Rate Splitting Multiple Access for a MISO SWIPT System Aided by a Power Beacon

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***Abstract*—In this paper, we investigate a multiple-input single-output (MISO) rate-splitting multiple access (RSMA) system by using the simultaneous wireless information and power transfer (SWIPT) technology. A base station (BS) co-exists with a power beacon (PB) to transmit energy and information to several energy harvesting (EH) users and power-splitting users. We minimize the transmission power of the PB and BS subject to rate and EH requirements. The semidefinite relaxation technique and the particle swarm optimization algorithm are used to solve the non-convex problem. Simulation results proved the significant reduction in the transmission power achieved by RSMA compared with several conventional methods.**

Keywords— Rate-splitting multiple access (RSMA), simultaneous wireless information and power transfer (SWIPT), particle swarm optimization (PSO), semidefinite relaxation (SDR), power beacon.

I. Introduction

Rate splitting multiple access (RSMA) is a promising multiple access technique proposed as a candidate technology for future 6G networks [1]. RSMA proved to achieve higher spectral and energy efficiency compared with the traditional multiple access techniques of space-division multiple access (SDMA) and non-orthogonal multiple access (NOMA) [2], [3]. RSMA divides the user's messages into common and private parts, where the common parts are transmitted together to be decoded by all the users. Then, RSMA can softly cover the cases of totally decoding the interference and treating the interference as noise, which makes RSMA a general framework with RSMA and NOMA as special cases [3], [4].

In wireless networks, the problem of the limited battery life needs to be considered during the design of modern wireless techniques. In this aspect, simultaneous wireless information and power transfer (SWIPT) [5] is recognized as an efficient scheme that allows to the BS simultaneously transmit information and energy to the wireless users. In SWIPT, the power-splitting (PS) structure is known to achieve the best trade-off between information decoding (ID) and energy harvesting (EH). The PS structure divides the received radio-frequency (RF) signal into two streams to be used for the ID module and the EH module based on a PS ratio. In [6], low-cost stations known as power beacons (PBs) are deployed in the system for recharging wireless devices with RF energy. At the PB, complex computations are not required, and the backhaul link has low requirements, which permits a dense deployment of PBs at a low cost.

In the literature, SWIPT in a multi-user MISO system was proposed in [7] to minimize the transmission power under data rate and EH requirements. A multi-user MISO system composed of several ID users and EH users was presented in [8] by considering the ability to remove the interference from the energy signal. A wireless-powered communication system aided by PBs was proposed in [9] to maximize the weighted sum-rate of the network. A multi-antenna base station (BS) is considered in [10] to transmit information signals to an ID user, while a multi-antenna PB was deployed to transmit RF to several EH users. By considering a SWITP MISO system aided by a PB, the minimization of the transmission power subject to rate and EH constraints was investigated in [11] with the SDMA method and in [12] with the NOMA method. The aforementioned articles considered the traditional methods of SDMA or NOMA, where the performance of RSMA was not investigated yet in PB-assisted systems.

RSMA has been applied to MISO systems to maximize the sum rate of the users [3], the spectral efficiency, and the energy efficiency [13]. In SWIPT MISO systems, RSMA was considered to minimize the transmission power [14], [15] and maximize the sum rate [16]. Therefore, motivated by the significant improvement of RSMA over the traditional methods of SDMA and NOMA, we investigated a multi-user MISO SWIPT system assisted by a PB by considering the RSMA method. The considered system model is composed of several PS users and EH users with the aim to maximize the total transmission power subject to data rate and EH requirements. The contributions of the paper are summarized as follows.

- We minimize the total transmission power in the considered system model subject to requirements of minimum EH in the EH users and PS users, and requirements of minimum data rate in the PS users.
- We divide the proposed non-convex problem into two subproblems which are solved by the particle swarm optimization (PSO) and semidefinite relaxation (SDR) techniques. In particular, the PSO algorithm optimizes the common rate variables and the SDR technique optimizes the beamforming vectors and PS ratios.
- As comparative methods, we consider the traditional SDMA and NOMA techniques. In addition, we compare the proposed solution with a system model that does not include the PB. The performance comparison is performed by numerical simulations under different scenarios.

II. System Model and Problem Formulation

We investigate a multi-user MISO SWIPT system aided by a PB by using the RSMA method. Fig. 1 illustrates the proposed system model with a BS composed of $N \geq 2$ antennas, a PB composed of $L \geq 2$ antennas, K EH users, and M PS users, where the PS users and EH users are equipped

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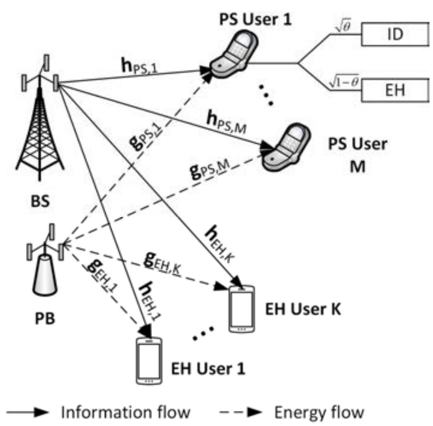

Fig. 1. An RSMA MISO system assisted by a PB with SWIPT.

with a single-antenna. According to RSMA, the message of the m-th PS user, W_m, is divided into the common part $W_m^{(c)}$ and the private part $W_m^{(p)}$ [3]. Next, the common parts are jointly encoded into the common stream s_0^{PS}, while the private parts are encoded into the independent streams s_m^{PS}. In the PB, the transmitted RF signal to the k-th EH user is denoted as s_k^{EH}, which can be removed at the ID module in the PS users since this signal does not contain information and the energy signal is assumed to be prior known at the PS users [8]. The transmitted signals at the BS and PB are given by $\mathbf{x}_{BS} = \mathbf{f}_0 s_0^{PS} + \sum_{m=1}^{M} \mathbf{f}_m s_m^{PS}$ and $\mathbf{x}_{PB} = \sum_{k=1}^{K} \mathbf{w}_k s_k^{EH}$, respectively, where $\mathbf{f}_0 \in \mathbb{C}^{Nx1}$, $\mathbf{f}_m \in \mathbb{C}^{Nx1}$ and $\mathbf{w}_k \in \mathbb{C}^{Lx1}$ are the information beamforming vectors and energy beamforming vector for s_0^{PS}, s_m^{PS} and s_k^{EH}, respectively.

The achievable rate of the common stream s_0^{PS} at the m-th PS user is given by

$$R_{0,m} = \log_2\left(1 + \frac{\theta_m \left|\mathbf{h}_{PS,m}^H \mathbf{f}_0\right|^2}{\theta_m\left(\sum_{i=1}^{M}\left|\mathbf{h}_{PS,m}^H \mathbf{f}_i\right|^2 + \sigma_m^2\right) + \delta_m^2}\right), \forall m, \quad (1)$$

where $\mathbf{h}_{PS,m} \in \mathbb{C}^{Nx1}$ is the channel vector from the BS to the m-th PS user, $\theta_m \in (0,1)$ represents the PS ratio, $n_m \sim \mathcal{CN}(0, \sigma_m^2)$ represents the antenna noise at the m-th PS user, and $v_m \sim \mathcal{CN}(0, \delta_m^2)$ is the additional processing noise at the ID of the m-th PS user.

Once s_0^{PS} is decoded, the SIC procedure is used to remove the interference of the common stream. Then, the achievable rate of the private stream s_m^{PS} at the m-th PS user is given by

$$R_{p,m} = \log_2\left(1 + \frac{\theta_m \left|\mathbf{h}_{PS,m}^H \mathbf{f}_m\right|^2}{\theta_m\left(\sum_{i=1, i\neq m}^{M}\left|\mathbf{h}_{PS,m}^H \mathbf{f}_i\right|^2 + \sigma_m^2\right) + \delta_m^2}\right), \forall m. \quad (2)$$

The transmission rate of s_0^{PS}, denoted as R_0, must not exceed the achievable rate of the common messages to guarantee successful decoding of s_0^{PS}, i.e., $R_0 = min\{R_{0,1}, \dots, R_{0,K}\}$. Next, we have that R_0 is shared to transmit the common parts $\{W_m^c\}$ denoted as $R_0 = \sum_{m=1}^{M} r_m$, where r_m is the common rate to transmit $\{W_m^c\}$.

The energy harvested at the EH module of the m-th PS user is defined by

$$EH_m^{PS} = \eta_m^{PS}(1-\theta_m)\left(\sum_{i=0}^{M}\left|\mathbf{h}_{PS,m}^H \mathbf{f}_i\right|^2 + \sum_{k=1}^{K}\left|\mathbf{g}_{PS,m}^H \mathbf{w}_k\right|^2 + \sigma_m^2\right), \forall m, \quad (3)$$

where η_m^{PS} is the EH efficiency and $\mathbf{g}_{PS,m} \in \mathbb{C}^{Lx1}$ is the channel vector from the PB to the m-th PS user. Moreover, the energy harvested at the k-th EH user is defined by

$$EH_k^{EH} = \eta_k^{EH}\left(\sum_{i=0}^{M}\left|\mathbf{h}_{EH,k}^H \mathbf{f}_i\right|^2 + \sum_{k=1}^{K}\left|\mathbf{g}_{EH,k}^H \mathbf{w}_k\right|^2\right), \forall k, \quad (4)$$

where η_k^{EH} is the EH efficiency, $\mathbf{h}_{EH,k} \in \mathbb{C}^{Nx1}$ and $\mathbf{g}_{EH,k} \in \mathbb{C}^{Lx1}$ are the channel vectors from the BS and PB to the k-th EH user, respectively.

Our objective is to optimize the beamforming vectors, PS ratios, and common rate variables to minimize the transmission power of the BS and PB under the constraints of minimum data rate and EH requirements. Therefore, the optimization problem can be formulated as follows:

$$\min_{\mathbf{f}_0, \{\mathbf{f}_m, r_m, \theta_m, \mathbf{w}_k\}} \quad \sum_{i=0}^{M}\left\|\mathbf{f}_i\right\|^2 + \sum_{k=1}^{K}\left\|\mathbf{w}_k\right\|^2 \quad (5a)$$

$$\text{s.t.} \quad r_m + R_{p,m} \geq \gamma_m, \ \forall m \quad (5b)$$

$$\sum_{i=1}^{M} r_i \leq R_{0,m}, \ \forall m \quad (5c)$$

$$\mathrm{EH}_m^{PS} \geq \chi_m^{PS}, \ \forall m \quad (5d)$$

$$\mathrm{EH}_k^{EH} \geq \chi_k^{EH}, \ \forall k \quad (5e)$$

$$r_m \geq 0, \ \forall m \quad (5f)$$

$$0 < \theta_m < 1, \ \forall m, \quad (5g)$$

where γ_m is the minimum rate required at the m-th PS user, χ_m^{PS} specifies the minimum EH requirement at the m-th PS user, and χ_k^{EH} defines the minimum EH required at the k-th EH user. Note that problem (5) is non-convex because of intricately coupled variables in constraints (5b), (5c), (5d), and (5e). Therefore, we propose a solution based on the SDR and PSO techniques detailed in Section III.

III. Proposed Solution to Problem (5)

To solve the non-convex problem (5), we propose to divide it into two subproblems to be optimized in an iterative manner. In the first subproblem, we fix the common rate variables and optimize the beamforming vectors and PS ratios with an SDR-based method. In the second subproblem, we fix the beamforming vectors and PS ratios to optimize the common rate variables with a PSO-based algorithm.

A. Optimizing $\mathbf{f}_0, \{\mathbf{f}_m, \theta_m, \mathbf{w}_k\}$ with a given $\{r_m\}$

To solve the first subproblem, we propose an SDR-based solution. Let us define $\mathbf{F}_m = \mathbf{f}_m\mathbf{f}_m^H$, $\mathbf{W}_k = \mathbf{w}_k\mathbf{w}_k^H$, $\mathbf{H}_{PS,m} = \mathbf{h}_{PS,m}\mathbf{h}_{PS,m}^H$, $\mathbf{H}_{EH,k} = \mathbf{h}_{EH,k}\mathbf{h}_{EH,k}^H$, $\mathbf{G}_{PS,m} = \mathbf{g}_{PS,m}\mathbf{g}_{PS,m}^H$, and $\mathbf{G}_{EH,k} = \mathbf{g}_{EH,k}\mathbf{g}_{EH,k}^H$. Moreover, the matrix variable $\mathbf{F}_m$ establishes $\mathbf{F}_m \succcurlyeq 0$ and $\mathrm{rank}(\mathbf{F}_m) = 1$, and the matrix $\mathbf{W}_k$ establishes $\mathbf{W}_k \succcurlyeq 0$ and $\mathrm{rank}(\mathbf{W}_k) = 1$. Then, given the common rate variables and by removing the rank-one constraints, problem (5) can be reformulated as a convex problem as follows:

$$\min_{\mathbf{F}_0,\{\mathbf{F}_m,\theta_m,\mathbf{W}_k\}} \sum_{i=0}^{M}\mathrm{Tr}\left(\mathbf{F}_i\right)+\sum_{k=1}^{K}\mathrm{Tr}\left(\mathbf{W}_k\right) \tag{6a}$$

$$\left(\sum_{i=1,i\neq m}^{M}\mathrm{Tr}\left(\mathbf{H}_{PS,m}\mathbf{F}_i\right)+\sigma_m^2+\frac{\delta_m^2}{\theta_m}\right)\kappa_m-\mathrm{Tr}\left(\mathbf{H}_{PS,m}\mathbf{F}_m\right)\leq 0,\ \forall m \tag{6b}$$

$$\left(\sum_{i=1}^{K}\mathrm{Tr}\left(\mathbf{H}_{PS,m}\mathbf{F}_i\right)+\sigma_m^2+\frac{\delta_m^2}{\theta_m}\right)\alpha-\mathrm{Tr}\left(\mathbf{H}_{PS,m}\mathbf{F}_0\right)\leq 0,\ \forall m \tag{6c}$$

$$\frac{\chi_m^{PS}}{\left(1-\theta_m\right)}-\sum_{i=0}^{M}\mathrm{Tr}\left(\mathbf{H}_{PS,m}\mathbf{F}_i\right)-\sum_{k=1}^{K}\mathrm{Tr}\left(\mathbf{G}_{PS,m}\mathbf{W}_k\right)-\sigma_m^2\leq 0,\ \forall m \tag{6d}$$

$$\chi_k^{EH}-\sum_{i=0}^{M}\mathrm{Tr}\left(\mathbf{H}_{EH,k}\mathbf{F}_i\right)-\sum_{k=1}^{K}\mathrm{Tr}\left(\mathbf{G}_{EH,k}\mathbf{W}_k\right)\leq 0,\ \forall k \tag{6e}$$

$$\mathbf{F}_0,\mathbf{F}_m,\mathbf{W}_k\succeq 0,\ \forall m,\forall k \tag{6f}$$

$$0<\theta_m<1,\ \forall m, \tag{6g}$$

where $\kappa_m=\max\left\{2^{\gamma_m-r_m}-1,0\right\}$ and $\alpha=2^{\sum_{i=1}^{M}r_i}-1$. Problem (6) is convex and can be solved with the CVX toolbox of MATLAB [17]. We denote the optimal solutions to problem (6) as $\{\mathbf{F}_i^*,\mathbf{W}_k^*\}$. Then, if the matrix solutions are rank-one, the optimal beamforming vectors can be obtained as follows:

$$\mathbf{f}_i=\sqrt{\lambda_{\mathrm{L}}\left(\mathbf{F}_i\right)}\boldsymbol{\upsilon}_{\mathrm{L},\mathbf{F}_i},\ i=0,\ldots,M, \tag{7a}$$

$$\mathbf{w}_k=\sqrt{\lambda_{\mathrm{L}}\left(\mathbf{W}_k\right)}\boldsymbol{\upsilon}_{\mathrm{L},\mathbf{W}_k},\ k=1,\ldots,K, \tag{7b}$$

where $\lambda_{\mathrm{L}}\left(\mathbf{C}\right)$ is the largest eigenvalue of the matrix $\mathbf{C}$ and $\boldsymbol{\upsilon}_{\mathrm{L},\mathbf{C}}$ is its corresponding eigenvector. On the other hand, if $\{\mathbf{F}_m^*,\mathbf{W}_k^*\}$ are not rank-one, the penalty method [18] or the Gaussian randomization method [15] can be used to obtain the approximately optimal beamforming vectors.

B. Optimizing $\{r_m\}$ with a given $\mathbf{f}_0,\{\mathbf{f}_m,\theta_m,\mathbf{w}_k\}$

The PSO-based algorithm [15] is used to optimize the common rate variables by solving the second subproblem given the beamforming vectors and PS ratios. First, a population of P_{PSO} particles is initialized with positions representing the common rate variables, i.e., $\boldsymbol{x}_q=\{r_1,\ldots,r_M\}, q=1,\ldots,P_{PSO}$. The local best position for each particle is initialized as $\boldsymbol{lb}_q=\boldsymbol{x}_q$. Second, we solve the problem (6) for each particle to obtain the fitness function $f(\boldsymbol{x}_q)$ from (6a). Based on $f(\boldsymbol{x}_q)$, the global best position is defined by $\boldsymbol{gb}=\underset{1\leq q\leq P_{PSO}}{\mathrm{argmin}}\ f(\boldsymbol{x}_q)$. Then, the velocity factor for each particle in each iteration is given by

$$\boldsymbol{v}_q^{(t+1)}\leftarrow w_{in}\boldsymbol{v}_q^{(t)}+\epsilon_1 d_1^q\left(\boldsymbol{lb}_q^{(t)}-\boldsymbol{x}_q^{(t)}\right)+\epsilon_2 d_2^q\left(\boldsymbol{gb}^{(t)}-\boldsymbol{x}_q^{(t)}\right), \tag{8}$$

where $\boldsymbol{x}_q^{(t)}$ is the position of q-th particle in t-th iteration, w_{in} is the inertia weight parameter, ϵ_1 and ϵ_2 are internal PSO coefficients, and d_1^q and d_2^q are generated from a uniform distribution between $(0,1)$. Next, the position of the q-th particle is updated in each iteration as follows:

$$\boldsymbol{x}_q^{(t+1)}\leftarrow\boldsymbol{x}_q^{(t)}+\boldsymbol{v}_q^{(t+1)}. \tag{9}$$

The value of the particle's position is limited by $r_m\in[0,\gamma_m]$. Then, we evaluate the updated particles by solving the problem (6) to obtain $\{\mathbf{f}_m,\mathbf{w}_k,\theta_m\}$ and $f\left(\boldsymbol{x}_q^{(t+1)}\right)$. The local best position for the q-th particle is updated as $\boldsymbol{lb}_q^{(t+1)}=\boldsymbol{x}_q^{(t+1)}$ if $f\left(\boldsymbol{x}_q^{(t+1)}\right)<f\left(\boldsymbol{lb}_q^{(t)}\right)$. Otherwise, $\boldsymbol{lb}_q^{(t+1)}=\boldsymbol{lb}_q^{(t)}$. The global best position is updated by $\boldsymbol{gb}^{(t+1)}=\underset{1\leq q\leq P_{PSO}}{\mathrm{argmin}}\ f\left(\boldsymbol{lb}_q^{(t+1)}\right)$. Based on the updated local and global best position, the velocity and position of all the particles are updated for the next iteration. Finally, the aforementioned process is repeated until reaching the convergence, which is determined by a maximum number of iterations, I_{PSO}. Table I summarizes the proposed scheme to solve the problem (5).

TABLE I. PROPOSED SCHEME TO SOLVE PROBLEM (5).

1: **inputs:** P_{PSO}, I_{PSO}, γ_m, χ_m^{PS}, χ_k^{EH}.
2: Start $t=1$.
3: Initialize the position and velocity of each particle.
4: Initialize $\boldsymbol{lb}_q$ and $\boldsymbol{gb}$.
5: **while** $t\leq I_{PSO}$ **do**
6: **for each** particle **do**
7: Calculate the velocity with (8).
8: Update the position with (9).
9: Limit the position of the particle.
10: Evaluate the fitness function $f\left(\boldsymbol{x}_q^{(t+1)}\right)$ by solving the problem (6) with the common rate variables given by $\boldsymbol{x}_q^{(t+1)}$.
11: Update the local best position $\boldsymbol{lb}_q$.
12: **end for**
13: Update the global best position $\boldsymbol{gb}$.
14: $t=t+1$.
15: **end while**
16: **outputs:** The minimum transmit power is given by $f(\boldsymbol{gb})$, and the beamforming vectors and PS ratios are obtained after solving the problem (6) with the common rate variables defined by $\boldsymbol{gb}$.

IV. SIMULATION RESULTS

We provide numerical simulations to evaluate the performance of the proposed solution based on the SDR and PSO techniques to minimize the total transmission power of the PB and BS in the RSMA MISO SWIPT system. The value of the parameters used in our simulations are given by M=3 PS users, K=2 EH users, N=8 antennas at the BS, L=8 antennas at the PB, $\sigma_m^2=\sigma^2=-60$dBm, $\delta_m^2=\delta^2=-60$dBm, $\eta_m^{PS}=\eta_k^{EH}=1$, $\gamma_m=\gamma$, $\chi_m^{PS}=\chi_k^{EH}=\chi$. The channels from the BS to the m-th PS user can be denoted as

$$\mathbf{h}_{PS,m}=\sqrt{\beta d_{BS-PS,m}^{-\nu}}\tilde{\mathbf{h}}_{PS,m},\ \forall m, \tag{10}$$

where ν defines the path-loss exponent set to be $\nu=2.2$, $\beta=10^{-3}$, $d_{BS-PS,m}^{-\nu}$ denotes the distance between the BS and the m-th PS user and $\tilde{\mathbf{h}}_{PS,m}$ follows an independent Rician fading. The channels $\mathbf{h}_{EH,k}$, $\mathbf{g}_{PS,m}$, and $\mathbf{g}_{EH,k}$ are generated based on (10). The location of BS is (10m, 24m), and the PB is (14m, 10m). The PS users are randomly deployed in an area

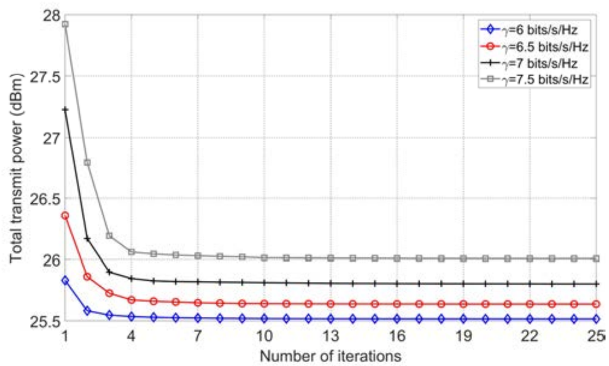

Fig. 2. Convergence behavior of the proposed scheme.

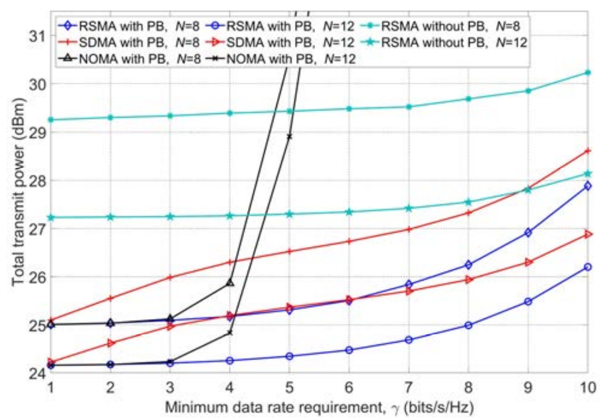

Fig. 3. Sum transmission power of BS and PB versus the rate requirements of the PS users.

limited by $x_{PS} \in [15\text{m}, 25\text{m}]$ and $y_{PS} \in [15\text{m}, 30\text{m}]$. The EH users are randomly deployed in an area limited by $x_{EH} \in [18\text{m}, 25\text{m}]$ and $y_{EH} \in [4\text{m}, 15\text{m}]$.

We compare the proposed PSO-SDR scheme with the conventional methods of SDMA and NOMA, where the message of the m-th PS user, W_m, is directly encoded into the stream s_m^{PS} and there are no common rate variables. In SDMA [11], the interference from other users is considered as noise. In NOMA [12], the interference from other users is decoded by using several layers of the SIC procedure. In particular, we ordered the PS users according to their channel strengths, i.e., $\left\|\mathbf{h}_{PS,1}\right\| \geq \ldots \geq \left\|\mathbf{h}_{PS,M}\right\|$. In the NOMA method, the m-th PS user first decodes the messages intended for the M-th, (M-1)-th, …, (m+1)-th PS users. Then, the m-th PS user can decode its own intended message by considering the rest of the messages as interference. Moreover, we include the comparative scheme by considering that the PB is not deployed in the network.

For the PSO algorithm we set $P_{PSO} = 10$, $w_{in} = 0.7$, $\epsilon_1 = \epsilon_2 = 1.494$. Fig. 2 shows the convergence behavior of the proposed PSO-SDR scheme for different values of rate requirements, γ. We observe that the proposed scheme achieves convergence within 15 iterations for all the rate requirement values. Therefore, we set $I_{PSO} = 15$.

The total transmission power of the BS and PB versus the data rate requirements, γ, is presented in Fig. 3 by considering a different number of antennas at the BS, N. We see that the proposed RSMA scheme with PB achieves a

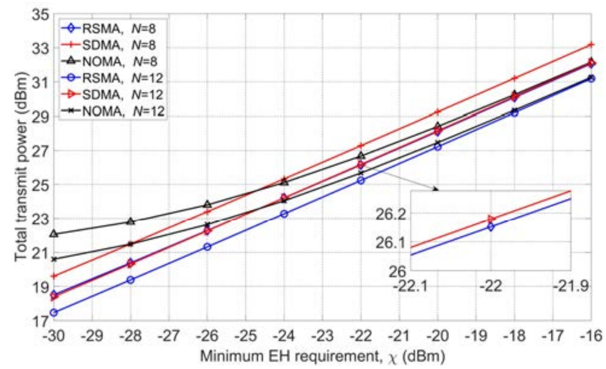

Fig. 4. Sum transmission power of BS and PB versus the EH requirement at the PS and EH users.

significantly low transmission power compared with SDMA and NOMA. The superior performance of RSMA over SDMA is because RSMA can decode part of the interference by applying the SIC procedure over the common message while SDMA considers all the interference as noise. The degradation in the performance of the NOMA scheme after $\gamma = 4$ bits/s/Hz is because the m-th PS user needs to decode and satisfy the rate requirements of all the messages intended for the far users by using several layers of SIC. Instead, in RSMA, the PS users are required to decode only the common message. From Fig. 3 it is proved that the deployment of a PB leads to a decrease of around 3dBm in the total transmission power, i.e., we can reduce the transmission power to around half. Moreover, we observe that the transmission power decreases as we increase the number of antennas at the BS because of higher degrees of freedom.

Finally, Fig. 4 presents the total transmission power of the BS and PB versus the EH requirements, χ, by considering a different number of antennas at the BS. Similar to Fig. 3, we see that the proposed RSMA method outperforms the comparative schemes for all the considered scenarios.

V. Conclusion

We consider a multi-user RSMA MISO SWIPT system aided by a PB. The sum of the total transmission power at the BS and PB is minimized by optimizing the PS ratios and beamforming vectors under data rate constraints at the PS users and EH requirements at the EH users and PS users. The non-convex problem is solved based on the SDR technique and the PSO algorithm. Numerical simulations proved that RSMA achieves a significantly lower transmission power compared with traditional methods such as NOMA and SDMA. In addition, we showed that a suitable location of a PB leads to a substantial reduction of the total transmit power because the PB can be located near EH users to satisfy their EH requirements.

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