

## Wireless power transfer enabled NOMA relay systems: two SIC modes and performance evaluation

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### Abstract

*In this study, we deploy design and performance analysis in new system model using a relaying model, energy harvesting, and non-orthogonal multi-access (NOMA) network. It is called such topology as wireless powered NOMA relaying (WPNR). In the proposed model, NOMA will be investigated in two cases including single successive interference cancellation (SIC) and dual SIC. Moreover, the simultaneous wireless information and power transfer (SWIPT) technology can be employed to feed energy to relays who intend to serve far NOMA users. In particular, exact outage probability expressions are provided to performance evaluation. The results from the simulations are used to demonstrate the outage performance of the proposed model in comparison with the current models and to verify correct of derived expressions.*

**Keywords:** energy harvesting, non-orthogonal multiple access, outage probability

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### 1. Introduction

The fifth generation (5G) of mobile communication networks is considered as a progressive form of the fourth generation (4G) networks with many tremendous functions like internet-of-thing (IoT) and cloud-based applications in [1, 2]. These modern services lead to challenging requirements such as faster data rates, lower suspension, wider connectivity and better spectral and energy impact. Consequently, in order to meet these demands, a range of modern techniques used as a new technological tool to access NOMA may be a very potential selection for the 5G network since it complies with all the specifications for spectral impact, massive connectivity, user fairness and low suspension as mentioned in [3]. On the other hand, when NOMA utilizes the energy domain, many different users will be accessed at the same time, in terms of frequency, time and code according to their own channel conditions. Whereas high power transmission rates will be selected for users with poor channel conditions, users with better channel conditions can use lower power levels. As a result, NOMA requires multiple communication notes at the base station superposition for receivers using superposition coding (SC) technique. With SIC technology, NOMA users eliminate all weaker ones' communication notes and consider the stronger users' notes as an intervention to decipher the own note in [4]. The active strong users (SU) can employ the weaker users' (WU) notes to transfer WU's notes and increase the network security which are considered as the collaborative NOMA models in [5, 6].

In recent times, SWIPT has been suggested as a potential technique that can extend the working time of some devices such as energy-limited devices, energy-limited sensors, IoT devices, etc. SWIPT can endure terminals with traditional wires and considerably expand its spare time. For that reason, SWIPT is considered a favorable technique for energy limited networks. In most recent studies, SWIPT in information systems has implemented in centralized antenna systems (CAS). There has been concentration on extracting the maximum beam-forming energy splitting SWIPT to take advantage of focusing on a remote field electromagnetic radiation as regards in [7–10]. By combining relaying network with NOMA, cooperative NOMA has well studied

in [11–15]. In [13], the authors combine SWIPT with NOMA network for existing SUs to transmit WUs notes because there is no necessity to use energy for this cooperation. In the meantime, in order to increase the individual data rate, the wireless powered communication networks (WPCN) technology was combined with NOMA uplink network [14]. On the other hand, in [15], NOMA is examined in term of energy effects in WPC systems. Additionally, in [16], the downlink of NOMA is researched together with SWIPT (rather than WPC). Nevertheless, SWIPT is only adjusted by close users and remote users are overwhelmed. It is shown that on-off power splitting (OPS) as a special case of dynamic power splitting (DPS) which can obtain the maximum rate area in such design. Therefore, the outage probability and the diversity degree are extracted for the downlink cooperative NOMA where SWIPT is only deployed at adjacent users and the static power splitting (SPS) as a specific situation of OPS. In [17], NOMA security is explored attentively. In particular, an artificial noise-aided beam-forming design issue is investigated to provide the high security level of a multiple-input single-output NOMA SWIPT network. EH mode facilitates NOMA network with extended time of operation as limited power as recent work [18, 19]. Furthermore, NOMA scheme can be applied in device-to-device transmission, cognitive radio or physical layer security-aware network [20–24].

The rest of this paper is arranged as follows. The model system is demonstrated in section 1. Section 3 introduces the entire downlink transmission of outage probability. The simulation results are presented in section 4. After all, conclusion is taken in section 5.

## 2. System Model

We examine a wireless communication system as in Figure 1, with a base station indicated by BS (assigned capability of wireless power transfer), two relays indicated by  $R_1$  and  $R_2$  which can be approached by using NOMA and two remote users indicated by  $U_1$  and  $U_2$ . It is noted that  $R_1$  and  $R_2$  are located in the coverage area of wireless power transfer. It is supposed that non-existence of direct link from BS with  $U_1$  and  $U_2$  and thus we need two relays to transfer to the  $U_1$  and  $U_2$  users. These relays are self-powered devices thanks to EH (energy harvesting). It can be found that symbol appears in the baseband whereas EH appears in RF band. The separated Rayleigh channel factor between S and  $R_1$  and  $R_2$  is  $h_{R_1}$  and  $h_{R_2}$ . At the same time, between  $R_1$  and  $U_1$  and  $R_2$  and  $U_2$  are  $h_{U_1}$  and  $h_{U_2}$ , respectively. Two SIC modes are deployed here. Dual SIC is required at link BS- $R_1$ - $U_1$  while single SIC assigned at link BS- $R_2$ - $U_2$ .

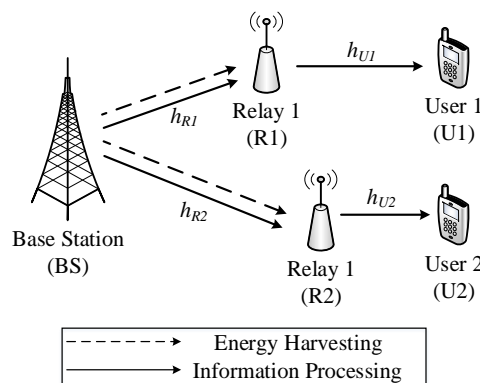


Figure 1. System model for EH NOMA network

### 2.1. Downlink NOMA Relays (WPNR)

First, the BS transmits a superimposed NOMA signal ( $\sum_{i \in \{1,2\}} x_i a_i$ ) to  $R_1$  and  $R_2$  with power distribution fractions  $a_1$  and  $a_2$ , respectively, where  $a_1 < a_2$  and  $a_1^2 + a_2^2 = 1$ . The received signal at relay  $R_1$  and  $R_2$ , respectively is given as:

$$y_{R_1}^{T_1} = \sqrt{a_1 P} x_1 h_{R_1} + \sqrt{a_2 P} x_2 h_{R_1} + n_{R_1} \quad (1)$$

and

$$y_{R_2}^{T_1} = \sqrt{a_1 P} x_1 h_{R_2} + \sqrt{a_2 P} x_2 h_{R_2} + n_{R_2} \quad (2)$$

In this case,  $x_1$  and  $x_2$  are signal intended for  $U_1$  and  $U_2$ , respectively,  $n_{R_1} \sim CN(0, \sigma_{R_1}^2)$  and  $n_{R_2} \sim CN(0, \sigma_{R_2}^2)$  define the additive white Gaussian noise (AWGN) at  $R_1$  and  $R_2$  with equivalent variance  $\sigma_{R_1}^2 = \sigma_{R_2}^2 = \sigma^2$ . We first compute Signal to Interference and Noise Ratio (SINR) at  $R_1$  to detect signal  $x_2$  as

$$\gamma_{x_2}^{R_1} = \frac{\rho |h_{R_1}|^2 a_2}{\rho |h_{R_1}|^2 a_1 + 1} \quad (3)$$

where  $\rho = \frac{P}{\sigma^2}$  is the transmit Signal to Noise ratio (SNR) at  $R_1$ . Then, SNR is computed at  $R_1$  to detect signal  $x_1$  as

$$\gamma_{x_1}^{R_1} = \rho |h_{R_1}|^2 a_1 \quad (4)$$

not the same  $R_1, R_2$  deciphers  $x_2$  only when it receives higher energy:

$$\gamma_{x_2}^{R_2} = \frac{\rho |h_{R_2}|^2 a_2}{\rho |h_{R_2}|^2 a_1 + 1} \quad (5)$$

## 2.2. Energy Harvesting

In order to deploy the relay structure simply, the two relays in WPNR harvest energy from the signals ( $x_e$ ) transmitted by the BS in the second phase with  $E(\{x_e\}^2)=1$ . When  $R_1$  is closer S than  $R_2$ , it harvests more energy than  $R_2$ . This unbalance is verified by  $R_1$  consumes more energy to analyze data and transmits it to  $U_1$ . All of the powers harvested in this phase are

$$P_{R_1}^{T_2} = \frac{\eta P \alpha |h_{R_1}|^2}{3} \quad (6)$$

and

$$P_{R_2}^{T_2} = \frac{\eta P \alpha |h_{R_2}|^2}{3} \quad (7)$$

## 2.3. Downlink NOMA using Relay

During this time, the WPNR utilizes the harvested energy to transmit the symbols to the certain users, that is,  $R_1$  transmits both  $x_1$  and  $x_2$  to  $U_1$ , while  $R_2$  transmits  $x_2$  to  $U_2$ , the received signal can be obtained at and respectively as

$$y_{U_1} = \sqrt{P_{R_1}^{T_2}} (\sqrt{b_1} x_1 + \sqrt{b_2} x_2) h_{U_1} + n_{U_1} \quad (8)$$

where power allocation factors  $b_1 > b_2$  and  $b_1^2 + b_2^2 = 1$

$$y_{U_2} = \sqrt{P_{R_2}^{T_2}} x_2 h_{U_2} + n_{U_2} \quad (9)$$

It is worth noting that  $P_{R_1}$  and  $P_{R_2}$  are the power harvested, we obtained as (6) and (7). The SINR at  $U_1$  to detect  $x_1$  and  $x_2$  and  $U_2$  detects  $x_2$  respectively illustrated as

$$\gamma_{x_1}^{U_1} = \frac{P_{R_1}^{T_2} b_1 |h_{U_1}|^2}{P_{R_1}^{T_2} b_2 |h_{U_1}|^2 + \sigma^2} \quad (10)$$

and

$$\gamma_{x_2}^{U_1} = \frac{P_{R_1}^{T_2} |h_{U_1}|^2}{\sigma^2} \quad (11)$$

and

$$\gamma_{x_2}^{U_2} = \frac{P_{R_2}^{T_2} |h_{U_2}|^2}{\sigma^2} \quad (12)$$

### 3. Outage Probability for the Entire Downlink Transmission

The outage probability in downlink transfer will occur if the transmitted data is not performed well by the relay or by the end NOMA user. The outage probability ( $O_{x_1}^{U_1}$ ) of  $x_1$  at  $U_1$  is indicated as:

$$O_{x_1}^{U_1} = 1 - (O_{R_1} O_{U_1}) \quad (13)$$

in which  $O_{R_1} = (1 - \Pr(\gamma_{x_2}^{R_1} < \gamma_2))(1 - \Pr(\gamma_{x_1}^{R_1} < \gamma_1))$ ,  $O_{U_1} = (1 - \Pr(\gamma_{x_1}^{U_1} < \gamma_1))(1 - \Pr(\gamma_{x_2}^{U_1} < \gamma_1))$ ,  $\gamma_1 = 2^{R_1} - 1$  and  $\gamma_2 = 2^{R_2} - 1$ , whereas  $R_1$  and  $R_2$  stand for the threshold rates of  $x_1$  and  $x_2$  respectively. From (3) and (4),  $O_{R_1}$  can be given as

$$\begin{aligned} O_{R_1} &= \left(1 - \Pr\left(\frac{\rho |h_{R_1}|^2 a_2}{\rho |h_{R_1}|^2 a_1 + 1} < \gamma_2\right)\right) \left(1 - \Pr(\rho |h_{R_1}|^2 a_1 < \gamma_1)\right) \\ &= \Pr\left(|h_{R_1}|^2 > \max\left(\frac{\gamma_2}{\rho(a_2 - \gamma_2 a_1)}, \frac{\gamma_1}{\rho a_1}\right)\right) = e^{-\frac{\chi_1}{\lambda_{R_1}}} \end{aligned} \quad (14)$$

By substituting the value of  $P_{R_1}^{T_2}$  from (6) into above expression and after some numerical computations, we can figure out:

$$O_{U_1} = \underbrace{\left(1 - \Pr\left(\frac{P_{R_1}^{T_2} |h_{U_1}|^2 (b_1 - b_2 \gamma_1)}{\sigma_U^2} < \gamma_1\right)\right)}_{I_1} \times \underbrace{\left(1 - \Pr\left(\frac{P_{R_1}^{T_2} |h_{U_1}|^2 b_2}{\sigma_U^2} < \gamma_2\right)\right)}_{I_2} \quad (15)$$

we consider each component and  $I_1$  are expressed as

$$I_1 = 1 - \Pr\left(\frac{P_{R_1}^{T_2} |h_{U_1}|^2 (b_1 - b_2 \gamma_1)}{\sigma_U^2} < \gamma_1\right) = 1 - \int_0^\infty \left(1 - e^{-\frac{\theta_1}{x}}\right) e^{-x} dx \quad (16)$$

with the assistance of [[25], Eq (3.324.1)], the above equation can be rewritten as

$$I_1 = 2 \sqrt{\frac{\theta_1}{\lambda_{R_1} \lambda_{U_1}}} K_1 \left(2 \sqrt{\frac{\theta_1}{\lambda_{R_1} \lambda_{U_1}}}\right) \quad (17)$$

Similar computation can be deployed for  $I_2$

$$I_2 = 1 - \Pr\left(\frac{P_{R_1}^{T_2} |h_{U_1}|^2 b_2}{\sigma_U^2} < \gamma_2\right) = 1 - \int_0^\infty \left(1 - e^{-\frac{\theta_2}{x}}\right) e^{-x} dx \quad (18)$$

and

$$I_2 = 2 \sqrt{\frac{\theta_2}{\lambda_{R_2} \lambda_{U_1}}} K_1 \left( 2 \sqrt{\frac{\theta_2}{\lambda_{R_2} \lambda_{U_1}}} \right) \quad (19)$$

where  $K_1(\cdot)$  is the first order Bessel function of the second kind. After replacing (14) and (15) into (13), it can be obtained  $O_{x_1}^{U_1}$  as

$$O_{U_1} = 4 \sqrt{\frac{\theta_1 \theta_2}{\lambda_{R_1} \lambda_{R_2} \lambda_{U_1}^2}} K_1 \left( 2 \sqrt{\frac{\theta_1}{\lambda_{R_1} \lambda_{U_1}}} \right) K_1 \left( 2 \sqrt{\frac{\theta_2}{\lambda_{R_2} \lambda_{U_1}}} \right) \quad (20)$$

Now the outage probability at  $U_2$  can be calculated for  $x_2$  which can be taken as:

$$O_{x_2}^{U_2} = 1 - O_{R_2} O_{U_2} \quad (21)$$

where  $O_{R_2} = (1 - \Pr(\gamma_{x_2}^{R_2} < \gamma_2))$  and  $O_{U_2} = (1 - \Pr(\gamma_{x_2}^{U_2} < \gamma_2))$ . Based on (5),  $O_{R_2}$  is given by

$$O_{R_2} = \left( 1 - \left( \frac{\rho |h_{R_2}|^2 a_2}{\rho |h_{R_2}|^2 a_1 + 1} < \gamma_2 \right) \right) = e^{-\frac{\gamma_2}{\rho \lambda_{R_2} (a_2 - \gamma_2 a_1)}} \quad (22)$$

similarly, with the support of [[20], Eq. (3.324.1)], we can express following equation

$$O_{U_2} = \left( 1 - \Pr \left( \frac{P_{R_2} |h_{U_2}|^2}{\sigma_U^2} < \gamma_2 \right) \right) = 2 \sqrt{\frac{\theta_3}{\lambda_{R_2} \lambda_{U_2}}} K_1 \left( 2 \sqrt{\frac{\theta_3}{\lambda_{R_2} \lambda_{U_2}}} \right) \quad (23)$$

by substituting (22) and (23) into (21), the respective expression of  $O_{x_2}^{U_2}$  is acquired.

#### 4. Simulation Results

In this section, the system outage probability for such EH-NOMA is evaluated under different target rates, transmit SNR, percentage of harvested power. We set power allocation factors as illustrations in each figure. Figure 2 plot the outage performance is merely referred to  $R_i$ . However, in order to ensure a communication reliability, we should select a small value for the target rate and the SNR is guaranteed enough high. It can be seen that higher target rates limit outage performance. It is obvious that the NOMA networks have different power allocation factors, and hence performance gap between two far NOMA users exist.

Figure 3 indicates that the outage probability for such EH NOMA with different power splitting fractions for energy harvesting policy, where energy harvesting contributes to increasing power assigned at relay. We can conclude from Figure 3 that in comparison with three circumstances of EH-NOMA with varying power splitting fractions, the proposed model with higher time power collecting allocation can distinguish the outage probability. Furthermore, Figure 3 indicates that EH-NOMA can raise remarkably the outage probability at high transmit SNR at the BS. Besides, the analytic lines adapt the Monte-Carlo simulation very well.

Figure 4 shows outage performance of EH NOMA versus transmit SNR. It is obvious that  $\alpha$  has a significant effect on the outage probability of the proposed network. It is shown that in Figure 5 the network throughput in delay-limited mode can be compared as varying target rates. The throughput of the second NOMA user is better than that of the first user, since they are allocated different power factors. In addition, the figures illustrate that EH-NOMA hits the flux ceiling in the high SNR scheme. Moreover, it is important noting that the throughput is resulted from achieved outage probably and these trends of lines can be expected.

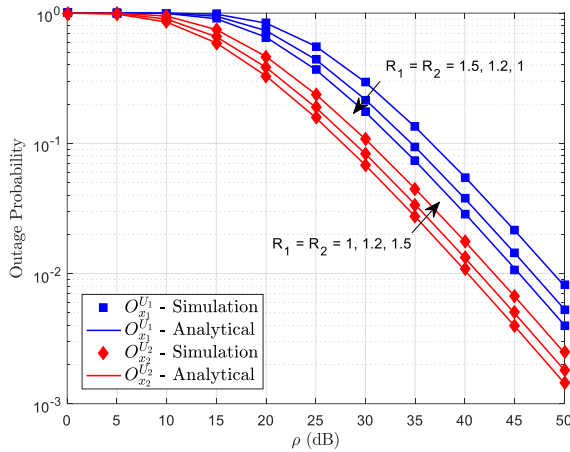


Figure 2. Outage probability versus the transmit  $\rho$ , with  $\alpha = 0.2$ ,  $\eta = 0.9$ ,  $a_1 = b_2 = 0.2$  and  $a_2 = b_1 = 0.8$

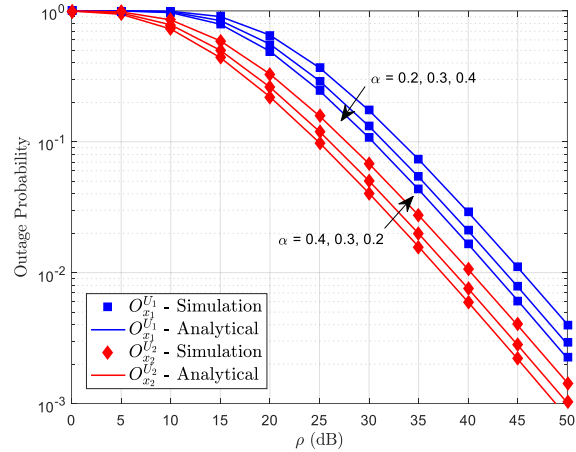


Figure 3. Outage probability versus the transmit  $\rho$ , with  $\eta = 0.9$ ,  $a_1 = b_2 = 0.2$  and  $a_2 = b_1 = 0.8$

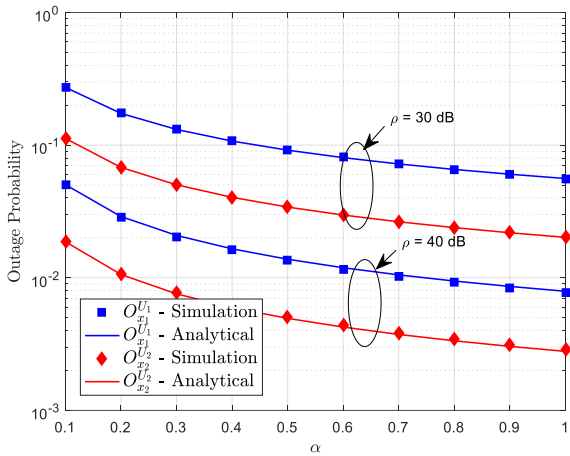


Figure 4. Outage probability versus the power splitting fraction  $\alpha$ , with  $\eta = 0.9$ ,  $R_1 = R_2 = 1$  (bps/Hz),  $a_1 = b_2 = 0.2$  and  $a_1 = b_2 = 0.2$

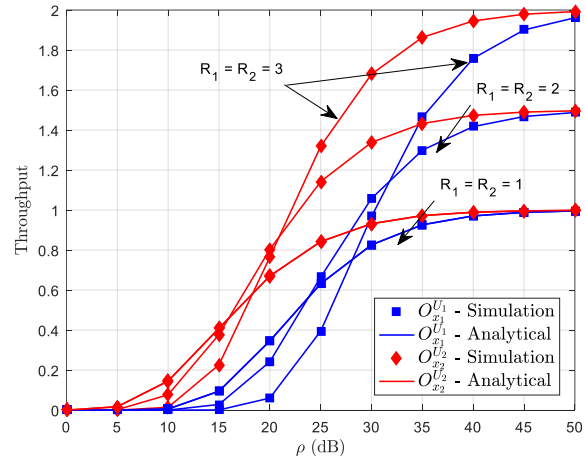


Figure 5. Throughput performance of EH NOMA with  $\alpha = 0.2$ ,  $\eta = 0.9$ ,  $a_1 = b_2 = 0.2$  and  $a_1 = b_2 = 0.2$

**5. Conclusion**

In conclusion, a modern EH NOMA model for downlinks has been introduced in this paper. The main results attempt to distinguish two NOMA users in the same design group from users from other groups using the NOMA concept. We propose two situations related SIC deployment. Therefore, performance gap among two NOMA users still remains fairness if careful selection of power allocation factors. Simulation results demonstrate that all of the energy utilized in the model is not as much of the NOMA transmission but reasonable performance can be achieved.

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