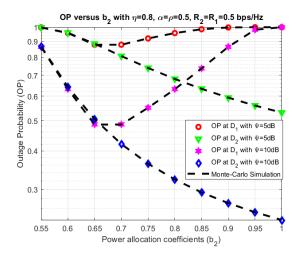


Figure 3. OP versus b2

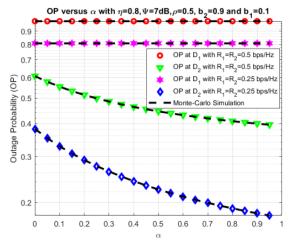
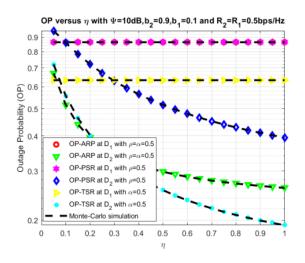


Figure 4. OP versus α

Furthermore, we investigate the effect of η and ψ on the OP of the model system, as plotted in Figure 5 and Figure 6. In these Figure, we set the primary parameters as a 2=0.7, 0.9, R₁=R₂=0.5 bps/Hz, P_S/N₀=0.5. From Figure 5 and Figure 6, it can be observed that the system OP has a slight decrease when η varies from 0 to 1, and the system OP crucially decreases with the rising of ψ from 0 to 25. In all two Figure, 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 Figure. From the results, we can state that the system OP of the destination node D₂ is better than the destination node D₁.



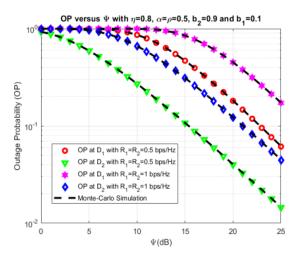


Figure 5. OP versus η

Figure 6. OP versus ψ

5. CONCLUSION

In this research, we propose the ARP For wireless energy harvesting and information processing in NOMA systems. Firstly, we investigate and derive the closed-form and integral form expression of the outage probability (OP) of the model system. Then, all the results are convinced by Monte Carlo simulation in connection with all primary system parameters. From the results, we can convince that all the analytical and simulation results are the same in connection with the primary system parameters.

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