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Exact Outage Performance of Power Beacon Assisted Non-Orthogonal Multiple Access Networks

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Abstract —The paper considers Non-Orthogonal Multiple Access (NOMA) together with Multiple Input Single Output (MISO) model in transmitting of proximity users under help of wireless power transfer. To support more harvested energy, a multiple-antenna Power Beacon (PB) is proposed to robust NOMA transmission network, especially enhanced successful communication with short distance transmission. Accordingly, the alternative energy source can be used to maintain small devices which can operate at close position efficiently. In this paper, a model of RF wireless energy transfer for NOMA system will be investigated. As an important result, we derive novel analytical expressions for outage probability to performance evaluation. This paper will analyze outage probability by matching Monte-Carlo and analytical simulations to corroborate the exactness of derived expressions.

Index Terms**—**Beamforming, power beacon, multiple input single output, NOMA networks

I. INTRODUCTION

Because of the increasing speed of Internet of things and smart devices, investigating more energy and spectral effective energy consuming wireless technique becomes more important. Wireless Power Transfer (WPT) has a potential capability in energy transfer and becomes efficient in long run energy consuming, which makes it a promising research trend. Moreover, the leading advancement of hardware in wireless charging technology has given a practical solution for these applications in the near future [1]. It is obvious that RF signals can help in WPT [2], [3] to transmit energy to low power consuming devices for charging. Besides that, a lot of attention has been paid to a promising area which is the simultaneously-carried possibility of both energy and information during transmission [4]-[6]. Model of a perfect receiver - simultaneous wireless information and power transfer (SWIPT) can figure out the information and collect energy from the alike signal as described in [4]. However, because of the limited hardware, this supposition can not be used in actual environment [5]. To reduce this difficulty, many works presented Time Switching (TS) and Power Splitting (PS) as two different receivers in a MIMO system [6].

In other line of energy harvesting technique, most of the current studies in the RF-EH model concentrated on using RF signal transferred from the Base Station (BS). Nevertheless, in fact, the RF-EH capability is reduced partially as a result of the overall loss between BS and EH users. By introducing the Power Beacon (PB) for wireless energy transfer, the authors in [7]-[10] can adopt a devoted power supply for RF-EH. Therefore, the EH assisted network (EHN) can be considered as a solution to increase the productivity of RF-EH. Nevertheless, in EHN, because the PB and BS are at the same cell, the Information-Decoding (ID) users near the PB can be prevented by the information transmitting of PB. To reduce this limitation, researching of the distance problem in wireless powered network [8] and performance and improvement of PB [9], [10] is really necessary. The other advantage of PB-assisted energy harvesting in which PB is attached with a lot of antennas. Therefore, when using the transmit beamforming with PB, the intervention during transmission in EHN can be reduced like in Multiple Input Multiple Output (MIMO) or Multiple Input Single Output (MISO) systems with RF-EH. However, how to transmit the energy beamforming excellently is still an open problem because the optimization problem has not been widely discovered.

Regarding on an innovative access technology, Non-Orthogonal Multiple Access (NOMA) is broadly recommended as a potential candidate multiple access to obtain high traffic volume and optimal spectral effectiveness in the Fifth Generation (5G) [11], [12]. In term of operation in the transmitter of NOMA, by splitting signal in the power domain, NOMA can serve multiple signals to multiple users. At the receiver side, to separate multiplexed users' signals, one can deploy Successive Interference Cancellation (SIC). It is required that user fairness need be considered as first priority in NOMA deployment and spectrum utilization is second priority. Contrasting with traditional waterfilling power distribution, NOMA users with better channel conditions are allocated less power and users need more power in case of worse channel conditions, and hence such scheme need be computed to balance role of user fairness and system throughput. In the same time, frequency and spreading codes but different power level, multiple users are assisted to increasing spectral efficiency and qualified user fairness. Recent works presented that cooperative relaying together with NOMA networks have attracted some attentions to expand the reliability of NOMA and system capacity [13]–[16]. In particular, the authors in

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[13] considered C-NOMA networks in term of the achievable average rate. Interestingly, to enhance the system performance NOMA can be combined with multiple-antenna model, and the system outage behavior will be improved. In [15], relaying network was applied into forwarding transmission to improve the corverage efficiency. In [16], a novel scheme with wireless powered realying is investigated by exploiting exact closed-form expressions of transmission rates which related to transmit power, transmission modes. Such important results in [14] and [17] motivate me to find system performance of PB-assisted NOMA (i.e. so-called as PB-NOMA) under impact the harvested energy amount from the PB on system performance.

The rest of the paper is structured as follows. System model and related assumptions are designated in Section 2. Next, the outage probability analysis of power beacon (PB) assisted NOMA system with two considered case related to signal detection for the near user and the far user are presented. Simulation results are performed in Section 4. Finally the conclusions of the paper are delivered in Section 5.

Notation: bold face vector $\mathbf{x}$ is matrix, $E(.)$ stands for expectation operation.

II. SYSTEM MODEL AND SNR CALCULATION

In this paper, we consider a point-to-point system where the base station (BS) send information to the two destination users, namely the near user (NU) and the far user (FU) as described in Fig. 1. Regarding on wireless power transfer, it is assumed power splitting protocol for wireless power transfer to the self-power BS due to its simplicity [19]. In such architecture in proposed system, the power beacon (PB) is selected to expenditure multiple transmit antennas. Due to limitation of size of mobile devices, it can be recommended the near device and far device only use single antenna for reception. In cellular network or IoT network where can be applied wireless power transfer, we assume the BS need to harvest wireless energy. With target to special case BS with energy shortage, to prolong lifetime of cellular transmission link, such device NU, FU require the outside energy charging through wireless power transfer from a multi-antenna aided PB. In particular, we denote N antennas are multiple energy scheme equipped in the PB. All of the channel state information of the connection between the PB and BS is expected to well-known at the PB. In fact, the channel can be exactly predicted by sending to the pilot message by the PB and using channel estimation algorithm. Such pilot processing algorithm is beyond the scope of this paper.

More specifically as considering on power splitting relaying protocol, i.e. during the first phase of duration εP , where $0<\varepsilon<1$ stands for power percentage for energy transfer and P is transmit power at the PB, BS (i.e. energy harvesting station) collects energy from the PB and using such energy for direct communicate with users which represent non- energy harvesting NOMA devices. In such model, the energy transfer occurs in first phase from the PB to the BS. In this paper, we determine outage performance for direct communication where BS transfers information to NU, FU where are on different demand. For example, FU need internet surfing while NU need download video files. Such a dual-hop communication protocol has also been researched in previous works [19], where it was so-called as the "harvest-then-transmit" protocol.

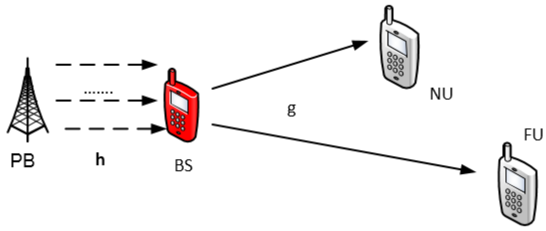

Fig. 1. System model for power beacon-assisted NOMA network

The novel model of this work can be described briefly as follows. In PB-NOMA networks, there are two users, i.e. the NU can be video streaming transmission while the FU can serve data transmission at low rate due to longer distance between BS and users. In the transmit BS, the system can transmit two simultaneous signals directly in same physical link. In the received device, it can be detached the right signal on demand by using SIC circuits.

In this study, we explore PB-NOMA, during the energy collecting phase, the harvested power at BS can be obtained via the channel $\mathbf{h}$ with supporting of transmit signal $\mathbf{x}_s$. We denote P as the transmit power at the PB, $\mathbf{x}_s$ is an $N\times1$ signal vector.

Because the power transfer distance is quite short, the line-of-sight path is probably to occur between the PB and BS. Therefore, it is reasonable to apply the Rician allocation to model the PB to BS channel. Nevertheless, the complex Rician declining probability density function (PDF) causes a big difficulty for the following analysis. Otherwise, it is obvious that the Nakagami-m fading distribution gives a very excellent estimation to the Rician allocation. Thanks to this , we apply the Nakagami-m fading to model the PB to BS channel in this paper in order to make the analysis easier. Hence, the elements of $\mathbf{h}=\left[h_i\right], i=1,...,N$, are considered to be independent and identically distributed (i.i.d.) with consistently allocated phase and the intensity, $x=\left[h_i\right]$, following a Nakagami-m

$$f(x)=\frac{2x^{2m-1}}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m e^{\left(-\frac{mx^2}{\Omega}\right)},\quad x\geq0, \tag{1}$$

where $\Gamma(\cdot)$ indicates the Gamma function, $m=\frac{E^2\left[x^2\right]}{\mathrm{var}\left[x^2\right]}$, and $\Omega=E\left[x^2\right]$. If there is no general loss, we set $\Omega = 1$.

Because the PB is attached with multiple antennas, energy beamforming is employed to enhance the capability of energy transfer, i.e.,

$$\mathbf{x}_s = \mathbf{w}s_e \tag{2}$$

where $\mathbf{w}$ is the beamforming vector with $\|\mathbf{w}\|^2 = 1$, while s_e is the energy symbol with unit power.

Since BS has equipped with multiple antennas and hence the BS can use following strategies for antenna usage by deploying beamforming for transmissions. The beamforming approach applied in channel gains is that following Gamma distribution. This following notation can be supplied more detail understanding. We denotet $\mathbf{h}$ as the fading column vector (size of this vector be subject to on number of antennas of the PB) between the PB and its desired/beamformed BS. Under the transmit beamforming, the transmitter will multiply the information signal with beamforming vector before transmitting $\mathbf{x}_s$ in (2) above

$$\mathbf{w} = \frac{\mathbf{h}^{\dagger}}{\|\mathbf{h}\|} \tag{3}$$

As such, the total received energy at the end of the first phase can be calculated as

$$E_n = \eta\varepsilon\|\mathbf{h}\|^2 P \tag{4}$$

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

The BS broadcasts a superposition message desired for both NU and FU simultaneously in the t-th time slot as

$$S[t] = \sqrt{P\alpha}s_1[t] + \sqrt{P(1-\alpha)}s_2[t] \tag{5}$$

where s_1, s_2 represent the messages to the user NU. FU respectively and α stands for the power allocation coefficients in NOMA.

Thus, the received message at NU can be expressed as

$$y_{NU}[t] = \mathbf{h}S[t] + n_{NU}[t], \tag{6}$$

where $n_{NU} \sim \mathcal{CN}(0, N_0)$ is the additive white Gaussian noise (AWGN) at NU.

Similarly, the received message at FU can be expressed as

$$y_{FU}[t] = \mathbf{h}S[t] + n_{FU}[t], \tag{7}$$

For simplicity, we only consider signal processing at the FU. It worth noting that the BS transfers overall information to FU using the energy collected in the first phase. Here, we omit index t for simplicity. Therefore, the received signal y_{FU} at the FU is given by

$$y_{FU} = \eta\varepsilon\|\mathbf{h}\|^2 Pg\left(\alpha s_1 + (1-\alpha)s_2\right) + n_{FU}, \tag{8}$$

in which, g is the channel coefficient following complicated Gaussian distribution with zero-mean and unit variance, s_1, s_2 is the information symbol with unit energy, and n_{FU} is the additive white Gaussian noise (AWGN) with $E\left\{n_{FU}n_{FU}^*\right\} = N_0$. It is noted that power splitting factor for the first hop is ε.

Such SIC opreration will be implemented until two users' messages are all decoded, where the SINR for the FU user to decode the NU user's signal can be expressed as below. In particular, the signal to interference plus noise ratio (SINR) for detecting signal s_1 at the FU can be calculated as

$$\gamma_{2,1} = \frac{\eta\varepsilon\alpha\|\mathbf{h}\|^2|g|^2 P}{\eta\varepsilon(1-\alpha)\|\mathbf{h}\|^2|g|^2 P + N_0} \tag{9}$$

After applying SIC procedure, the SINR for the FU user to decode its own signal can be given by following formula and the SINR for detecting signal s_2 at the FU can be calculated as

$$\gamma_{2,2} = \frac{\eta\varepsilon(1-\alpha)\|\mathbf{h}\|^2|g|^2 P}{N_0} \tag{10}$$

III. OUTAGE PERFORMANCE ANALYSIS

We call P_{out} as the outage probability and it is denoted as $\Pr(.)$. Such outage event can be defined as probability to SINR less than the threshold SINR.

$$P_{out} = \Pr(\gamma_{2,i} < \gamma_0), \quad i = 1,2 \tag{11}$$

Proposition 1: Consider system performance, the outage probability for detecting NU's signal at the FU with respect to the target rate R_0 can be formulated as [20]

$$P_{out,NU} = \Psi_1\gamma_0^{\frac{Nm}{2}}\frac{2m^{\frac{Nm}{2}}}{\Gamma\ Nm}K_{Nm}\ 2\sqrt{mc_1\gamma_0} \tag{12}$$

where $\Gamma(\ )$ is the Gamma function [18, Eq. (8.310)], $K_n(.)$ is the modified Bessel function of the second kind [18, Eq. (8.432)], $\Psi_1 = \frac{N_0}{\eta\varepsilon P\left(\alpha - \gamma_0 + \alpha\gamma_0\right)}$ and $\gamma_0 = 2^{R_0} - 1$ is the threshold SNR.

Proof:

We can compute outage probability of the system to evaluate performance, and it can be described as

$$\begin{aligned} P_{out,NU} &= \Pr\left(\frac{\eta\varepsilon\alpha\|\mathbf{h}\|^2|g|^2 P}{\eta\varepsilon(1-\alpha)\|\mathbf{h}\|^2|g|^2 P + N_0} < \gamma_0\right) \\ &= \Pr\left(\|\mathbf{h}\|^2|g|^2 < \Psi_1\gamma_0\right) \end{aligned} \tag{13}$$

In such case, it is required the condition on power splitting factor as $\alpha > \gamma_0 / (\gamma_0 + 1)$. It is worth noting that $\|\mathbf{h}\|^2$ is a Gamma random variable with PDF given by

$$f(z) = \frac{m^{Nm}\ z^{\frac{Nm-1}{2}}\ e^{-mz}}{\Gamma\ \ Nm}, \qquad for \qquad z \geq 0. \tag{14}$$

It is noted that the cumulative distribution function (CDF) of $\|\mathbf{h}\|^2 |g|^2$ can be achieved by with some mathematical manipulations. Conditioned on $\|\mathbf{h}\|^2$, the CDF of $\|\mathbf{h}\|^2 |g|^2$ is given by

$$F(z|\|\mathbf{h}\|) = 1 - e^{-\frac{z}{\|\mathbf{h}\|}}. \tag{15}$$

To further computation, averaging over $\|\mathbf{h}\|^2$ and using eq. 3.471.9 in [18] the absolute CDF of such function can be calculated as

$$F(z) = 1 - 2K_{Nm}\ \ 2\sqrt{zm}\ \ \frac{m^{\frac{Nm}{2}} z^{\frac{Nm}{2}}}{\Gamma\ \ Nm} \tag{16}$$

We obtained the expected results after several computation steps, in which Ψ_1 and γ_0 is given in Proposition 1.

Proposition 2: Consider outage performance, the outage probability of FU for detaching own signal with the target rate R_0 can be formulated as

$$P_{out,FU} = 2m^{\frac{Nm}{2}} \frac{\Psi_2\gamma_0^{\ \frac{Nm}{2}}}{\Gamma\ \ Nm} K_{Nm}\ \ 2\sqrt{m\Psi_2\gamma_0} \tag{17}$$

where $\Psi_2 = \dfrac{N_0}{\eta\varepsilon P}$.

Proof:

We omit the manipulation steps here due to similarity as in Proposition 1.

In the asymptotically large number of antennas regime, i.e., N → ∞, it can be the approximate expression of outage probability as below

Remark 1: In the asymptotically large number of antennas regime, in accordance with the law of large numbers, we have $\|\mathbf{h}\| \approx N$.

As such, the outage probability of the system can be computed in simple formula as

$$\begin{aligned} P_{assym} &\approx \Pr\left(|g|^2 < \frac{\Psi_i\gamma_0}{N}\right) \\ &= 1 - \exp\left(-\frac{\Psi_i\gamma_0}{N}\right), \quad i = 1, 2 \end{aligned} \tag{18}$$

As important result, Proposition 1 and 2 provide an accurate expression for the outage performance of the system, which may be applicable computed in practical design of PB-NOMA where require more energy from the PB for NOMA transmission.

IV. NUMERICAL AND SIMULATION RESULTS

Simulations are accomplished for system performance evaluation in MATLAB to obtain role of parameters which have affected on PB-NOMA networks in analytical and simulation results. The important parameters for the simulations are provided in each illustration. In this part, the results of Monte Carlo imitation are introduced to confirm the analytical expressions from the previous sections. All the simulation results are gained by averaging over 106 independent trials. Unless stated differently, the following set of parameters were employed in simulations: $R_0 = 3(bps/Hz)$, so the outage SNR threshold is given by $\gamma_0 = 2^{R_0} - 1 = 7$. The energy conversion efficiency is set to be $\eta = 0.4$ and $\rho = P/N_0$ is denoted as transmit SNR, while the Nakagami-m parameter is set to be $m = 4$, which correlates to a Rician factor of $K = 3 + \sqrt{12}$. For simplicity, the distances between the PB and BS, NU and FU are set to be unit.

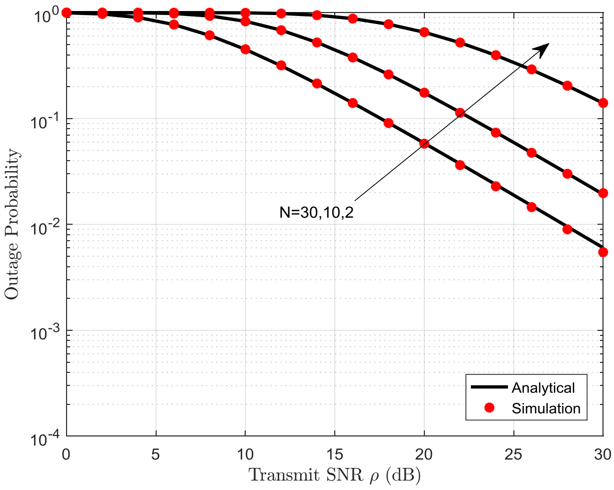

Fig. 2. Outage performance for detecting NU'signal with different number of antenna of the PB

Fig. 2 shows the outage probability of PB-NOMA link when the BS use transmit beamforming for the near device which use energy harvesting capability for transmission. It can be observed that the more antenna equipped at the PB outperforms the case which uses lower number of antenna in high SNR regime. Such performance gap related to the number of antenna can be seen clearly at high SNR value. The improvement can be clarified as follows. In the low SNR, energy for signal processing cannot lead to large impacts on outage performance while more energy for better signal communication between BS and users.

Fig. 3 demonstrates the outage performance as varying power percentage of energy harvesting from the PB where can be enhanced quality of short distance transmission of PB-NOMA. It is noted that in this case we do not consider impact of the NU's interference signal due to applying SIC. As clear observation, it can be easily noticed that adding more energy to the PB can considerably enhance the achievable outage performance. Nonetheless, when the transmit power is low, the advantage of putting more antennas rapidly declines. This problem is quite normal, because growing the number of antennas can contribute higher energy beamforming gain, thus, the amount of the collected energy at the source is improved, which alternatively decreases the outage probability of the system. Moreover, it is obvious that the analytical result maintains efficiently tight with Monte-Carlo simulation in various parameter of energy harvesting and the number of antenna.

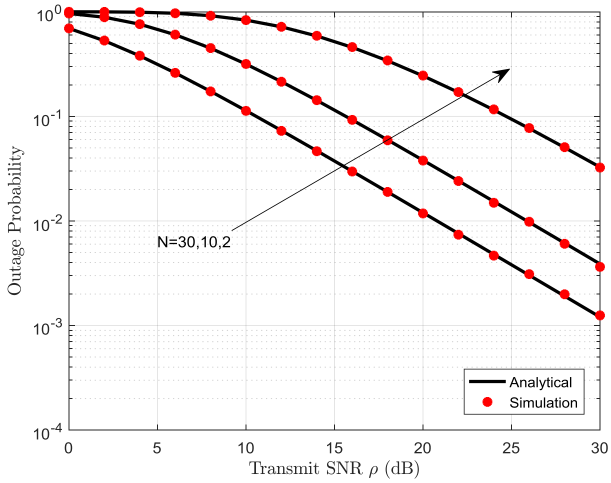

Fig. 3. The outage performance for detecting FU's signal

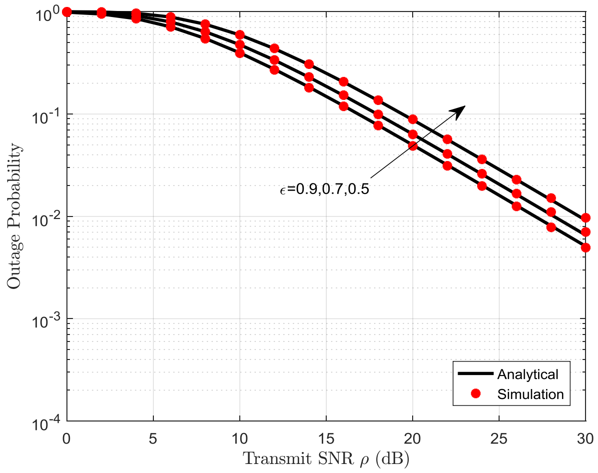

Fig. 4. The outage performance with different power splitting N=20 for detecting NU's signal

Similarly, Fig. 4 validates the outage performance as varying power splitting fraction where can be affected quality of transmission link. It is noted that in this case the higher requirement of the performance must be need higher harvested power but increasing level of performance is small. In practical design, one can clarify the number of outside wireless power source to evaluate system performance to satisfy requirement of such network.

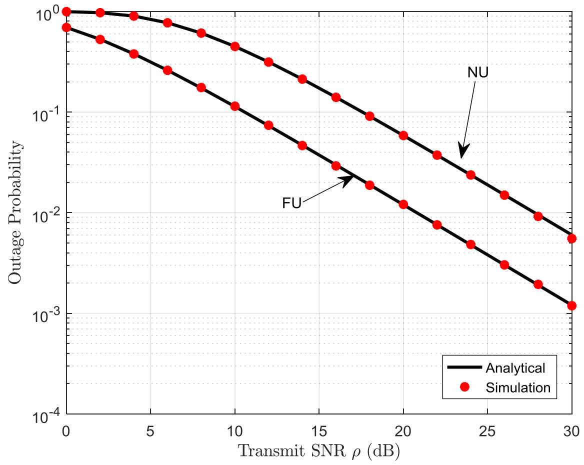

Fig. 5. The comparison study on the outage performance N=30

Now Fig. 5 in this paper shows the outage probability results for the two cases related impact of the interference. Fig. 5 demonstrates the outage probability comparison of the such PB NOMA links. It can be seen clearly that the FU's signal contributes to decreasing outage performance of NU signal processing at the FU although obtaining more energy beamforming from the PB.

V. CONCLUSIONS

In this studied work, we introduced a multi-antenna PB design and hence the outage probability is evaluated in PB-NOMA link under impact of the harvested energy. The simulation results revealed that the proposed PB regime obtained the reasonable performance to deploy in wireless sensor network. In future, the proposed scheme will be extended to multiple antenna users for NU, FU where can be able to signal transfer and harvest energy beamforming from the PB. We also can further investigate the other system performance such as the throughput of the concerned PB-NOMA approach.

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