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Implement of multiple access technique by wireless power transfer and relaying network

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Article Info

ABSTRACT

In this paper, we investigate non-orthogonal multiple access (NOMA) network relying on wireless power transfer to prolong lifetime. The base station (BS) sends common signals to the relay with two functions (energy harvesting (EH) and signal processing) to further serve two NOMA users in downlink. Performance gap exists since different power allocation factor assigned from power splitting protocol adopted at the relay and such relay employs both amplify-and-forward (AF) and decode-and-forward schemes. To provide performance metrics, we prove formulas of the outage probability which is a function of transmit signal to noise ratio. Simulation results indicate specific parameters to adjust system performance of two user in the considered EH-NOMA system. This finding is important recommendation to design EH-NOMA which shows particular outage performance at required target rates.

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1. INTRODUCTION

Recently, non-orthogonal multiple access (NOMA) has proposed as a leading multiple access technique to implement various networks in the fifth generation (5G) wireless communication. NOMA provides lots of improvements such as massive connections, higher spectral efficiency, guaranteed user fairness, and low access latency [1], [2]. In principle, NOMA relying on non-orthogonal resource to serve many users in same time and this scheme is different with conventional orthogonal multiple access (OMA) relaying networks [3]-[6]. Popular schemes are employed in NOMA such as frequency-division multiple access (FDMA) and time-division multiple access (TDMA). The challenging models are developed by the authors in [7]-[9], in which combination between relay schemes and NOMA is introduced as novel scheme, namely cooperative NOMA. The novel idea of NOMA is to devide the power domain for realizing MA. In NOMA, different power levels are allocated for different users with respect to distinguished signals [10]-[12]. To further detect signal from received mixture signal, the successive interference cancellation (SIC) is required to eliminate the multiuser interference at the receivers [13]. To further increase spectrum efficiency, cognitive radio (CR) can be integrated with NOMA [14].

The authors in [15]-[21] investigated important role of EH in deployment of NOMA. In the context of EH-NOMA, the secondary users receive the radio-frequency signals to harvest energy and to securely transmit

the secondary privacy information with advantage of the NOMA approach [15]. Different from the traditional ideal linear EH scheme, the authors in [15] implemented the practical non-linear EH architecture. The authors in [16] studied a multiple-access channel (MAC), in which transmitters with capability of EH. The batteries equipped in the transmitters have non-ideal charging and discharging characteristics, which leads to a fractional loss of power driven [16]. Two modes of CR-NOMA are studied in [16] including underlay network and overlay network. Such NOMA system relying on Simultaneous Wireless Information and Power Transfer (SWIPT) architecture to form a SWIPT-aided CR-NOMA system model which exhibits better performance with the approximate formula of energy efficiency for two modes are derived.

Motivated by recent works [2], [7], [8], this paper considers a new cooperative EH-NOMA protocol, where the intermediate relay has not equipped the fixed power source and acts as a wireless powered relay with respect to optimal instantaneous rate. Such relay is designed to help signal forwarding to representative weak user and strong user in NOMA.

2. SYSTEM MODEL AND SNR COMPUTATION

2.1. System model

The considered system model in Figure 1 comprises of a base station (BS), two destinations (U_1, U_2) and a power splitting-based EH relay [18]-[21]. The channel gains h_{ab} for link from node a to node b corresponding exponential distribution with means λ_{ab}. It is assumed that the channels are quasistatic which means that the channels remains constant over one transmission time while different values for these channels over different transmission times. The Amplify-and-Forward (AF) or Decode-and-Forward (DF) relaying protocol is employed at relay. T is called as the whole transmission time and it is divided into two transmission phases. Regarding EH function, it uses only the harvested power during the first transmission phase to transmit during the second transmission phase. P_S is the transmit power of the BS, x_1 and x_2 are the messages BS intends to send to the weak user U_1 and the strong user U_2. a_1 and a_2 are denoted as the power allocation coefficients in NOMA scheme. Following the principle of NOMA, we assume that $a_1 > a_2$ with $a_1 + a_2 = 1$.
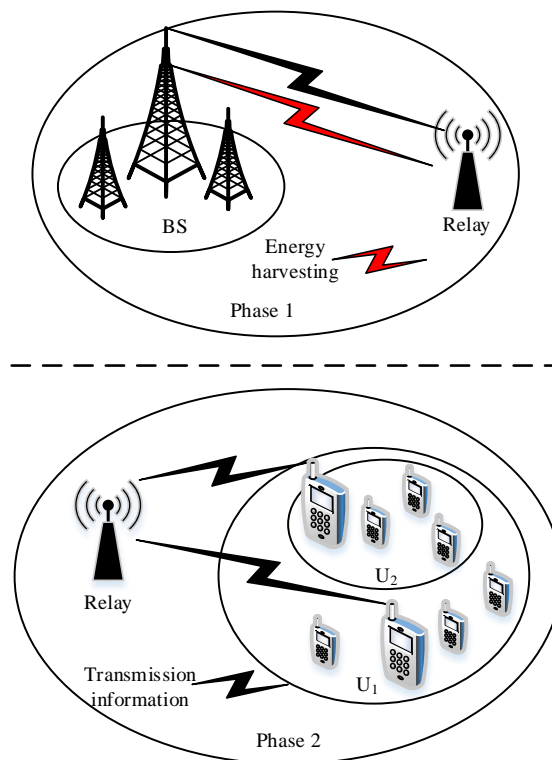

Figure 1. System model of wireless powered NOMA

2.2. SNR computation

In the first transmission phase, the received signal at the relay R is expressed by

$$y_R = \sqrt{(1-\beta)}h_{SR}\left(\sqrt{a_1 P_S}x_1 + \sqrt{a_2 P_S}x_2\right) + n_R \tag{1}$$

where n_R stands for the additive white Gaussian noise (AWGN) with variance N_0, PS coefficient is denoted by β $(0 < \beta < 1)$ assigned at relay.

The harvested power during the first transmission phase is given as [20, 25]

$$P_h = \beta P_S |h_{SR}|^2 \tag{2}$$

Thus, the signal-to-interference-plus-noise ratio (SINR) and signal-to-noise ratio (SNR) after performing successive interference cancellation (SIC) in NOMA can be determined to detect signal x_1, x_2 respectively at R and they can be given as

$$\begin{aligned}\gamma_{SR1} &= \frac{(1-\beta)\,a_1 P_S |h_{SR}|^2}{(1-\beta)\,a_2 P_S |h_{SR}|^2 + N_0} \\ &= \frac{(1-\beta)\,a_1 \rho |h_{SR}|^2}{(1-\beta)\,a_2 \rho |h_{SR}|^2 + 1},\end{aligned} \tag{3}$$

and

$$\gamma_{SR2} = (1-\beta)\,a_2 \rho |h_{SR}|^2, \tag{4}$$

where $\rho = \frac{P_S}{N_0}$ is so-called as transmit SNR at the BS.

Then, the SINR to detect x_1 at user U_1 is given by

$$\gamma_{RU_1} = \frac{\beta \rho a_1 |h_{RU_1}|^2 |h_{SR}|^2}{\beta \rho a_2 |h_{SR}|^2 |h_{RU_1}| + 1} \tag{5}$$

Similarly, the SINR to detect x_2 at user U_2 is computed by

$$\gamma_{RU_{2,1}} = \frac{\beta \rho a_1 |h_{RU_2}|^2 |h_{SR}|^2}{\beta \rho a_2 |h_{SR}|^2 |h_{RU_2}| + 1}. \tag{6}$$

After SIC implementation at U_2, SNR to to detect x_2 is

$$\gamma_{RU_2} = \beta \rho a_2 |h_{RU_2}|^2 |h_{SR}|^2. \tag{7}$$

2.3. Mode of decode-and-forward relaying

With regard to EH-NOMA using DF relaying the end-to-end SNR from the BS to user U_1 can be expressed as

$$\begin{aligned}\gamma_{U_1}^{DF} &= \min\left(\gamma_{SR1}, \gamma_{RU_1}\right) \\ &= \min\left(\frac{(1-\beta)\,a_1 \rho |h_{SR}|^2}{(1-\beta)\,a_2 \rho |h_{SR}|^2 + 1}, \frac{\beta \rho a_1 |h_{RU_1}|^2 |h_{SR}|^2}{\beta \rho a_2 |h_{SR}|^2 |h_{RU_1}| + 1}\right)\end{aligned} \tag{8}$$

It is worth noting that such *min* function is maximized when all of its argument becomes equal. As a result, the following optimal value of β is found to achieve maximal instantaneous rate as

$$\beta_{DF,U_1}^* = \frac{1}{|h_{RU_1}|^2 + 1} \tag{9}$$

For DF case, the SNR from the BS to U_2 can be computed as

$$\begin{aligned}\gamma_{U_2}^{DF} &= \min\left(\gamma_{SR2}, \gamma_{RU_2}\right) \\ &= \min\left((1-\beta)\,a_2 \rho |h_{SR}|^2, \beta \rho a_2 |h_{RU_2}|^2 |h_{SR}|^2\right).\end{aligned} \tag{10}$$

Similarly, the optimal value of β can be obtained to achieve optimal instantaneous rate as

$$\beta_{DF,U_2}^* = \frac{1}{|h_{RU_2}|^2 + 1}. \tag{11}$$

2.4. Mode of amplify-and-forward relaying

For AF- based EH-NOMA, the received SNR at the U_1 can be formulated by (4) [22]

$$
\gamma_{U_1}^{AF} \simeq \frac{\gamma_{SR1}\gamma_{RU_1}}{\gamma_{SR1} + \gamma_{RU_1}}
$$
$$
\simeq \frac{(1-\beta)\,\beta\rho a_1 |h_{RU_1}|^2 |h_{SR}|^2}{2\,(1-\beta)\,\beta\rho a_2 |h_{SR}|^2 |h_{RU_1}| + (1-\beta) + \beta|h_{RU_1}|^2}
\tag{12}
$$

Similarly, the SINR can be obtained at U_2 as

$$
\gamma_{U_2}^{AF} \simeq \frac{(1-\beta)\,\beta\rho a_2 |h_{RU_2}|^2 |h_{SR}|^2}{(1-\beta) + \beta|h_{RU_2}|^2}
\tag{13}
$$

The following optimal value of β in AF scenario is expressed by

$$
\beta_{AF,U_i}^* = \frac{1}{|h_{RU_i}| + 1}
\tag{14}
$$

3.   OUTAGE PROBABILITY
3.1.   Decode-and-forward relaying
3.1.1. Outage probability of U_1

As definition and considering as important metric reported in [7], [8], this section presents outage performance of such EH-NOMA.

Putting optimal value of β raised in (9) into (8), it can be obtained SINR in new form as

$$
\gamma_{U_1}^{DF} = \frac{\rho a_1 |h_{SR}|^2 |h_{RU_1}|^2}{\rho a_2 |h_{SR}|^2 |h_{RU_1}|^2 + |h_{RU_1}|^2 + 1}
\tag{15}
$$

Then, the outage probability of U_1 can be formulated as

$$
OP_{U_i}^{DF} = \Pr\left(\gamma_{U_i}^{DF} < \gamma_{thi}\right)
\tag{16}
$$

where $\gamma_{thi} = 2^{2R_i} - 1$, $i \in \{1,2\}$, with R_i is target rates for U_1, U_2, respectively.

Proposition 1: The expected outage of U_1 is given by

$$
OP_{U_1}^{DF} = \int_0^\infty \left(1 - e^{-\frac{\gamma_{th1}(x+1)}{(a_1 - \gamma_{th1}a_2)\rho x}}\right)\lambda_{RU_1}e^{-\lambda_{RU_1}x}dx
$$
$$
= 1 - 2e^{-\frac{\lambda_{SR}\gamma_{th1}}{(a_1 - \gamma_{th1}a_2)\rho}}\sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{(a_1 - \gamma_{th1}a_2)\rho}}K_1\left(2\sqrt{\frac{\gamma_{th1}\lambda_{RU_1}\lambda_{SR}}{(a_1 - \gamma_{th1}a_2)\rho}}\right)
\tag{17}
$$

Proof: See appendix A.

3.1.2. Outage probability of U_2

Similarly, originating from SINR we have

$$
\gamma_{U_2}^{DF} = \frac{\rho a_2 |h_{RU_2}|^2 |h_{SR}|^2}{|h_{RU_2}|^2 + 1}
\tag{18}
$$

Then, after some algebra mathematical manipulations, the outage probability of U_2 can be computed as

$$
OP_{U_2}^{DF} = 1 - 2e^{-\frac{\lambda_{SR}\gamma_{th2}}{\rho a_2}}\sqrt{\frac{\lambda_{SR}\lambda_{RU_2}\gamma_{th2}}{\rho a_2}}
$$
$$
\times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RU_2}\gamma_{th2}}{\rho a_2}}\right)
\tag{19}
$$

where $K_n(.)$ stands for the modified Bessel function of second kind and nth order.

3.2.   Amplify-and-Forward relaying
3.2.1. Outage probability of U_1

After putting the optimal PS ratio β of AF based EH-NOMA we can write the SINR for this case and it is expressed in approximate form as

$$\gamma_{U_1}^{AF} \simeq \frac{\rho a_1 |h_{RU_1}|^2 |h_{SR}|^2}{2\rho a_2 |h_{SR}|^2 |h_{RU_1}|^2 + (1 + |h_{RU_1}|)^2} \tag{20}$$

Then, the expected outage performance at U_1 can be formulated by

$$OP_{U_1}^{AF} \simeq \Pr\left(\gamma_{U_1}^{AF} < \gamma_{th1}\right)$$
$$\simeq \Pr\left(|h_{SR}|^2 < \frac{\gamma_{th1}(1 + |h_{RU_1}|)^2}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)|h_{RU_1}|^2}\right) \tag{21}$$

Performing computational technique reported in [7], it can be obtained outage probability for U_1 in AF mode as

$$OP_{U_1}^{AF} \simeq 1 - 2e^{-\frac{\lambda_{SR}\gamma_{th1}}{\rho(a_1 - 2\gamma_{th1}a_2)}}\sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)}}$$
$$\times K_1\left(2\sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)}}\right) + e^{-\frac{\lambda_{SR}\gamma_{th1}}{\rho(a_1 - 2\gamma_{th1}a_2)}}$$
$$\times \int_0^\infty \frac{2\gamma_{th1}\lambda_{SR}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)\sqrt{x}}e^{-\frac{-\lambda_{SR}\gamma_{th1}}{\rho(a_1 - 2\gamma_{th1}a_2)x}}e^{-\lambda_{RU_1}x}dx \tag{22}$$

With help [23, 3.471.9], (22) can be formulated as

$$OP_{U_1}^{AF} \simeq 1 - 2e^{-\frac{\lambda_{SR}\gamma_{th1}}{\rho(a_1 - 2\gamma_{th1}a_2)}}\sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)}}$$
$$\times K_1\left(2\sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)}}\right) + e^{-\frac{\lambda_{SR}\gamma_{th1}}{\rho(a_1 - 2\gamma_{th1}a_2)}}\frac{4\gamma_{th1}\lambda_{SR}\lambda_{RU_1}^2}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)}$$
$$\times \left(\frac{\gamma_{th1}\lambda_{SR}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)\lambda_{RU_1}}\right)^{1/4}K_{1/2}\left(2\sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{\rho\left(a_1 - 2\gamma_{th1}a_2\right)}}\right) \tag{23}$$

3.2.2. Outage probability of U_2

Similarly, we first consider SINR in AF mode for U_2 as

$$\gamma_{U_2}^{AF} = \frac{\rho a_2 |h_{SR}|^2 |h_{RU_2}|^2}{(1 + |h_{RU_2}|)^2} \tag{24}$$

Then, the outage probability can be determined at U_2 as

$$OP_{U_2}^{AF} \simeq 1 - 2e^{-\frac{\lambda_{SR}\gamma_{th2}}{\rho a_2}}\sqrt{\frac{\lambda_{SR}\lambda_{RU_2}\gamma_{th2}}{\rho a_2}}$$
$$\times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RU_2}\gamma_{th2}}{\rho a_2}}\right) + e^{-\frac{\lambda_{SR}\gamma_{th2}}{\rho a_2}}\frac{4\gamma_{th2}\lambda_{SR}\lambda_{RU_2}^2}{\rho a_2}$$
$$\times \left(\frac{\gamma_{th2}\lambda_{SR}}{\rho a_2\lambda_{RU_2}}\right)^{1/4}K_{1/2}\left(2\sqrt{\frac{\gamma_{th2}\lambda_{SR}\lambda_{RU_2}}{\rho a_2}}\right) \tag{25}$$

By using (15) for (19), we formulate the outage probability as

$$OP_{U_1}^{DF} = \Pr\left(|h_{SR}|^2 < \frac{\gamma_{th1}\left(|h_{RU_1}|^2 + 1\right)}{(a_1 - \gamma_{th1}a_2)\rho|h_{RU_1}|^2}\right) \tag{26}$$

Based on probability density function (PDF) of $|h_i|^2$ is given as $f_{|h_i|^2}(x) = \lambda_{RU_1} e^{-\lambda_{RU_1} x}$, it can be rewritten as

$$OP_{U_1}^{DF} = \int_0^\infty f_{|h_{RU_1}|^2}(x) \int_0^{\frac{\gamma_{th1}(x+1)}{(a_1 - \gamma_{th1} a_2)\rho x}} f_{|h_{SR}|^2}(y) dx dy$$

$$= \int_0^\infty \left(1 - e^{-\frac{\gamma_{th1}(x+1)}{(a_1 - \gamma_{th1} a_2)\rho x}} \right) \lambda_{RU_1} e^{-\lambda_{RU_1} x} dx$$

(27)

Thus, based on [23, 3.324.1] $OP_{U_1}^{DF}$ can be obtained as

$$OP_{U_1}^{DF} = \int_0^\infty \left(1 - e^{-\frac{\gamma_{th1}(x+1)}{(a_1 - \gamma_{th1} a_2)\rho x}} \right) \lambda_{RU_1} e^{-\lambda_{RU_1} x} dx$$

$$= 1 - 2e^{-\frac{\lambda_{SR}\gamma_{th1}}{(a_1 - \gamma_{th1} a_2)\rho}} \sqrt{\frac{\gamma_{th1}\lambda_{SR}\lambda_{RU_1}}{(a_1 - \gamma_{th1} a_2)\rho}} K_1 \left(2\sqrt{\frac{\gamma_{th1}\lambda_{RU_1}\lambda_{SR}}{(a_1 - \gamma_{th1} a_2)\rho}} \right)$$

(28)

It is end of the proof.

4. SIMULATION RESULT

In this section, we perform numerical simulations to exhibit performance metrics of EH-NOMA system. We set fixed power allocation factors as $a_1 = 0.9$, $a_2 = 0.1$. To form wireless channels, we set $\lambda_{SR} = \lambda_{RU_2} = 1$, $\lambda_{RU_1} = 2$.

The outage behavior of two users in DF and AF can be seen in Figure 2 and Figure 3. It can be confirmed that at high SNR, such outage performance can be improved significantly. Regardless architecture of AF and DF modes, similar trends of outage probability for two users can be reported. More importantly, theorical and Monte-Carlo simulation results are matched very tight which verify the correction of expression derived. Different power factors used in users are main reason of performance gap in Figure 2 and Figure 3.

In Figure 4, trends of outage probability are varied based on how percentage of power allocated to each user. When a_1 varies from 0.5 to 1, outage probability of user U_1 improves clearly. Which situation is opposite with performance of user U_2.
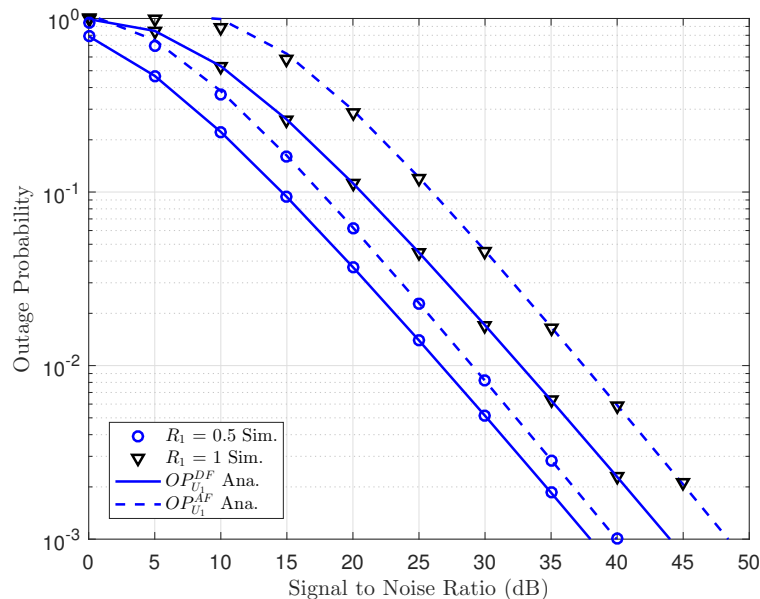

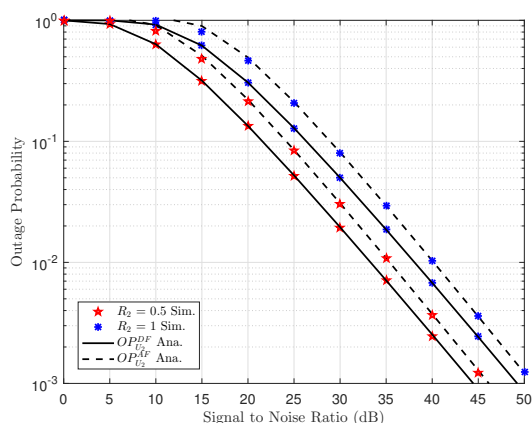Figure 2. Outage performance of U_1 versus SNR with $R_2 = 0.5$

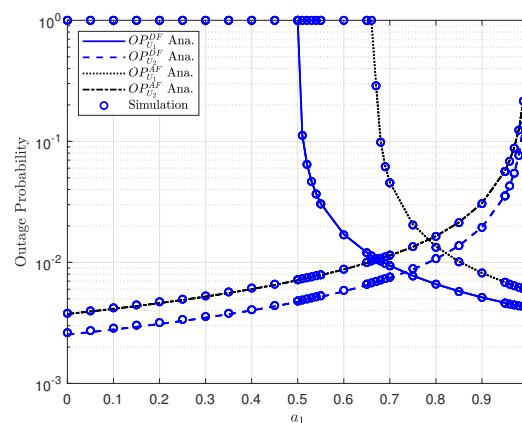Figure 3. Outage performance of U_2 versus transmit SNR at BS with $R_1 = 0.5$

Figure 4. Outage performance of U_1 and U_2 versus a_1

5.   CONCLUSION

This paper considers main parameters make influence on EH-NOMA system, in which NOMA users cooperate with relay by exploiting wireless powered capability. The detail performance analysis has been performed in terms of outage probability. The closed-form expressions related to such are derived, and it is shown that performance gap exists among two NOMA users for both AF and DF mode. The target rates and power allocation factors are main impacts on outage probability. By implement EH in such NOMA systems, we can prolong their operation and the constraint of outage performance is still acceptable.

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