Secrecy Sum Rate Optimization in MIMO NOMA OSTBC Systems with Imperfect Eavesdropper CSI

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Abstract. In this research, we investigate the secrecy sum rate optimization problem for a multiple-input multiple-output (MIMO) non-orthogonal multiple access (NOMA) system with orthogonal space-time block codes (OSTBC). We construct a model where the transmitter and the relay send information by employing OSTBC, while both the source and the relay have imperfect channel state information (CSI) of the eavesdropper. The precoders and the power allocation scheme are jointly designed to maximize the achievable secrecy sum rate subject to the power constraints and the minimum transmission rate requirements of the weak user. To solve this non-convex problem, we propose the constrained concave convex procedure (CCCP)-based iterative algorithm and the alternative optimization (AO) method, where the closed-form expression for power allocation is derived. The simulation results demonstrate the superiority of our proposed scheme.

Keywords: Multiple-input Multiple-output (MIMO) · Relay Non-orthogonal multiple access (NOMA) · Orthogonal space-time block codes (OSTBC) · Secrecy sum rate · Imperfect CSI

1 Introduction

With the popularization of smart terminals and the rapid development of 5G wireless communication technology, people are looking for a method to take full use of spectrum resources. Nowadays, non-orthogonal multiple access (NOMA) scheme can not only meet the requirements of wireless communication for spectrum utilization, but also achieve better throughput gain. In [1], the NOMA technique is applied in the multiple-input multiple-output (MIMO) systems.

With the aid of linear processing at the receiver, the orthogonal space-time block codes (OSTBC) technique for MIMO NOMA systems can achieve full diversity and full rate using [2]. Meanwhile, since the existence of potential

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eavesdroppers in the current communication system, wireless information is susceptible to be eavesdropped. Thus, effective measures should be taken to deal with the threat of eavesdropping events in MIMO NOMA systems [4]. However, to the best of our knowledge, the secure precoding scheme in the MIMO NOMA robust systems with OSTBC has not been studied yet.

In this paper, a MIMO NOMA robust system is investigated to ensure secure information transmission between the transmitter and relay, which employ OSTBC. The precoder and power allocation scheme are jointly designed to maximize achievable secrecy sum rate. Since the optimization problem is non-convex, we propose the constrained concave convex procedure (CCCP)-based iterative algorithm and the AO method, where the closed-form expression for power allocation is derived. The remainder of the paper is organized as follows. In Sect. 2, we describe the system model and problem formulation. Section 3 presents the proposed algorithm to solve the precoder and power allocation problem. Simulation results are provided in Sects. 4 and 5 concludes this paper.

2 System Model and Problem Formulation

As shown in Fig. 1, we consider a MIMO NOMA system consisting of one transmitter, one relay, two legal users U_1, U_2, and a potential eavesdropper U_3, equipped with M_s, M_r, M_1, M_2, M_3 antennas, respectively. The channel coefficient from the transmitter to relay is denoted as $\boldsymbol{H_r}$, and the ones from the relay to U_1, U_2 and U_3 are $\boldsymbol{H_1}$, $\boldsymbol{H_2}$ and $\boldsymbol{H_3}$, respectively. In this system, the transmitter tends to send information to U_1 and U_2 safely.

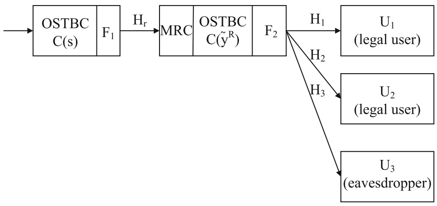

Fig. 1. Precoding of OSTBC for MIMO relay system.

We assume that the transmitter knows the perfect CSI of the relay, U_1 and U_2 while the CSI of U_3 is imperfect. Thus, the channel response $\boldsymbol{H_3}$ is defined as

$$\boldsymbol{H_3} = \boldsymbol{\hat{H}_3} + \triangle \boldsymbol{H_3} \tag{1}$$

where $\boldsymbol{\hat{H}_3}$ denotes the estimation of the channel from the transmitter to the eavesdropper, $\triangle \boldsymbol{H_3}$ refers to the channel uncertainty of $\boldsymbol{H_3}$, which is bounded by the elliptical regions, i.e., $\mathcal{H}_3$

$$\mathcal{H}_3 = \{\triangle \boldsymbol{H_3} | Tr(\triangle \boldsymbol{H_3^\dagger} \boldsymbol{Q_3} \triangle \boldsymbol{H_3}) \leq 1\} \tag{2}$$

where $\boldsymbol{Q_3}$ is assumed to be known and determine the qualities of CSI.

The S-R-D signal transmission procedure takes place in two steps. In the first phase, the received signal at the relay is expressed as $\boldsymbol{Y}_r = \boldsymbol{H}_r \boldsymbol{F_1} \boldsymbol{C}(\boldsymbol{s}) + \boldsymbol{N}_r$, where $\boldsymbol{F_1} \in \mathbb{C}^{M_s \times M_s}$ denotes the transmitter's precoder; $\boldsymbol{N}_r$ refers to the Gaussian noise with $\boldsymbol{N}_r \sim \mathcal{CN}(0, \sigma_r^2 \boldsymbol{I})$; $\boldsymbol{C}(\boldsymbol{s}) \in \mathbb{C}^{M_s \times T}$ ($\boldsymbol{C}(\boldsymbol{s})\boldsymbol{C^H}(\boldsymbol{s}) = \tilde{a} P_s \boldsymbol{I}_{M_s}$) is the OSTBC matrix with a code specific constant $\tilde{a}$.

We assume that the U_1's information corresponds to the symbols $x_{1,1}$ and $x_{1,2}$, the U_2's information corresponds to the symbols $x_{2,1}$ and $x_{2,2}$. The encoding and transmission sequence at the transmitter for the MIMO NOMA system with OSTBC is shown in Table 1 [3], where $T = 2$, $M_s = 2$.

Table 1. Transmitter schematic of OSTBC

Antenna 1	Antenna 2
$t_1 : s_1 = \sqrt{\phi_1 P_s} x_{1,1} + \sqrt{\phi_2 P_s} x_{2,1}$,	$s_2 = \sqrt{\phi_1 P_s} x_{1,2} + \sqrt{\phi_2 P_s} x_{2,2}$
$t_2 : -s_2^* = -\sqrt{\phi_1 P_s} x_{1,2}^* - \sqrt{\phi_2 P_s} x_{2,2}^*$,	$s_1^* = \sqrt{\phi_1 P_s} x_{1,1}^* + \sqrt{\phi_2 P_s} x_{2,1}^*$

As presented in Table 1, s_1 and s_2 are simultaneously transmitted to the relay in the time slot t_1. In the next time slot t_2, s_1^* and $-s_2^*$ are transmitted. ϕ_1 and ϕ_2 are the power allocation factors of U_1, U_2, which satisfy $\phi_1 + \phi_2 = 1$. P_s is the transmission power of the transmitter and $E\{|x_{j,i}|^2\} = 1,\ i, j \in \{1, 2\}$.

Since the relay processes $\boldsymbol{Y}_r$ with maximum ratio combiner (MRC), thus, the received signal at the relay can be written as [5]

$$y_k^R = \|\boldsymbol{H_r} \boldsymbol{F_1}\| z_k + n_{r,k}, i \in \{1, ..., K\} \tag{3}$$

where $z_k = \sqrt{\frac{\phi_1 P_s}{K}} x_{1,k} + \sqrt{\frac{\phi_2 P_s}{K}} x_{2,k}$, $n_{r,k} \sim \mathcal{CN}(0, \sigma_r^2)$ refers to the AWGN at the relay for the kth S-R SISO channel and follows complex Gaussian distribution with zero-mean and variance σ_1^2. The relay normalizes $\{y_k^R\}_{k=1}^K$ yielding

$$\tilde{y}_k^R = \frac{y_k^R}{\sqrt{E\{|y_k^R|^2\}}} = \frac{\|\boldsymbol{H_r} \boldsymbol{F_1}\| z_k + n_{r,k}}{\sqrt{\|\boldsymbol{H_r} \boldsymbol{F_1}\|^2 + \sigma_r^2}} \tag{4}$$

In the second phase, the destination receive signal $\boldsymbol{Y_d} = \boldsymbol{H_j} \boldsymbol{F_2} \boldsymbol{C}(\tilde{\boldsymbol{y}}^R) + \boldsymbol{N_j^d}$, where $\boldsymbol{C}(\tilde{\boldsymbol{y}}^R) \in \mathbb{C}^{M_r \times T}$ is the OSTBC formed from $\tilde{\boldsymbol{y}}^R = [\tilde{y}_1^R, ..., \tilde{y}_K^R]$; $\boldsymbol{F_2} \in \mathbb{C}^{M_r \times M_r}$ is the relay precoder; $\boldsymbol{H_j}$, $j \in \{1, 2, 3\}$ is the R-D MIMO channel and $\boldsymbol{N_j^d}$ is the matrix of AWGN samples at the destination with zero mean and variance $\tilde{\sigma}_j^2$.

As in the case of kth S-R SISO channel, the signal received by the destination in the kth R-D SISO channel is given by

$$y_k^D = \|\boldsymbol{H_j} \boldsymbol{F_2}\| \tilde{y}_k^R + n_{2,k}, \forall k \tag{5}$$

where $n_{j,k} \sim \mathcal{CN}(0, \sigma_j^2)$ is the AWGN at the relay for the kth S-R SISO channel. Using (4), (5) can be expressed as

$$y_k^D = \frac{\|\boldsymbol{H_j F_2}\|\|\boldsymbol{H_r F_1}\|z_k + \|\boldsymbol{H_j F_2}\|n_{r,k}}{\sqrt{\|\boldsymbol{H_r F_1}\|^2 + \sigma_1^2}} + n_{j,k} \tag{6}$$

Therefore, the SNR at the destination is given as

$$y_k^D = \frac{\|\boldsymbol{H_j F_2}\|\|\boldsymbol{H_r F_1}\|z_k + \|\boldsymbol{H_j F_2}\|n_{r,k}}{\sqrt{\|\boldsymbol{H_r F_1}\|^2 + \sigma_1^2}} + n_{j,k} \tag{7}$$

We assume that $\|\boldsymbol{H_1 F_2}\|^2 \geqslant \|\boldsymbol{H_2 F_2}\|^2 \geqslant \|\boldsymbol{H_3 F_2}\|^2$, user U_1 is the strong user and user U_2 is the weak user. At the strong user U_1, the signal-to-noise ratio (SNR) to decode signals of the weak user U_2 is

$$\gamma_1^2 = \frac{\frac{\phi_2 P_s}{K}\|\boldsymbol{H_1 F_2}\|^2\|\boldsymbol{H_r F_1}\|^2}{\frac{\phi_1 P_s}{K}\|\boldsymbol{H_r F_1}\|^2\|\boldsymbol{H_1 F_2}\|^2 + \|\boldsymbol{H_r F_1}\|^2\sigma_1^2 + \|\boldsymbol{H_1 F_2}\|^2\sigma_2^2 + \sigma_1^2\sigma_2^2} \tag{8}$$

$$= \frac{\frac{\phi_2 P_s}{K}\gamma_1\gamma}{\frac{\phi_1 P_s}{K}\gamma_1\gamma + \gamma_1 + \gamma + 1}. \tag{9}$$

At the weak user U_2, the SNR to detect its own signals is

$$\gamma_2^2 = \frac{\frac{\phi_2 P_s}{K}\gamma_2\gamma}{\frac{\phi_1 P_s}{K}\gamma_2\gamma + \gamma_2 + \gamma + 1}. \tag{10}$$

The minimum SNR requirement of the weak user U_2 is denoted as γ_0, due to $\gamma_1^2 \geq \gamma_2^2$, the strong user U_1 can remove signals of U_2. After successive interference cancelation (SIC), the SNR of U_1 to detect its own signals is given by

$$\gamma_1^1 = \frac{\frac{\phi_1 P_s}{K}\gamma_1\gamma}{\gamma_1 + \gamma + 1} \tag{11}$$

Then at the eavesdropper U_3, the SNR to detect the signals of U_1 and U_2 is

$$\gamma_3^{1,2} = \frac{\frac{P_s}{K}\gamma_3\gamma}{\gamma_3 + \gamma + 1}. \tag{12}$$

where $\gamma = \frac{\|\boldsymbol{H_r F_1}\|^2}{\sigma_r^2}$, $\gamma_j = \frac{\|\boldsymbol{H_i F_2}\|^2}{\sigma_j^2}, j \in \{1, 2, 3\}$. The transmit powers of the source and relay per OSTBC block can be given by $P_s = \tilde{a}P_s Tr(\boldsymbol{F_1 F_1}^{\boldsymbol{H}})$ and $P_r = \tilde{a}P_s Tr(\boldsymbol{F_2 F_2}^{\boldsymbol{H}})$, where $P_s{=}P_r$.

Based on (11), (2) and (12), the achievable secrecy sum rate can be calculated as

$$\begin{aligned} R_s = &\log_2(1 + \gamma_1^1) + \log_2(1 + \gamma_2^2) \\ &- \log_2(1 + \gamma_3^{1,2}) \end{aligned} \tag{13}$$

3 Precoder and Power Optimization

The secrecy sum rate optimization problem can be formulated as

$$\max_{\{\boldsymbol{W_1},\boldsymbol{W_2},\gamma_1,\gamma_2,\phi_1,\phi_2\}} \quad \log_2(1+\gamma_1^1)+\log_2(1+\gamma_2^2) - \log_2(1+\gamma_3^{1,2}) \tag{14a}$$

$$\text{s.t.} \quad \gamma_2^2 \geq \gamma_0, \tag{14b}$$

$$\phi_1+\phi_2 = 1, \tag{14c}$$

$$0 \leq \phi_1 \leq 1, \tag{14d}$$

$$0 \leq \phi_2 \leq 1, \tag{14e}$$

$$\frac{\|\boldsymbol{H_r F_1}\|^2}{\sigma_r^2} = \gamma, \tag{14f}$$

$$\frac{\|\boldsymbol{H_1 F_2}\|^2}{\sigma_1^2} \geq \gamma_1, \tag{14g}$$

$$\frac{\|\boldsymbol{H_2 F_2}\|^2}{\sigma_2^2} \geq \gamma_2, \tag{14h}$$

$$Tr(\boldsymbol{F_1 F_1^H}) \leq \frac{1}{\tilde{a}}, Tr(\boldsymbol{F_2 F_2^H}) \leq \frac{1}{\tilde{a}}, \tag{14i}$$

$$Tr(\boldsymbol{H_1^H H_1 W_2}) \geqslant Tr(\boldsymbol{H_2^H H_2 W_2}), \tag{14j}$$

$$Tr(\boldsymbol{H_2^H H_2 W_2}) \geqslant Tr(\boldsymbol{H_3^H H_3 W_2}) \tag{14k}$$

$$\frac{\|\boldsymbol{H_3 F_2}\|^2}{\sigma_3^2} \leq \gamma_3 \tag{14l}$$

Next, we employ the S-procedure to convert the constraints (14l) into linear matrix inequalities (LMIs).

$$\begin{cases} \forall \triangle \boldsymbol{H_3} : Tr(\triangle \boldsymbol{H_3^\dagger Q_3} \triangle \boldsymbol{H_3}) \leq \theta_3 \\ Tr(\boldsymbol{H_3^\dagger W_2 H_3}) - \gamma_3 \sigma_3^2 \leq 0 \end{cases} \tag{15}$$

Then we rewrite it as follows:

$$\begin{cases} \forall \triangle \boldsymbol{h_3} : \triangle \boldsymbol{h_3^\dagger}(\boldsymbol{I} \otimes \boldsymbol{Q_3}) \triangle \boldsymbol{h_3} - \theta_3 \leq 0 \\ \triangle \boldsymbol{h_3^\dagger}(\boldsymbol{I} \otimes \boldsymbol{Q_3}) \triangle \boldsymbol{h_3} + 2Re\{((\boldsymbol{I} \otimes \boldsymbol{Q_3})\boldsymbol{h_3^\dagger}) \triangle \boldsymbol{h_3^\dagger}\} + \boldsymbol{h_3^\dagger}(\boldsymbol{I} \otimes \boldsymbol{Q_3})\boldsymbol{h_3} - \gamma_3 \sigma_3^2 \leq 0 \end{cases} \tag{16}$$

$$\begin{bmatrix} \lambda_3(\boldsymbol{I} \otimes \boldsymbol{Q_3}) - (\boldsymbol{I} \otimes \boldsymbol{W_2}) & -(\boldsymbol{I} \otimes \boldsymbol{W_2})\boldsymbol{h_3} \\ -\boldsymbol{h_3^\dagger}(\boldsymbol{I} \otimes \boldsymbol{W_2}) & \gamma_3 \sigma_3^2 - \lambda_3 \theta_3 - \boldsymbol{h_3^\dagger}(\boldsymbol{I} \otimes \boldsymbol{Q_3})\boldsymbol{h_3} \end{bmatrix} \succeq 0 \tag{17}$$

where $\lambda_3 >= 0$ is a slack variable, $\boldsymbol{h_3} = vec(\boldsymbol{H_3})$.

The problem is recast as

$$\max_{\{\boldsymbol{W_1},\boldsymbol{W_2},\gamma_1,\gamma_2,\phi_1,\phi_2,\lambda_3\}} \quad \log_2(1+\gamma_1^1)+\log_2(1+\gamma_2^2) - \log_2(1+\gamma_3^{1,2}) \tag{18a}$$

$$\text{s.t.} \quad Tr(\boldsymbol{DW_1})=\gamma, \tag{18b}$$

$$Tr(\boldsymbol{AW_2}) \geq \gamma_1\sigma_1^2, \tag{18c}$$

$$Tr(\boldsymbol{BW_2}) \geq \gamma_2\sigma_2^2, \tag{18d}$$

$$Tr(\boldsymbol{W_1}) \leq \frac{1}{\tilde{a}}, Tr(\boldsymbol{W_2}) \leq \frac{1}{\tilde{a}}, \tag{18e}$$

$$Tr(\boldsymbol{AW_2}) \geqslant Tr(\boldsymbol{BW_2}), \tag{18f}$$

$$Tr(\boldsymbol{BW_2}) \geqslant Tr(\boldsymbol{CW_2}), \tag{18g}$$

$$(14b)-(14e), (17). \tag{18h}$$

where γ_0 denotes the minimum SNR requirement of the weak user U_2; $\boldsymbol{W_1} = \boldsymbol{F_1^H F_1}$, $\boldsymbol{W_2} = \boldsymbol{F_2^H F_2}$, $\boldsymbol{A} = \boldsymbol{H_1^H H_1}$, $\boldsymbol{B} = \boldsymbol{H_2^H H_2}$, $\boldsymbol{C} = \boldsymbol{H_3^H H_3}$, $\boldsymbol{D} = \boldsymbol{H_r^H H_r}$. Because the objective and constraints are non-convex, problem (18) can not be directly solved by convex method. As far as we know, (18) has no global optimal solution, so we will use an effective method to attain the local optimal solution.

By introducing slack variables $\{a,b,c\}$ such that $\gamma_1^1 \geq a$, $\gamma_2^2 \geq b$, $\gamma_3^{1,2} \leq c$, (18) is equivalently recast as

$$\max_{\{\boldsymbol{W_1},\boldsymbol{W_2},\gamma_1,\gamma_2,\phi_1,\phi_2,a,b,c\}} \quad \log_2(1+a)+\log_2(1+b) - \log_2(1+c) \tag{19a}$$

$$\text{s.t.} \quad \gamma_2^2 \geq \gamma_0, \tag{19b}$$

$$\gamma_1^1 \geq a, \tag{19c}$$

$$\gamma_2^2 \geq b, \tag{19d}$$

$$\gamma_3^{1,2} \leq c, \tag{19e}$$

$$(18b)-(18h). \tag{19f}$$

Based on (12), (19e) is expressed as

$$\frac{1}{\gamma_3}+\frac{1}{\gamma}+\frac{1}{\gamma_3\gamma} \geq \frac{P_s}{cK} \tag{20a}$$

$$\tau_3+\tau_{min}+t_3 \geq \frac{P_s}{cK} \tag{20b}$$

$$\tau_3\gamma_3 \leq 1 \tag{20c}$$

$$\tau_{min}\gamma \leq 1 \tag{20d}$$

$$t_3\gamma_3\gamma \leq 1 \tag{20e}$$

Equation (20e) is expressed as

$$\begin{bmatrix} \mu_3 & t_3 \\ \gamma & \mu_3 \end{bmatrix} \succeq 0 \tag{21a}$$

$$\begin{bmatrix} \mu_{3,3} & 1 \\ 1 & \mu_{3,3} \end{bmatrix} \succeq 0 \tag{21b}$$

$$\mu_3 \mu_{3,3} \leq 1 \tag{21c}$$

Similarly, (19b), (19c), (19d) are expressed as

$$\frac{1}{\gamma_1} + \frac{1}{\gamma} + \frac{1}{\gamma_1 \gamma} \leq \frac{\phi_1 P_s}{aK} \tag{22a}$$

$$\tau_1 + \tau_{max} + t_1 \leq \frac{\phi_1 P_s}{aK} \tag{22b}$$

$$\frac{1}{\gamma_2} + \frac{1}{\gamma} + \frac{1}{\gamma_2 \gamma} \leq \frac{1}{b - \frac{\phi_1}{\phi_2}} \frac{\phi_2 P_s}{K} \tag{22c}$$

$$\tau_2 + \tau_{max} + t_2 \leq \frac{1}{b - \frac{\phi_1}{\phi_2}} \frac{\phi_2 P_s}{K} \tag{22d}$$

$$\frac{1}{\gamma_2} + \frac{1}{\gamma} + \frac{1}{\gamma_2 \gamma} \leq (\frac{1}{\gamma_0} - \frac{\phi_1}{\phi_2}) \frac{\phi_2 P_s}{K} \tag{22e}$$

$$\tau_2 + \tau_{max} + t_2 \leq (\frac{1}{\gamma_0} - \frac{\phi_1}{\phi_2}) \frac{\phi_2 P_s}{K} \tag{22f}$$

$$\tau_i \gamma_i \geq 1 \tag{22g}$$

$$\tau_{max} \gamma \geq 1 \tag{22h}$$

$$t_i \gamma_i \gamma \geq 1 \tag{22i}$$

Hyperbolic constraints (22g) and (22h) can be converted into convex forms

$$\tau_i + \gamma_i \geq \|[\sqrt{2}, \tau_i, \gamma_i]^T\| \tag{23a}$$

$$\tau_{max} + \gamma \geq \|[\sqrt{2}, \tau_{max}, \gamma]^T\| \tag{23b}$$

Equation (22i) can be expressed as

$$\begin{bmatrix} t_i & \mu_i \\ \mu_i & \gamma \end{bmatrix} \succeq 0 \tag{24a}$$

$$\begin{bmatrix} 1 & \mu_{i,i} \\ \mu_{i,i} & \gamma_i \end{bmatrix} \succeq 0 \tag{24b}$$

$$\mu_i + \mu_{i,i} \geq \|[\sqrt{2}, \mu_i, \mu_{i,i}]^T\| \tag{24c}$$

where $i \in \{1, 2\}$.

Because of the non-convexity of these functions: $-\log_2(1 + c)$, (20c), (20d) and (21c), we can employ the first-order Taylor method to recast them, which are expressed as $f(c, \bar{c})$, $f(\tau_3, \bar{\tau}_3)$, $f(\tau_{min}, \bar{\tau}_{min})$, $f(\mu_{3,3}, \bar{\mu}_{3,3})$, respectively.

Then problem (18) can be rewritten as

$$
\begin{aligned}
\max_{\{\boldsymbol{W_1},\boldsymbol{W_2},\gamma_1,\gamma_2,\phi_1,\phi_2,a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t}\}} \quad & \log_2(1+a)+\log_2(1+b) \\
& -f(c,\bar{c}) && \text{(25a)}\\
\text{s.t.} \quad & (22\text{b}),(22\text{d}),(22\text{f}),(23), && \text{(25b)}\\
& (24),(20\text{b}), && \text{(25c)}\\
& (21\text{a}),(21\text{b}), && \text{(25d)}\\
& (18\text{b})-(18\text{h}) && \text{(25e)}\\
& f(\tau_3,\bar{\tau}_3), f(\tau_{min},\bar{\tau}_{min}), f(\mu_{3,3},\bar{\mu}_{3,3}). && \text{(25f)}
\end{aligned}
$$

To solve problem (25), we employ AO method which alternatively optimizes ϕ_1 and $(\boldsymbol{W_1},\boldsymbol{W_2},a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t})$. Given ϕ_1, problem (25) is convex with respect to $(\boldsymbol{W_1},\boldsymbol{W_2},a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t})$, which can be solved by interior point method [6].

With given $(\boldsymbol{W_1},\boldsymbol{W_2},a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t})$, we can obtain ϕ_1 as follow. Based on $\gamma_2^2 \geq \gamma_0$, the objective function is an increasing function with respect to ϕ_1, then the closed-form solution of ϕ_1 can be achieved as

$$
\phi_1 = \frac{1}{1+M} - M\frac{1+Tr(\boldsymbol{W_1D})+Tr(\boldsymbol{W_2A})}{0.5P_s(1+M)Tr(\boldsymbol{W_2B})+Tr(\boldsymbol{W_1D})}. \tag{26}
$$

The proposed AO method is shown in Algorithm 1 as below.

Algorithm 1 The Proposed AO Method to Solve Problem (21)

1: **Initialization:** $n=0$ and $\phi_1^{(0)}$ and an accuracy parameter ϵ;
2: **Repeat:**
   Solve problem (21) to update $(\boldsymbol{W_1},\boldsymbol{W_2},a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t})^{(n)}$, with $\phi_1^{(n)}$ fixed;
   Use (26) to update $\phi_1^{(n+1)}$ with $(\boldsymbol{W_1},\boldsymbol{W_2},a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t})^{(n)}$;
   Update $n=n+1$;
3: **Until:** $|R^{(n)}-R^{(n-1)}| \leq \epsilon$, where $R^{(n)}$ is the objective value in the nth iteration.

By solving problem (25), we get the optimal solution $(\boldsymbol{W_1},\boldsymbol{W_2},a,b,c,\boldsymbol{\mu},\boldsymbol{\tau},\boldsymbol{t})^{(o)}$. If the rank of $\widehat{\boldsymbol{W}^o}$ equals to one, the optimal $\boldsymbol{F}^o$ can be easily found. Otherwise, we can generate a suboptimal solution through the Gaussian random method in [9].

4 Simulation Results

Here, the simulation results are provided to validate the proposed robust precoding schemes with NOMA OSTBC are more effective than other cases.

In Fig. 2, we present the average achievable secrecy sum rates achieved by the proposed scheme, equal power allocation scheme and the conventional orthogonal multiple access scheme both with OSTBC (denoted as “OSTBC+NOMA”, "OSTBC+EP" "OSTBC+OMA", respectively), versus the transit power P_s with setting $M_s = M_r = M_1 = M_2 = M_3 = 2$, $\tilde{a} = 1$ and the minimum SNR requirement of the weak user $\gamma_0 = 0.10$ dB.

It can be observed that our proposed "NOMA+OSTBC" scheme achieves better performance than the other two schemes for different P_s. This is because the superposition of signals to different users and SIC cause the bandwidth is explored more efficiently.

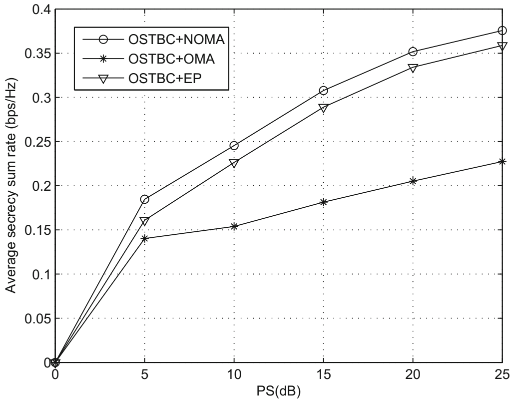

Fig. 2. The achievable secrecy sum rate versus P_s, obtained by "OSTBC+NOMA" scheme, the conventional "OSTBC+OMA" and "OSTBC+EP" scheme.

In Fig. 3, we show the effect of the power allocation factors of U_1, i.e.,ϕ_1, where no eavesdropper situation (denoted as "No Eve") is also compared. From Fig. 3, we find that "NOMA+OSTBC" scheme outperforms the "OSTBC+OMA" scheme with different ϕ_1, for NOMA can achieve higher spectral efficiency and better user fairness than conventional OMA. Besides, larger ϕ_1 leads to higher secrecy sum rate. As ϕ_1 continues to increase, the performance gab between the "OSTBC+NOMA" and "OSTBC+OMA" becomes larger.

5 Conclusion

In this paper, the precoders and power allocation design for MIMO NOMA robust system with OSTBC is studied, where source and relay have imperfect CSI of the eavesdropper. To tackle the non-convexity of the optimization problem, we employ the CCCP-based algorithm and AO method to optimize the precoders and power allocation. The simulation results demonstrate the superiority of our proposed scheme.

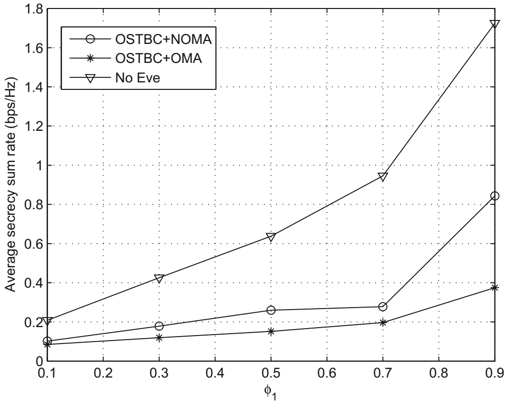

Fig. 3. The achievable secrecy sum rate versus ϕ_1, obtained by "OSTBC+NOMA" scheme, the conventional "OSTBC+OMA" scheme and "No Eve" scheme.

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