Joint Energy-Efficient Power Allocation and Beamforming Design for mmWave-NOMA System with Imperfect CSI

CAI Jiali[1], *YU Xiangbin*[1,2*], *XU Fangcheng*[1], *WANG Guangying*[1]

1. College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, P. R. China;

2. State Key Laboratory of Millimeter Waves, Southeast University, Nanjing 211189, P. R. China

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Abstract: The joint power allocation (PA) and beamforming (BF) design problem is studied to maximize the energy efficiency of a two-user downlink millimeter-wave system with non-orthogonal multiple access under imperfect channel state information (CSI). By means of block coordinate descent, convex-concave procedure, and successive convex approximate, we propose a suboptimal joint PA and BF design scheme to address this non-convex problem. Simulation results verify that the proposed joint PA and BF design scheme is more effective when compared to some existing schemes.

Key words: energy efficiency; millimeter wave; non-orthogonal multiple access (NOMA); imperfect channel state information

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0 Introduction

Nowadays, spectrum resources are more and more scarce. A promising multiple access technique, non-orthogonal multiple access (NOMA), has been proposed. Different from traditional orthogonal transmission, NOMA exploits the new approach of user multiplexing in the power-domain[1-2]. Meanwhile, millimeter-wave (mmWave) communication is considered as one of the major candidate technologies of 5G due to the rich spectrum resources in the high frequency band[3]. Thus, mmWave with NOMA has received more and more attention.

Most of the existing literatures concerning mmWave-NOMA assume that perfect channel state information (CSI) is available, which cannot be guaranteed in practice. In Ref.[4], the joint power allocation (PA) and beamforming (BF) problem is decomposed into two sub-problems to maximize the sum rate of a downlink mmWave-NOMA system. Different from the study above that focused on the spectral efficiency, Ref.[5] explored the energy-efficient PA strategy for multi-user mmWave-NOMA system with different hybrid precoding structures, and Ref.[6] studied mmWave-NOMA uplink systems and considered the fairness of the energy-efficient optimization problem. Ref.[7] explored the joint PA and BF design problem to maximize energy efficiency (EE) for an uplink mmWave-NOMA system. In Ref.[8], an energy-efficient joint PA and BF scheme was developed. And in Ref.[9], the authors proposed two beamwidth control methods and analyzed the energy-efficient digital precoder design by adopting a NOMA user scheduling algorithm for downlink mmWave-NOMA system.

Thereforce, this paper focuses on the problem of maximizing EE under imperfect CSI. We study the EE optimization in a downlink mmWave-NOMA system and propose a suboptimal joint PA and BF design scheme. Since this problem is non-con-

*Corresponding author, E-mail address: yxbxwy@nuaa.edu.cn.

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vex, we develop an efficient iterative algorithm based on the block coordinate descent (BCD) method. Specially, we decompose the original optimization problem into the PA sub-problem and the BF sub-problem, which are solved by means of concave-convex procedure (CCCP) and successive convex approximation (SCA), respectively. Simulation results verify that the system with the proposed scheme can achieve better EE performance than some existing schemes.

Notation: The upper-case and lower-case bold letters denote matrices and vectors, respectively. $(\cdot)^{\mathrm{H}}$, $|\cdot|$, and $\|\cdot\|$ denote the conjugate transpose, absolute value and two-norm operation, respectively. $(0,\boldsymbol{R})$ denotes a complex Gaussian distribution with zero-mean and covariance matrix $\boldsymbol{R}$. $\mathrm{Re}(\cdot)$ and $[\cdot]_i$ denote the real part of a complex number and the i-th entry of a vector, respectively.

1 System Model and Problem Formulation

1.1 System model

We consider a downlink mmWave-NOMA system similar to that in Ref.[6], where two single-antenna users send their signals simultaneously to a base station (BS) equipped with N antennas and one radio frequency (RF) chain. The mmWave channel vector for User-i ($i=1,2$) can be modeled as[5,10]

$$\boldsymbol{h}_i=\hat{\boldsymbol{h}}_i+\sqrt{1-\rho}\,\tilde{\boldsymbol{h}}_i \tag{1}$$

where $\hat{\boldsymbol{h}}_i$ denotes the estimated channel vector, ρ the CSI accuracy of the non-line-of-sight (NLOS) component, and $\tilde{\boldsymbol{h}}_i\sim\mathcal{CN}(0,\boldsymbol{I}_N)$. Then the received signal of User-i can be expressed as

$$y_i=\hat{\boldsymbol{h}}_i^{\mathrm{H}}\boldsymbol{w}\sqrt{p_1}\,x_1+\hat{\boldsymbol{h}}_i^{\mathrm{H}}\boldsymbol{w}\sqrt{p_2}\,x_2+\sqrt{1-\rho}\,\tilde{\boldsymbol{h}}_i^{\mathrm{H}}\boldsymbol{w}\sqrt{p_1}\,x_1+\sqrt{1-\rho}\,\tilde{\boldsymbol{h}}_i^{\mathrm{H}}\boldsymbol{w}\sqrt{p_2}\,x_2+\boldsymbol{n}_i \tag{2}$$

where x_i denotes the transmission signal of User-i, $\boldsymbol{w}$ the BF vector, p_i the transmitted power, and $\boldsymbol{n}_i$ the Gaussian white noise with zero-mean and variance σ^2.

1.2 Problem formulation

In the above system, we need to consider the following two decoding orders:

Case-1: The signal of User-1 x_1 is decoded first. In this case, the achievable rates of two users are given as

$$\begin{cases} R_1^{(1)}=\log_2\left(1+\dfrac{\hat{c}_1p_1}{\hat{c}_1p_2+q(p_1+p_2)+\sigma^2}\right)\\ R_2^{(1)}=\log_2\left(1+\dfrac{\hat{c}_2p_2}{q(p_1+p_2)+\sigma^2}\right)\end{cases} \tag{3}$$

where $q=1-\rho$ and $\hat{c}_i=\left|\hat{\boldsymbol{h}}_i^{\mathrm{H}}\boldsymbol{w}\right|^2, i=1,2,$ in which the implicit assumption is $\hat{c}_1\leqslant\hat{c}_2$.

Case-2: The signal of User-2 x_2 is decoded first. In this case, the achievable rates of two users are given as

$$\begin{cases} R_1^{(2)}=\log_2\left(1+\dfrac{\hat{c}_1p_1}{q(p_1+p_2)+\sigma^2}\right)\\ R_2^{(2)}=\log_2\left(1+\dfrac{\hat{c}_2p_2}{\hat{c}_2p_1+q(p_1+p_2)+\sigma^2}\right)\end{cases} \tag{4}$$

Accordingly, the EE optimization problem for Case-j ($j=1,2$) under imperfect CSI can be formulated as

$$\begin{aligned} \mathrm{P0:}\quad &\max_{\{p_1,p_2,\boldsymbol{w}\}}\ \eta_{\mathrm{EE}}^{(j)}=\frac{R_1^{(j)}+R_2^{(j)}}{\xi(p_1+p_2)+P_{\mathrm{C}}}\\ &\mathrm{s.t.}\quad R_i^{(j)}\geqslant r_i\quad i=1,2\\ &\qquad\ p_1+p_2\leqslant P_{\max}\\ &\qquad\ \left|[\boldsymbol{w}]_n\right|=\frac{1}{\sqrt{N}}\quad n=1,2,\cdots,N \end{aligned} \tag{5}$$

where $\eta_{\mathrm{EE}}^{(j)}$ denotes the system EE for Case-j; r_i the minimum rate for User-i and $P_{\max}$ the maximum transmission power at the BS; ξ the low-noise amplifier (LNA) coefficient; and the fixed circuit power consumption P_{C} is given by $P_{\mathrm{C}}=P_{\mathrm{BB}}+P_{\mathrm{RF}}+NP_{\mathrm{PS}}+NP_{\mathrm{LNA}}$, where P_{BB}, P_{RF}, P_{PS}, P_{LNA} represent the power consumption of the baseband, the RF chain, the phase shifter, and the LNA, respectively. The BF vector $\boldsymbol{w}$ has constant-modulus (CM) elements, i.e. $\left|[\boldsymbol{w}]_n\right|=1/\sqrt{N}, n=1,\cdots,N$[4].

2 The Proposed Solution

In this section, we develop a suboptimal energy-efficient joint design scheme of PA and BF. Considering the space limitation, we only give the solution for Case-2, and the solution for Case-1 can be attained by using the similar method. P0 is difficult to solve due to the non-concave objective function as well as the coupled optimization variables. However, we observe that when one of p_i and $\boldsymbol{w}$ is fixed, the resultant problems can be efficiently solved. Therefore, we adopt the BCD algorithm for solving P0.

First, we introduce a new variable $P=p_1+p_2$, then P0 can be transformed equivalently as follows

$$\max_{p_1,P,\mathbf{w}} \quad \eta_{\mathrm{EE}}=\frac{\log_2\left(\left(1+\frac{\hat{c}_1 p_1}{qP+\sigma^2}\right)\left(1+\frac{\hat{c}_2(P-p_1)}{\hat{c}_2 p_1+qP+\sigma^2}\right)\right)}{\xi P+P_{\mathrm{C}}} \tag{6}$$

$$\begin{aligned}\text{s.t.}\quad & \hat{c}_2(P-p_1)\geqslant\phi_2(\hat{c}_2 p_1+qP+\sigma^2)\\ & \hat{c}_1 p_1\geqslant\phi_1(qP+\sigma^2)\quad 0\leqslant P\leqslant P_{\max}\\ & \left|[\boldsymbol{w}]_n\right|=\frac{1}{\sqrt{N}}\quad n=1,2,\cdots,N\\ & \hat{c}_2\leqslant\hat{c}_1\end{aligned}$$

where $\phi_i=2^{r_i}-1, i=1,2$. Next, we will derive the optimal p_2. According to the first derivative of Eq.(6) with respect to p_1 and $\hat{c}_2\leqslant\hat{c}_1$, we get $\partial\eta_{\mathrm{EE}}/\partial p_1\geqslant 0$, i.e., η_{EE} is concave and monotonically increasing with respect to p_1. Thus, the optimal p_1^* is obtained by the rate constraint of User-2

$$p_1^*=\frac{\hat{c}_2 P-\phi_2(qP+\sigma^2)}{(\phi_2+1)\hat{c}_2} \tag{7}$$

With p_1^* and $p_2=P-p_1^*$, problem (6) can be reduced to the following problem with respect to $\{P,\boldsymbol{w}\}$

$$\max_{P,\boldsymbol{w}} \quad \frac{\log_2((\hat{c}_2\hat{c}_1+q(\phi_2+1)\hat{c}_2-\phi_2\hat{c}_1 q)P+\sigma^2((\phi_2+1)\hat{c}_2-\phi_2\hat{c}_1))-\log_2((qP+\sigma^2)\hat{c}_2)}{\xi P+P_{\mathrm{C}}} \tag{8}$$

$$\begin{aligned}\text{s.t.}\quad & \hat{c}_1\frac{\hat{c}_2 P-\phi_2(qP+\sigma^2)}{(\phi_2+1)\hat{c}_2}\geqslant\phi_1(qP+\sigma^2)\qquad P_{\min}\leqslant P\leqslant P_{\max}\\ & \left|[\boldsymbol{w}]_n\right|=\frac{1}{\sqrt{N}}\qquad n=1,2,\cdots,N\\ & \hat{c}_2\leqslant\hat{c}_1\end{aligned}$$

where $P_{\min}=\dfrac{\phi_1(\phi_2+1)\hat{c}_2\sigma^2+\hat{c}_1\phi_2\sigma^2}{\hat{c}_1\hat{c}_2-\hat{c}_1\phi_2 q-\phi_1(\phi_2+1)\hat{c}_2 q}$, which is obtained by the rate constraint of User-1.

2.1 Power allocation for a given w

For a given $\boldsymbol{w}$, the PA problem is formulated as

$$\max_{P} \quad \frac{\log_2((\hat{c}_2\hat{c}_1+q(\phi_2+1)\hat{c}_2-\phi_2\hat{c}_1 q)P+\sigma^2((\phi_2+1)\hat{c}_2-\phi_2\hat{c}_1))-\log_2((qP+\sigma^2)\hat{c}_2)}{\xi P+P_{\mathrm{C}}} \tag{9}$$

$$\text{s.t.}\quad P_{\min}\leqslant P\leqslant P_{\max}$$

A near-optimal solution of problem (9) can be obtained by CCCP. By adopting the first-order Taylor expansion[11], a pseudo-concave lower bound $\eta_{\mathrm{lb}}^{(t)}$ of η_{EE} in problem (9) at the tth iteration of CCCP can be calculated as

$$\eta_{\mathrm{EE}}\geqslant\eta_{\mathrm{lb}}^{(t)}\triangleq\frac{\log_2(aP+b)-cP-d}{\xi P+P_{\mathrm{C}}} \tag{10}$$

where

$$\begin{cases}a=\hat{c}_2\hat{c}_1+q(\phi_2+1)\hat{c}_2-\phi_2\hat{c}_1 q\\ b=\sigma^2((\phi_2+1)\hat{c}_2-\phi_2\hat{c}_1)\\ c=\dfrac{q}{\ln 2(qP^{(t-1)}+\sigma^2)}\\ d=\log_2((qP^{(t-1)}+\sigma^2)\hat{c}_2)-\dfrac{q}{\ln 2(qP^{(t-1)}+\sigma^2)}P^{(t-1)}\end{cases} \tag{11}$$

in which $P^{(t-1)}$ is the value of P at the $(t-1)$th iteration of CCCP. Correspondingly, a convex approximation of problem (9) at the tth iteration is

$$\max_{P}\quad \eta_{lb}^{(t)} \tag{12}$$

$$\text{s.t.}\quad P_{\min}\leqslant P\leqslant P_{\max}$$

With the aid of Lambert W function $W(\cdot)$[12], the solution of $\partial\eta_{lb}^{(t)}/\partial P=0$ can be expressed as

$$\widetilde{P}=\frac{\dfrac{aP_{\mathrm{C}}}{\xi}-b}{aW\left(\dfrac{\dfrac{aP_{\mathrm{C}}}{\xi}-b}{\exp\left(\left(d-\dfrac{cP_{\mathrm{C}}}{\xi}\right)\ln 2+1\right)}\right)}-\frac{b}{a} \tag{13}$$

Therefore, the optimal solution of Eq.(12) is given by

$$\begin{cases} p_1^* = \dfrac{\hat{c}_2 P - \phi_2 (qP + \sigma^2)}{(\phi_2 + 1)\hat{c}_2}, \\ P^* = \min\left\{P_{\max}, \max\left\{P_{\min}, \bar{P}\right\}\right\} \end{cases} \tag{14}$$

2.2 Beamforming design for a given P

For a fixed P, the BF problem is formulated as

$$\text{P1:} \quad \max_{\boldsymbol{w}} \quad J(\boldsymbol{w}) = \left|\hat{\boldsymbol{h}}_1^{\mathrm{H}} \boldsymbol{w}\right|^2 P - \phi_2 (qP + \sigma^2) \frac{\left|\hat{\boldsymbol{h}}_1^{\mathrm{H}} \boldsymbol{w}\right|^2}{\left|\hat{\boldsymbol{h}}_2^{\mathrm{H}} \boldsymbol{w}\right|^2} \tag{15}$$

$$\text{s.t.} \quad \left|\hat{\boldsymbol{h}}_2^{\mathrm{H}} \boldsymbol{w}\right|^2 \leqslant \left|\hat{\boldsymbol{h}}_1^{\mathrm{H}} \boldsymbol{w}\right|^2$$

$$\left|[\boldsymbol{w}]_n\right| = \frac{1}{\sqrt{N}} \quad n = 1, \cdots, N$$

Letting $\boldsymbol{H}_i = \hat{\boldsymbol{h}}_i \hat{\boldsymbol{h}}_i^{\mathrm{H}}$, we introduce auxiliary variables t_1, t_2, then P1 can be relaxed to the following P2.

$$\text{P2:} \max_{\boldsymbol{w}, t_1, t_2} \quad t_1 \tag{16}$$

$$\text{s.t.} \quad 1 \leqslant \frac{\boldsymbol{w}^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w}}{\boldsymbol{w}^{\mathrm{H}} \boldsymbol{H}_2 \boldsymbol{w}} \leqslant t_2$$

$$\boldsymbol{w}^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w} \geqslant \frac{t_1 + \phi_2 (qP + \sigma^2) t_2}{P}$$

$$\left|[\boldsymbol{w}]_n\right| \leqslant \frac{1}{\sqrt{N}} \quad n = 1, \cdots, N$$

Afterwards, we can adopt SCA to address P2 by solving the following convex optimization problem P3 iteratively.

$$\text{P3:} \max_{\mathrm{w}, t_1, t_2} \quad t_1 \tag{17}$$

$$\text{s.t.} \quad 2\mathrm{Re}\left\{\boldsymbol{w}_0^{\mathrm{H}} \boldsymbol{H}_2 \boldsymbol{w}\right\} - \boldsymbol{w}_0^{\mathrm{H}} \boldsymbol{H}_2 \boldsymbol{w}_0 \geqslant \frac{\boldsymbol{w}^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w}}{t_2}$$

$$2\mathrm{Re}\left\{\boldsymbol{w}_0^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w}\right\} - \boldsymbol{w}_0^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w}_0 \geqslant \boldsymbol{w}^{\mathrm{H}} \boldsymbol{H}_2 \boldsymbol{w}$$

$$2\mathrm{Re}\left\{\boldsymbol{w}_0^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w}\right\} - \boldsymbol{w}_0^{\mathrm{H}} \boldsymbol{H}_1 \boldsymbol{w}_0 \geqslant \frac{t_1 + \phi_2 (qP + \sigma^2) t_2}{P}$$

$$\left|[\boldsymbol{w}]_n\right| \leqslant \frac{1}{\sqrt{N}} \quad n = 1, \cdots, N$$

where $\boldsymbol{w}_0 = \boldsymbol{w}^{(l-1)}$ denotes the value of $\boldsymbol{w}$ at the $(l-1)$th iteration of SCA. Hence, we can use CVX toolbox in MATLAB to solve P3. To satisfy the CM constraint, we still need to make the CM normalization as follows

$$[\boldsymbol{w}^*]_n = \frac{[\boldsymbol{w}^*]_n}{\sqrt{N}\left|[\boldsymbol{w}^*]_n\right|} \quad n = 1, \cdots, N \tag{18}$$

In summary, we develop a suboptimal joint PA and BF scheme based on the BCD, CCCP, and SCA, which is presented in Algorithm 1.

Algorithm 1 Joint PA and BF design algorithm

(1) Initialize tolerances $\epsilon_1, \epsilon_2, \epsilon_3 > 0$, number of iterations $t = 0, P^{(t)}$.

(2) **repeat**

(3) $t = t + 1$

(4) Initialize number of iterations $l = 0$ and initial point $\boldsymbol{w}^{(l)}$

(5) **repeat**

(6) $l = l + 1$

(7) Find the optimal solution $\boldsymbol{w}^*$ of P3

(8) Update $\boldsymbol{w}^{(l)} = \boldsymbol{w}^*$

(9) **until** $\left\|\boldsymbol{w}^{(l)} - \boldsymbol{w}^{(l-1)}\right\| \leqslant \epsilon_2$

(10) Update $\boldsymbol{w}^{(t)} = \boldsymbol{w}^{(l)}, \hat{c}_1 = \left|\boldsymbol{h}_1^{\mathrm{H}} \boldsymbol{w}^{(t)}\right|^2, \hat{c}_2 = \left|\boldsymbol{h}_2^{\mathrm{H}} \boldsymbol{w}^{(t)}\right|^2$.

(11) Initialize number of iterations $q = 0$ and initial point $P^{(q)}$

(12) **repeat**

(13) $q = q + 1$

(14) Compute P^* according to Eq.(14)

(15) Update $P^{(q)} = P^*$

(16) **until** $\left|P^{(q)} - P^{(q-1)}\right| \leqslant \epsilon_3$

(17) Update $P^{(t)} = P^{(q)}$

(18) **until** $\left\|\boldsymbol{w}^{(t)} - \boldsymbol{w}^{(t-1)}\right\| + \left|P^{(t)} - P^{(t-1)}\right| \leqslant \epsilon_1$

(19) **output**: Suboptimal solution $\hat{\boldsymbol{w}}^* = \boldsymbol{w}^{(t)}$, $\hat{P}^* = P^{(t)}, \hat{p}_1^*, \hat{p}_2^*$.

2.3 Complexity analysis

We can find that Algorithm 1 solves the problem $L_1(L_2 + L_3)$ times, where L_1, L_2, L_3 denote the number of iterations of BCD, SCA and CCCP, respectively. Besides, CVX is used and its complexity is $O(L_2(2N+2)^{3.5}\log(1/\varepsilon))$, where $O(\cdot)$ represents the big-O notation and ε is the solution accuracy[13]. Then the computational complexity is $O(L_1(L_2(2N+2)^{3.5}\lg(1/\varepsilon) + L_3))$.

3 Simulation Results

In this section, we evaluate the EE performance of the proposed algorithm via computer simulation. We assume that User-1 has better channel condition than User-2. For the mmWave channel, the first channel path is the line-of-sight path, and the other paths are NLOS paths, whose path gains follow the complex Gaussian distribution with zero-mean and have variance of −15 dB. Other parameters[7] are $\epsilon_1=\epsilon_2=\epsilon_3=10^{-4}$, $\xi=1/0.38$, $L_1=L_2=4$, $r_1=r_2=1$ bit/(s·Hz), $N=32$, $P_{BB}=200$ mW, $P_{RF}=160$ mW, $P_{PS}=20$ mW, $P_{LNA}=40$ mW, $\sigma^2=1$ mW.

Fig.1 presents the EE performances of the downlink mmWave-NOMA with different BF schemes, including "Baseline scheme 1" based on maximizing the lower bound in Ref.[8] and "Baseline scheme 2" based on eigenvalue decomposition in Ref.[7]. It can be seen from the figure that the EE of "Proposed scheme" is about 4.95 bit·J^{-1}·Hz^{-1}, while that of "Baseline scheme 1" and that of "Baseline scheme 2" are about 4.94 bit·J^{-1}·Hz^{-1} when perfect CIS is available and $P_{max}=0.1292$ W. For imperfect CSI, the EE of "Proposed scheme" is about 3.19 bit·J^{-1}·Hz^{-1}, while that of "Baseline scheme 1" and that of "Baseline scheme 2" are about 3.15 bit·J^{-1}·Hz^{-1} when $P_{max}=0.2154$ W. Obviously, "Proposed scheme" has better performance than other schemes, which validates the effectiveness of the proposed scheme. In addition, Fig.1 shows the impact of imperfect CSI on the system EE, where the CSI accuracy of NLOS component is set as $\rho\in\{1, 0.9, 0.7, 0.5\}$. As can be observed, the system EE decreases along with the decrease of ρ, which concludes that the accuracy of channel estimation affects the EE significantly. This is because the channel estimation error results in the increase of interference when decoding the user's signals.

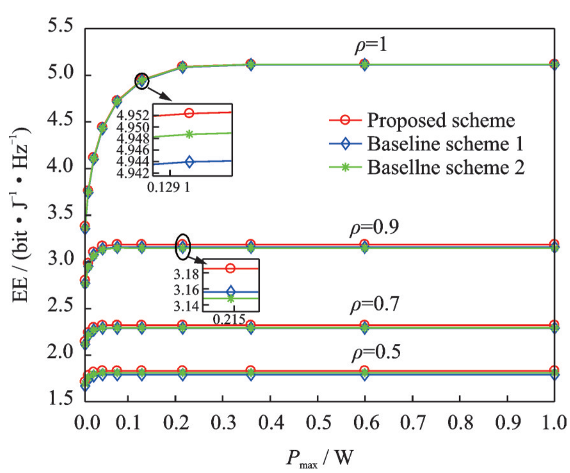

Fig.1 EE of mmWave-NOMA system with different schemes and impact of imperfect CSI on the EE

Fig.2 evaluates the impact of different rate constraints on the system EE for proposed scheme when $\rho=0.9$ and N is set as 32. It can be seen from Fig.2 that the system EE decreases with the increase of minimum rates. Namely, the system with $r_1=r_2=1$ bit/(s·Hz) has higher EE than that with $r_1=r_2=2$ bit/(s·Hz), and the system with $r_1=r_2=2$ bit/(s·Hz) has higher EE than that with $r_1=r_2=3$ bit/(s·Hz). And the higher the minimum rates are, the more EE is reduced. This is because the increase of minimum rates costs more transmission power allocated to the user with poor channel condition, which has a great impact on EE.

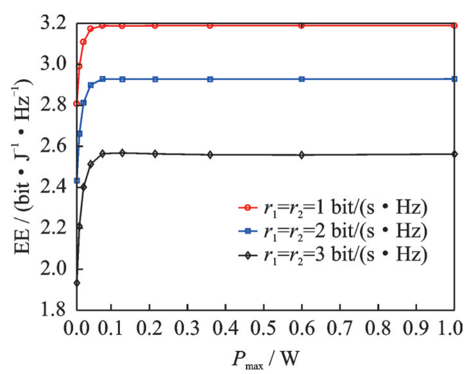

Fig.2 EE comparison under different rate constraints

4 Conclusions

We study the joint PA and BF design problem to maximize EE for downlink mmWave-NOMA system under imperfect CSI. We decompose the optimization problem into the PA problem and BF design problem, and then solve them successively. Then we use BCD to solve the optimization problem. With the proposed solution, the system can obtain higher EE. Besides, the accuracy of channel estimation and the minimum rate constraints have a great influence on the EE of the downlink mmWave-NOMA.

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Authors Ms. **CAI Jiali** is a postgraduate student of Nanjing University of Aeronautics and Astronautics (NUAA). Her research interests include NOMA and mmWave communication.

Prof. **YU Xiangbin** received his Ph.D. degree in communication and information systems from Southeast University in 2004. Now he is a professor of NUAA. His research interests include distributed multiple input multiple output, adaptive modulation and green communication

Author contributions Ms. **CAI Jiali** conducted the analysis, interpreted the results and wrote the manuscript. Prof. **YU Xiangbin** gave crucial directions, revised and modified the manuscript. Mr. **XU Fangcheng** and Ms. **WANG Guangying** commented on the manuscript draft. All authors commented on the manuscript draft and approved the submission.

Competing interests The authors declare no competing interests.

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不完全信道状态信息下毫米波非正交多址系统中联合能效的功率分配与波束成型设计

蔡嘉丽[1],虞湘宾[1,2],许方铖[1],王光英[1]

(1.南京航空航天大学电子信息工程学院,南京 211106,中国;
2.东南大学毫米波国家重点实验室,南京 211189,中国)

摘要:研究了不完全信道状态信息条件下联合功率分配和波束成型设计问题来最大化一个两用户下行毫米波非正交多址系统的能效。通过块坐标下降、凸凹过程和连续凸逼近的方法,提出了一个次优的联合功率分配和波束成型设计方案来解决这个非凸问题。仿真结果验证了本文所提出的联合功率分配和波束成型设计方案与一些现有方案相比的有效性。

关键词:能效;毫米波;非正交多址;不完全信道状态信息