

Joint impacts of relaying scheme and wireless power transfer in multiple access of cellular networks

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ABSTRACT

This paper considers ergodic capacity of energy harvesting (EH) based cellular networks. Such a network employs non-orthogonal multiple access (NOMA) together with relaying scheme to serve two far users. In this system model, relay is facilitated power splitting (PS) protocol to implement energy harvesting (EH). To examine capacity, expressions of signal to noise ratio (SNR) need be computed to achieve capacity. Power allocation factors are different for two users in such system and hence performance gap happens to distinguish requirements for separated users. It can be confirmed that the proposed paradigm exhibits maximal achievable capacity in some scenarios of setting parameters. To confirm exactness of the analytical expressions and show advantages of the proposed EH-NOMA, simulation results are performed in terms of ergodic capacity.

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1. INTRODUCTION

Considering as the potentials to implement infrastructure in the fifth generation (5G) cellular system, higher spectral efficiency benefits from the non-orthogonal multiple access (NOMA) technique to serve massive connections [1], [2]. To overcome disadvantages of the traditional orthogonal multiple access (MA) technique, the power domain is employed to require NOMA to provide MA in cellular networks [3]. To perform functions of NOMA, the signals of multiple users are multiplexed in the power domain at the base station (BS), i.e. superposition coding (SupC) is designed at transmitters. At the receivers, to restrain the inter-user interference, it is required to employ successive interference cancellation (SIC). In addition to power-reuse, NOMA provides extra advantage in term of user fairness as distinctive feature of this scheme [4]. In this MA scheme, users with worse channel conditions need allocate more power, while users with higher channel gains only require less power. By implementing NOMA communication system, it can be achieved improved trade-off between user fairness and system performance. For example, higher throughput and faster traffic are two advantages of NOMA compared with the conventional orthogonal MA protocols.

Together with NOMA, this technique has more benefits as combining with cooperative transmission scenarios and further improvement of the reliability in NOMA is obtained [5]–[8]. In cooperative manner, users and relays can cooperate to combat channel fading and improve the performances, namely new scheme as cooperative NOMA (C-NOMA) networks. At the receivers, the maximal-ratio combining (MRC) needs to combine the two independent signals received at two links including the direct and relaying. As a result, C-NOMA

provides ability of the diversity techniques. Thus, C-NOMA exhibits better qualities of services (Qos) criteria and the system can be improved significantly. Recently, C-NOMA has been intensively studied. Generally, various aspects of C-NOMA were introduced. The reliability in transmission and improved performance can be achieved as in recent works [9]–[15]. In recent works [13], [15], the authors indicated advantages of NOMA can be achieved in device to device networks. Regarding energy harvesting [16–19], results exhibits wireless power transfer as solution to prolong lifetime of network and applications of NOMA. The closed forms of the metrics, such as the in terms of outage probability, throughput. In most of works, the target rates are main factor affecting to outage behavior and they derived expressions to evaluate the performance of the NOMA scheme.

Nowadays, power domain based NOMA is widely studied in works, such as [20], [21], [22]. They introduced system adopting orthogonal frequency division multiplexing in the sub-channel transmission of PD-NOMA [23]. The multi-user detection uses SIC technology at the receiver to delete interference among users and such Non-orthogonal transmission still remains its performance. The authors in [24] examined performance of a hybrid NOMA-based wireless system. In this system, to transmit on the uplink, users harvest wireless power from the received downlink signals. To improve the spectral efficiency by exploiting the spatial domain]. W. Kim et al. proposed an integration of NOMA and generalized space shift keying [26].

Motivated by recent works [16], [17], [18], this paper considers a new the fixed power allocation scheme and relay harvests power and acts as relay with respect to implement cooperative EH-NOMA protocol. Such relay is designed to introduce performance gaps to representative how well the weak user and strong user operate in various scenarios.

2. SYSTEM MODEL AND SINR COMPUTATIONS

2.1. System model

By exploring wireless power transfer, relay in Figure 1 is able to harvesting power from a base station (BS). In this scenario, two destinations (U_1, U_2) with a power splitting-based EH relay [18]–[21] is studied. We denote channel gains h_{ab} for link from node a to node b and it falls into exponential distribution with means λ_{ab} . The channels are quasistatic, i.e. the channels remains constant over one transmission time while different values for these channels over different transmission times. Relay has two kinds, Amplify-and-Forward (AF) or Decode-and-Forward (DF) relaying and it suitable for relevant applications. T is denoted as the whole transmission time. T 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. Regarding the transmit power of the BS, P_S is transmit power. To serve two users, x_1 and x_2 are the messages intending to send to the weak user U_1 and the strong user U_2 . We denote a_1 and a_2 as the power allocation coefficients in NOMA scheme. It is strict required: $a_1 > a_2$ with $a_1 + a_2 = 1$.

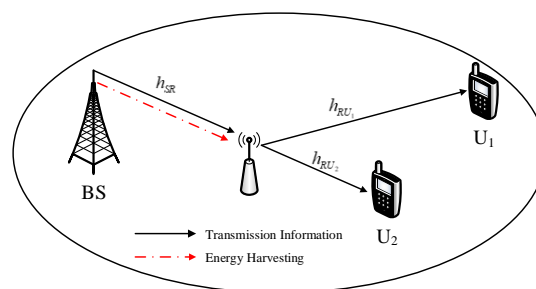


Figure 1. Wireless power transfer in NOMA.

The relay is able to harvest wireless energy to serve transmission in the next phase, it need be computed the received signal at the relay R as

$$y_R = \sqrt{(1 - \beta)} h_{SR} \mu(x) + n_R \quad (1)$$

where $\mu(x) = (\sqrt{a_1 P_S} x_1 + \sqrt{a_2 P_S} x_2)$ is mixture signal, n_R is known as the additive white Gaussian noise (AWGN) with variance N_0 . More importantly, by controlling transmit power P_S at the BS with arbitrary coeffi-

cient denoted by β ($0 < \beta < 1$), amount of harvested power varies significantly and hence system performance needs be guaranteed.

Although litter amount of harvested energy, the relay benefits from such energy, and it is formulated by [27]

$$P_h = \beta P_S |h_{SR}|^2. \quad (2)$$

We denote $|h_{SR}|^2$ as variable X_a . In the next section, the first metric needs be considered, i.e. the signal-to-interference-plus-noise ratio (SINR) and signal-to-noise ratio (SNR) are then used in further metrics.

2.2. SINR computations

Together with performing successive interference cancellation (SIC) in NOMA, SINR, SNR can be determined to detect signal x_1, x_2 respectively at R and they can be given as

$$\begin{aligned} \gamma_{SR1} &= \frac{(1 - \beta) a_1 P_S X_a}{(1 - \beta) a_2 P_S X_a + N_0} \\ &= \frac{(1 - \beta) a_1 \rho X_a}{(1 - \beta) a_2 \rho X_a + 1}, \end{aligned} \quad (3)$$

and

$$\gamma_{SR2} = (1 - \beta) a_2 \rho X_a, \quad (4)$$

Considering the main impact on outage performance $\rho = \frac{P_S}{N_0}$ is denoted as transmit SNR and it is computed at the BS.

In order to detect x_1 at user U_1 , the corresponding SINR is expressed by

$$\gamma_{RU1} = \frac{\beta \rho a_1 X_b X_a}{\beta \rho a_2 X_a X_b + 1} \quad (5)$$

where $|h_{SU1}|^2$ is denoted as variable X_b . Similarly, the SINR to detect x_2 at user U_2 is computed by

$$\gamma_{RU2,1} = \frac{\beta \rho a_1 |h_{RU2}|^2 X_a}{\beta \rho a_2 X_a |h_{RU2}| + 1}. \quad (6)$$

SNR to to detect x_2 is only determined after SIC implementation at U_2 , and it is formulated as

$$\gamma_{RU2} = \beta \rho a_2 |h_{RU2}|^2 |h_{SR}|^2. \quad (7)$$

2.3. Decode-and-forward relaying

DF relaying mode is also known as popular strategy to extend coverage of wireless network under the context of EH-NOMA using the end-to-end SNR from the BS to user U_1 can be expressed as

$$\begin{aligned} \gamma_{U1}^{DF} &= \min(\gamma_{SR1}, \gamma_{RU1}) \\ &= \min\left(\frac{(1 - \beta) a_1 \rho X_a}{(1 - \beta) a_2 \rho X_a + 1}, \frac{\beta \rho a_1 X_b X_a}{\beta \rho a_2 X_a X_b + 1}\right) \end{aligned} \quad (8)$$

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

$$\beta_{DF,U1}^* = \frac{1}{X_b + 1} \quad (9)$$

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

$$\begin{aligned} \gamma_{U2}^{DF} &= \min(\gamma_{SR2}, \gamma_{RU2}) \\ &= \min\left((1 - \beta) a_2 \rho X_a, \beta \rho a_2 |h_{RU2}|^2 X_a\right). \end{aligned} \quad (10)$$

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

$$\beta_{DF,U2}^* = \frac{1}{|h_{RU2}|^2 + 1}. \quad (11)$$

2.4. Amplify-and-forward relaying

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

$$\begin{aligned}\gamma_{U_1}^{AF} &\simeq \frac{\gamma_{SR1}\gamma_{RU_1}}{\gamma_{SR1} + \gamma_{RU_1}} \\ &\simeq \frac{(1-\beta)\beta\rho a_1 X_b X_a}{2(1-\beta)\beta\rho a_2 X_a X_b + (1-\beta) + \beta X_b}\end{aligned}\quad (12)$$

Similarly, the SINR can be obtained at U_2 as

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

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

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

3. ERGODIC CAPACITY

3.1. Decode-and-Forward relaying

3.1.1. The ergodic capacity at U_1

The analytical expression can be obtained for ergodic capacity [2]

$$\begin{aligned}C_{U_1}^{DF} &= \mathbb{E} \left[\frac{1}{2} \log_2 (1 + \gamma_{U_1}^{DF}) \right] \\ &= \frac{1}{2 \ln 2} \int_0^\infty \frac{1 - F_{\gamma_{U_1}^{DF}}(x)}{1+x} dx\end{aligned}\quad (15)$$

where $\mathbb{E}[\cdot]$ denotes the expectation over random variable. Then, we can write $F_{\gamma_{U_1}^{DF}}(x)$ as

$$\begin{aligned}F_{\gamma_{U_1}^{DF}}(x) &= \Pr(\gamma_{U_1}^{DF} < x) \\ &= 1 - \Pr\left(X_a > \frac{x(|h_1|^2 + 1)}{\rho(a_1 - xa_2)|h_1|^2}\right)\end{aligned}\quad (16)$$

It then can be written as

$$\begin{aligned}F_{\gamma_{U_1}^{DF}}(x) &= \int_0^\infty f_{|h_1|^2}(z) \int_0^{\frac{x(z+1)}{\rho(a_1 - xa_2)z}} f_{X_a}(y) dy dz \\ &= 1 - \frac{1}{\lambda_1} \int_0^\infty e^{-\frac{x(z+1)}{\rho(a_1 - xa_2)z\lambda_{SR}} - \frac{z}{\lambda_1}} dz \\ &= 1 - 2e^{-\frac{\gamma_{th1}}{(a_1 - xa_2)\rho\lambda_{SR}}} \sqrt{\frac{\gamma_{th1}}{(a_1 - xa_2)\rho\lambda_{SR}\lambda_1}} \\ &\quad \times K_1\left(2\sqrt{\frac{\gamma_{th1}}{(a_1 - xa_2)\rho\lambda_1\lambda_{SR}}}\right)\end{aligned}\quad (17)$$

As a result, ergodic capacity in optimal scenario and DF mode for U_1 is given by

$$\begin{aligned}C_{U_1}^{DF} &= \frac{1}{\ln 2} \int_0^\infty \frac{e^{-\frac{\lambda_{RU_1}x}{(a_1 - xa_2)\rho}}}{1+x} \\ &\quad \times \sqrt{\frac{x\lambda_{RU_1}\lambda_{SR}}{(a_1 - xa_2)\rho}} K_1\left(2\sqrt{\frac{x\lambda_{SR}\lambda_{RU_1}}{(a_1 - xa_2)\rho}}\right) dx\end{aligned}\quad (18)$$

3.1.2. The ergodic capacity at U_2

Similarly, ergodic capacity is expressed for U_2 in DF mode as

$$\begin{aligned} C_{U_2}^{DF} &= \mathbb{E} \left\{ \frac{1}{2} \log_2 (1 + \gamma_{U_1}^{DF}) \right\} \\ &= \mathbb{E} \left(\frac{e^{\frac{\lambda_{SR}(X_b+1)}{a_2 \rho X_b}} E_1 \left(\frac{\lambda_{SR}(X_b+1)}{a_2 \rho X_b} \right)}{2 \ln 2} dX_b \right) \end{aligned} \quad (19)$$

where $E_1(\cdot)$ is the exponential integral. Because, it is difficult to solve (19) in closed-form, so we can use the following approximation for the exponential integral [24]

$$E_1(x) \simeq 4\sqrt{2}\pi a_N a_I \sum_{n=1}^{N+1} \sum_{i=1}^{I+1} \sqrt{b_n} e^{-4b_n b_i x} \quad (20)$$

where $a_N = \frac{1}{2N+2}$, $a_I = \frac{1}{2I+2}$, $b_n = \frac{\cot(\theta_{n-1}) - \cot(\theta_n)}{(N+1)^{-1}\pi}$, $b_i = \frac{\cot(\theta_{i-1}) - \cot(\theta_i)}{(I+1)^{-1}\pi}$, $\theta_0 = 0$, $\theta_n = \frac{\pi n}{2N+2}$, $\theta_i = \frac{\pi i}{2I+2}$.

Hence, $C_{U_2}^{DF}$ can be rewritten as

$$\begin{aligned} C_{U_2}^{DF} &= \frac{2\sqrt{2}}{\ln 2} \pi a_N a_I \sum_{n=1}^{N+1} \sum_{i=1}^{I+1} \sqrt{b_n} \\ &\quad \times \int_0^\infty \lambda_{RU_1} e^{-\lambda_{RU_1} X_b} e^{-\varepsilon \frac{(X_b+1)}{X_b}} dX_b \end{aligned} \quad (21)$$

where $\varepsilon = \frac{4b_n b_i \lambda_{SR}}{a_2 \rho} - \frac{\lambda_{SR}}{a_2 \rho}$. Based on [23, 3.324.1], the capacity of U_2 can be expressed as

$$C_{U_2}^{DF} = \frac{2\sqrt{2}}{\ln(2)} \pi a_N a_I \sum_{n=1}^{N+1} \sum_{i=1}^{I+1} \sqrt{\lambda_{RU_1} b_n} e^{-\varepsilon} \sqrt{\varepsilon} K_1 \left(2\sqrt{\varepsilon \lambda_{RU_1}} \right) \quad (22)$$

3.2. Amplify-and-forward relaying

3.2.1. The ergodic capacity at U_1

We have formula for examining ergodic capacity at U_1 in AF mode as

$$\begin{aligned} C_{U_1}^{AF} &= \mathbb{E} \left[\frac{1}{2} \log_2 (1 + \gamma_{U_1}^{AF}) \right] \\ &= \frac{1}{2 \ln 2} \int_0^\infty \frac{1 - F_{\gamma_{U_1}^{AF}}(x)}{1+x} dx. \end{aligned} \quad (23)$$

It is worth noting that $F_{\gamma_{U_1}^{AF}}(x)$ is written as

$$\begin{aligned} F_{\gamma_{U_1}^{AF}}(x) &= \Pr(\hat{\gamma}_{U_2}^{AF} < x) \\ &= \Pr \left(\frac{\rho a_2 X_a |h_{RU_2}|^2}{(1 + |h_{RU_2}|)^2} < x \right) \\ &= \Pr \left(X_a < \frac{x(1 + |h_{RU_2}|)^2}{\rho a_2 |h_{RU_2}|^2} \right) \end{aligned} \quad (24)$$

Using the CDF of X_a and the approximation $e^{-\frac{2\lambda_{SR}\gamma_{th}2}{\rho a_2 \sqrt{z}}} = 1 - \frac{2\lambda_{SR}\gamma_{th}2}{\rho a_2 \sqrt{z}}$ we can write

$$\begin{aligned} F_{\gamma_{U_1}^{AF}}(x) &= 1 - \lambda_{RU_2} \int_0^\infty e^{-\frac{\lambda_{SR}x(1+\sqrt{z})^2}{\rho a_2 z}} e^{-\lambda_{RU_2}z} dz \\ &\simeq 1 - \int_0^\infty \lambda_{RU_2} e^{-\frac{\lambda_{SR}x}{\rho a_2}} e^{-\frac{\lambda_{SR}x}{\rho a_2 z} - \lambda_{RU_2}z} dz \\ &\quad + \frac{2\lambda_{SR}\lambda_{RU_2}xe^{-\frac{\lambda_{SR}x}{\rho a_2}}}{\rho a_2} \int_0^\infty \frac{1}{\sqrt{z}} e^{-\frac{\lambda_{SR}x}{\rho a_2 z} - \lambda_{RU_2}z} dz \end{aligned} \quad (25)$$

To continue compute it, $F_{\gamma_{U_1}^{AF}}(x)$ is rewritten as

$$\begin{aligned} F_{\gamma_{U_1}^{AF}}(x) &\simeq 1 - 2e^{-\frac{\lambda_{SR}x}{\rho a_2}} \sqrt{\frac{\lambda_{SR}\lambda_{RU_2}x}{\rho a_2}} K_1 \left(2\sqrt{\frac{\lambda_{SR}\lambda_{RU_2}x}{\rho a_2}} \right) \\ &\quad + e^{-\frac{\lambda_{SR}x}{\rho a_2}} \frac{4x\lambda_{SR}\lambda_{RU_2}^2}{\rho a_2} \left(\frac{x\lambda_{SR}}{\rho a_2\lambda_{RU_2}} \right)^{1/4} K_{1/2} \left(2\sqrt{\frac{x\lambda_{SR}\lambda_{RU_2}}{\rho a_2}} \right) \end{aligned} \quad (26)$$

After performing some manipulations, it can be obtained below result

$$\begin{aligned} C_{U_1}^{AF} &= \frac{1}{\ln 2} \int_0^{a_1/2a_2} \frac{1}{1+x} \left(e^{-\frac{\lambda_{SR}x}{\rho(a_1-2xa_2)}} \sqrt{\frac{x\lambda_{SR}\lambda_{RU_1}}{\rho(a_1-2xa_2)}} \right. \\ &\quad \times K_1 \left(2\sqrt{\frac{x\lambda_{SR}\lambda_{RU_1}}{\rho(a_1-2xa_2)}} \right) - e^{-\frac{\lambda_{SR}x}{\rho(a_1-2xa_2)}} \frac{2x\lambda_{SR}\lambda_{RU_1}^2}{\rho(a_1-2\gamma_{th1}a_2)} \\ &\quad \times \left(\frac{x\lambda_{SR}}{\rho(a_1-2xa_2)\lambda_{RU_1}} \right)^{1/4} K_{1/2} \left(2\sqrt{\frac{x\lambda_{SR}\lambda_{RU_1}}{\rho(a_1-2xa_2)}} \right) \Big) dx \end{aligned} \quad (27)$$

3.2.2. The ergodic capacity at U_2

Similarly, it can be illustrated ergodic capacity for U_2 as

$$\begin{aligned} C_{U_2}^{AF} &= E \left(\frac{1}{2} \int_0^\infty \log \left(1 + \frac{\rho a_2 |h_{RU_2}|^2 X_a}{(|h_{RU_2}| + 1)^2} \right) \right. \\ &\quad \times \lambda_{SR} e^{-\lambda_{SR}X_a} dX_a \Big) \\ &= \frac{1}{\ln 2} \int_0^\infty E_1 \left(\frac{\lambda_{SR}(|h_{RU_1}| + 1)^2}{a_2 \rho X_b} \right) \\ &\quad \times e^{-\frac{\lambda_{SR}(|h_{RU_1}| + 1)^2}{a_2 \rho X_b}} \lambda_{SR} e^{-\lambda_{SR}X_a} d|h_{SR}|^2 \end{aligned} \quad (28)$$

Finally, in AF mode, we can computed ergodic capacity for U_2 as

$$\begin{aligned} C_{U_2}^{AF} &= \frac{2\sqrt{2}}{\ln(2)} \pi a_N a_I \sum_{n=1}^{N+1} \sum_{i=1}^{I+1} \sqrt{b_n} e^{-\varepsilon} \\ &\quad \times \sqrt{\frac{\lambda_{RU_1}}{\varepsilon + \lambda_{RU_1}}} \varepsilon \lambda_{RU_1} K_1 \left(2\sqrt{\varepsilon(\varepsilon + \lambda_{RU_1})} \right) \end{aligned} \quad (29)$$

4. SIMULATION RESULT

The simulation model is based on Figure 1, and we assume fixed power allocation factors assigned for two NOMA users, $a_1 = 0.9$, $a_2 = 0.1$. In the simulations, we set $\lambda_{SR} = \lambda_{RU_2} = 1$, $\lambda_{RU_1} = 2$.

In Figure 2, we investigate the impact of AF and DF relaying mode on ergodic capacity performance of EH-NOMA system. It can be seen that ergodic of user U_1, U_2 at mode DF is better than that of AF mode. However, user U_2 provides higher ergodic capacity compared with that of user U_1 . The main reason is that different power allocation factors are used for two users. The second reason is related to decoding procedure at each user is differ.

Figure 3 depicts how strong channel of link from the BS to relay make influence to ergodic capacity. It can be intuitively seen that strong channel gain results in weaker channel of link from relay to destinations and such situation exhibits worse performance. Figure 4 indicates opposite trends for two users regarding power allocation factors. Therefore, controlling power factor a_1 guarantees fairness among two users in EH-NOMA system.

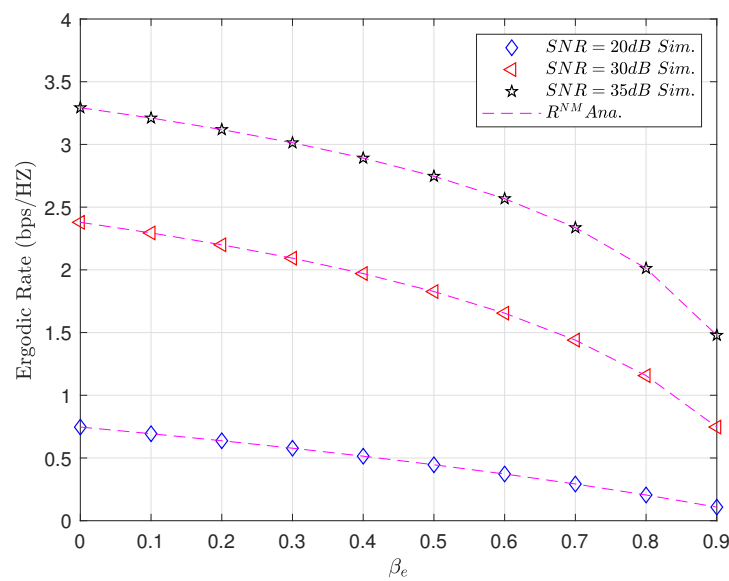


Figure 2. Ergodic capacity performance of two users versus SNR with $R_2 = 0.5$.

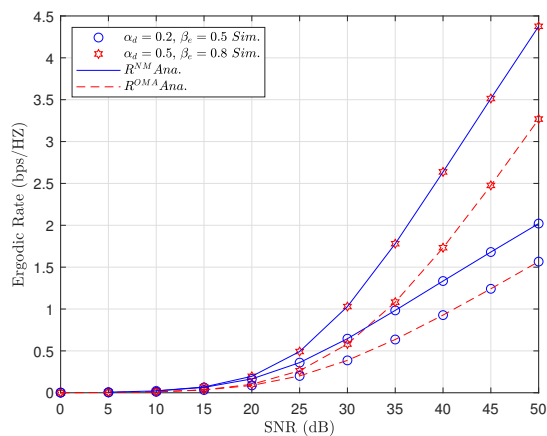


Figure 3. Ergodic capacity performance of two users versus channel gain λ_{SR}

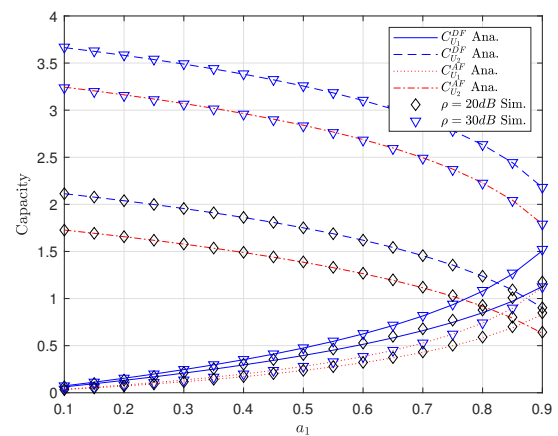


Figure 4. Ergodic capacity performance of two users versus $a_1 = 0.5$

5. CONCLUSION

This paper considers ergodic capacity of wireless powered network. It can be concluded that power allocation coefficients for each user in EH-NOMA leads to varying ergodic city performance. The detail performance analysis has been performed in term of ergodic capacity and it is provided via the closed-form expressions related to this metric. It is shown that performance gap exists among two NOMA users due to different mode of AF/DF, and different power allocation factors. Simulation results are performed to verify our analytical results and it is helpful guidelines to design EH-NOMA in practice.

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