Non-Orthogonal Multiple Access (NOMA) in Providing Services for High-Speed Railway and Local Users in DownLink MIMO System

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Abstract. In this paper, we contribute to investigate the problem that providing service for High Speed Railway (HSR) in multiple-input multiple-output non-orthogonal multiple access (MIMO-NOMA) system to increase HSR rate. A novel system model is proposed to serve both HSR and local users. Coordinated Regularized Zero Forcing (CRZF) precoding is applied to deal with inter-cluster and inter-cell interference with considering the effect of Doppler Shift of HSR and the feedback delay of the Channel State Information (CSI). The proof of the performance of proposed model can outperform conventional MIMO-NOMA and MIMO-OMA is provided. At last, simulation is performed to demonstrate the correctness of the theory.

Keywords: Non-orthogonal multiple access (NOMA) ·
Multiple-input multipleoutput (MIMO) ·
Coordinated Regularized Zero Forcing (CRZF) ·
Signal-to-interference-plus-noise (SINR)

1 Introduction

Recently, NOMA has been proposed as a promising technique to enhance spectrum efficiency in next generation networks [1]. The basic idea of NOMA is to serve multiple users at the same time, frequency and code, but with different power levels. These users with worse channel conditions (i.e., weak users) can decode their higher-power-level signals directly by treating others signals as noise. In contrast, those users with better channel conditions (i.e., strong users) adopt the successive interference cancellation (SIC) technique for signal detection.

On the other hand, current cellular systems are only powerful in providing high-data-rate wireless access services for low-mobility (<10 km/h) users. When users move with a high velocity (>120 km/h), the achievable data rates of those systems drop significantly [2]. All of these increase the demand to consider

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high-mobility users during developing communication systems. However, to the best of our knowledge, there are no previous works which studied NOMA scheme considering HSR. Therefore, we investigate the NOMA solution that provides services both for HSR and local users.

The application of MIMO to NOMA systems was presented in [3] by Ding et al., where a new design of precoding and detection matrices for MIMO-NOMA is proposed, the closed-form expressions of rate gap between MIMO-NOMA and MIMO-OMA was also derived and the outage probability of the users of a MIMO-NOMA cluster was evaluated. The concept of MIMO-NOMA has been validated by using systematic implementation in [4–6], which demonstrates that the use of MIMO can outperform conventional MIMO-OMA. A non-orthogonal multiple access based zero-forcing beamforming (NOMA-ZFBF) system has been designed to enhance the sum capacity in [7], where a clustering and power allocation algorithm was also been proposed to reduce interference from other beams as well as from the other user sharing the BF vector.

There are several tough problems to provide reliable communication for HSR including that severe Doppler frequency shift, high penetration loss, outdated channel feedback information, frequent handover processes, different channel statistics. Various ways was proposed to overcome some of these problems. The high-penetration loss and large simultaneous group handover processes are significantly reduced with the two-hop network architecture, in which an access point (AP) installed in the train cabin serves as a mobile relay (MR) [2].

In this paper, to solve the problems mentioned above building on these advantages inherent in NOMA and multiuser BF systems, we propose a coordinated MIMO-NOMA system model to enhance the HSR rate and provide services for HSR and local users at the same time.

Compared to these existing works, the contributions of this paper are as follows:

– We consider the problem of providing services for HSR in MIMO-NOMA systems for the first time. Propose a new system model that can serve both HSR and local users and increase the rate of HSR.
– In the proposed system model, we consider both inter-cell interference and inter-cluster interference and the coordinated RZF precoding method is applied to eliminate them.
– We analyze the performance of proposed system, the proof of proposed model can improve the rate of HSR compared with MIMO-NOMA and MIMO-OMA is given.
– Simulation is performed to verify the theory. And simulation of the proposed program using RZF and ZF precoding is compared to demonstrate that RZF can compensate for noise inflation in the low signal-to-noise-ratio (SNR) regime.

The rest of the paper is organized as follow. In Sect. 2, we propose the system model of this paper. In Sect. 3, we describe the CRZF precoding scheme used in the paper. In Sect. 4, we provide the proof of performance comparison between MIMO-NOMA and MIMO-OMA. In Sect. 5, we perform simulation to verify theory. In Sect. 6, we conclude the report and discuss about the future work.

2 System Model

In this section, we introduce the system model, which includes the network model, the channel model and the transmission model.

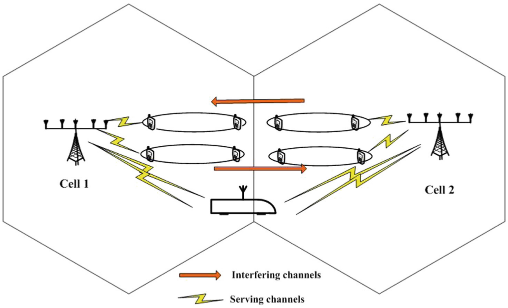

Fig. 1. Network model

2.1 Network Model

The system contains multiple cells, each cell has single base station (BS). Assuming that L cells cooperate to serve HSR, the BS of each cell serves U local users (moving speed <10 km/h, denoted by u = 1, 2, ..., U) and a passing HSR (moving speed >120 km/h denoted by user V). We consider a new downlink multi-BS cooperative MIMO-NOMA solution for serving both local users and HSR users. Each BS is equipped with N_t antennas. Each user is equipped with a single antenna. All the cells are interconnected via backhaul links assumed to be error free without delay. For HSR, we apply a two-hop architecture [8,9] to avoid frequent handovers and severe vehicle penetrative loss. The MR needs to reallocate the acquired resources to many users in the cabin. The MR referred to below all refer to the HSR. We consider the intra-cluster interference, inter-cluster interference and inter-cell interference at the same time, and analyze the performance of the proposed cooperative MIMO-NOMA solution. This paper uses two adjacent cells as an example for analysis, that is L = 2 as shown in the Fig. 1.

2.2 Channel Model

The local users and the MR experience the same kind of large-scale fading as they are in the same environment. Suppose user is located at a distance d from the BS, then the path loss of user is

$$L(d) = 10\alpha \log_{10}(d) \tag{1}$$

where α is the path loss exponent.

Small-scale fadings of local users and the MR are different. Suppose for local user u, u = 1, ..., U, the Doppler spread is zero. We consider a flat fading MIMO channel with N_t transmit antennas and single receive antennas. The timevarying channel at time t is represented by $1 \times N_t$ matrix $\mathbf{h_t}$. The entries of $\mathbf{h}_t$ are assumed to be independent identically distributed (i.i.d) and $h_{i,j} \sim \mathcal{CN}(0,1)(i = 1, 1 \leq j \leq N_t)$.

For the MR, to characterize the outdated CSI, the channel time variation is described by the first-order Markov process [10]

$$\mathbf{h}_t = \rho \mathbf{h}_{t-\tau} + \mathcal{K} \mathbf{\Xi}_t \tag{2}$$

where τ denotes the delay, ρ stands for the time correlation coefficient and $K = \sqrt{1-\rho^2}$. The term $\mathbf{\Xi}$ also has i.i.d entries and $\mathit{\Xi}_{i,j} \sim CN(0,1)$. And the temporal correlation ρ is defined as $\rho = E[\mathbf{H}_t \mathbf{H}_{t-\tau}^H]$. In Jake's model for simplicity $\rho(f_d \tau) = J_0(2\pi f_d \tau)$ [11], where $J_0(\cdot)$ is the zero-th order Bessel function of the first kind and f_d denotes the Maximum Doppler Frequency shift. Due to the outdated channel $\mathbf{h}_{t-\tau}$ is known at the transmitter instead of the true channel $\mathbf{h}_t$, therefore, we assume the feedback is given to the transmitter after the HSR receiver predicts the true channel state $\mathbf{h}_t$ according to the above formula, and assume that BS can obtain perfect CSI under this condition, so that the precoding of the transmitter is effective.

2.3 Transmission Model

To further improve the rate of HSR, each BS allocates more antennas and power resources to MR based on the cooperation of multiple base stations to provide services for MR. Based on the above analysis and combined with MIMO-NOMA system, we propose the following transmission model.

Local users of each cell are divided into $M_u = U/2$ clusters, M_u antennas of the base station are allocated to transmit the signals of local users in the same cluster, and N_v antennas are allocated to provide services for MR. In this case, the $N_v L$ antennas of the L BSs provide services for the MR to ensure the reliability of the HSR and increase the rate. In addition, for ease of analysis, we assume that there are two local users in each cluster, and actually it can be more than two. Let $N = (M_u + N_v)$, then the signal $\mathbf{x}_l \in N \times 1$ at the base station before precoding can be expressed as Eq. 3.

$$\mathbf{x}_l = \begin{bmatrix} x_{l,1} \\ \vdots \\ x_{l,M_u} \\ x_{l,M_u+1} \\ \vdots \\ x_{l,N} \end{bmatrix} = \begin{bmatrix} \sqrt{p_{l,1,1}} s_{l,1,1} + \sqrt{p_{l,1,2}} s_{l,1,2} \\ \vdots \\ \sqrt{p_{l,M_u,1}} s_{l,M_u,1} + \sqrt{p_{l,M_u,2}} s_{l,M_u,2} \\ \sqrt{p_{l,M_u+1,v}} s_{l,M_u+1,v} \\ \vdots \\ \sqrt{p_{l,N,v}} s_{l,N,v} \end{bmatrix} \tag{3}$$

Where $x_{l,n}$ represents the signal for the n-th cluster in the l-th cell, and $s_{l,n,k}$ represents the information bearer signal for the k-th local user in the n-th cluster in the l-th cell, $p_{l,n,k}$ represents the power of the k-th local user in the n-th cluster in the l-th cell, where $s_{l,v}$ represents the information bearer signal sent by the l-th base station to the HSR, and $p_{l,n,v}$ represents the power allocated by the n-th cluster to the HSR from the l-th BS. From Eq. 3, we can find that the signal sent by the BS to the local users is the superposition of two user signals in the cluster, and the signal sent to the MR is only the signal of HSR, which means that HSR occupy a whole cluster, so that they will not be influenced by the intra-cluster interference. In addition, the base station allocates N_v antennas exclusively for MR to increase diversity gain. Since the transmission signal vector of the base station is processed by the precoding matrix and then transmitted to each user through the wireless channel, the transmission signal processed by the precoding matrix can be further expressed as

$$\widetilde{\mathbf{x}}_l = \mathbf{G}_l \mathbf{x}_l \tag{4}$$

Without loss of generality, we focus on the local user and the MR served by the l-th BS and adjacent BS. The $1 \times N_t$ channel vector between the k-th local user n-th cluster in the l-th cell and the serving BS is given by $\mathbf{h}_{l,l,n,k}$. The interfering channel vector between the k-th user n-th cluster in the l-th cell and the z-th interfering BS is denoted by $\mathbf{h}_{z,l,n,k}$, where $z \neq l$. The downlink received signal at the k-th user n-th cluster in the l-th cell is given by

$$\mathbf{y}_{l,n,k} = \mathbf{h}_{l,l,n,k} \mathbf{G}_l \mathbf{x}_l + \sum_{\substack{z=1 \\ z \neq l}}^{L} \mathbf{h}_{z,l,n,k} \mathbf{G}_z \mathbf{x}_z + n_{l,n,k} \tag{5}$$

Where the $\mathbf{h}_{z,l,n,k}$ is the result of the combined effect of path loss and small-scale fading. $n_{l,n,k}$ is an additive Gaussian white noise with a mean value of 0 variance σ_n^2.

According to the cooperative MIMO-NOMA system model, the signal received by MR serviced by adjacent BSs can be expressed as

$$\mathbf{y}_v = \sum_{l=1}^{L} \mathbf{h}_{l,v} \mathbf{G}_l \mathbf{x}_l + n_{l,v} \tag{6}$$

The n-th column of $\mathbf{G}_l$ is shown as $\mathbf{g}_{l,n} \in N_t \times 1$, represents the precoding vector serving the n-th cluster generated by the l-th base station, and $\mathbf{g}_{l,v} \in N_t \times 1$ represents the precoding vector serving the MR generated by the l-th base station. It is worth noting that the superimposed signals sent by the base station to local users in different clusters are different, therefore, the precoding vectors are different. And the signals sent to HSR users are the same, therefore, the precoding vectors are the same. Then $\mathbf{G}_l$ can be expressed as

$$\mathbf{G}_l = [\mathbf{g}_{l,1}, \cdots, \mathbf{g}_{l,N}] = [\mathbf{g}_{l,1}, \cdots, \mathbf{g}_{l,M_u}, \mathbf{g}_{l,v}, \cdots, \mathbf{g}_{l,v}] \tag{7}$$

The signal models of the local users and MR above mentioned can be represented as:

$$y_{l,n,k} = \mathbf{h}_{l,l,n,k}\mathbf{g}_{l,n}x_{l,n} + \sum_{\substack{m=1\\m\neq n}}^{N}\mathbf{h}_{l,l,n,k}\mathbf{g}_{l,m}x_{l,m} + \sum_{\substack{z=1\\z\neq l}}^{L}\sum_{n=1}^{N}\mathbf{h}_{z,l,n,k}\mathbf{g}_{z,n}x_{z,n} + n_{l,n,k} \tag{8}$$

$$y_v = \sum_{l=1}^{L}\sum_{m=M_u+1}^{N}\mathbf{h}_{l,v}\mathbf{g}_{l,v}\sqrt{p_{l,m,v}}s_{l,v} + \sum_{l=1}^{L}\sum_{m=1}^{M_u}\mathbf{h}_{l,v}\mathbf{g}_{l,m}x_{l,m} + n_v \tag{9}$$

Each user in the cluster will be interfered by other users in the cluster. According to the NOMA principle, the strong user in the cluster can eliminate the interference of the weak user by performing SIC, the weak user directly demodulates the received signal by treating the strong user signal as interference. For the HSR represented by Eq. 9, since there is no intra-cluster interference, the HSR only needs to eliminate the interference of local users in other clusters through precoding. The specific cooperative precoding processing will be introduced in Sect. 3.

The channel state is very important for implementing NOMA. According to our hypothesis, the first user in each cluster is a strong user, and the second user is a weak user, so the channel gain is sorted as follows

$$\mathbf{h}_{l,l,n,1} \geq \mathbf{h}_{l,l,n,2} \tag{10}$$

According to the NOMA principle, the power distribution of users in a cluster are as follows

$$p_{l,n,1} \leq p_{l,n,2} \tag{11}$$

Based on the above signal model, the signal-to-interference-plus-noise-ratio (SINR) for the weak user in the n-th cluster is given by Eq. 12.

$$SINR_{l,n,2} = \frac{|\mathbf{h}_{l,l,n,2}\mathbf{g}_{l,n}|^2 p_{l,n,2}}{|\mathbf{h}_{l,l,n,2}\mathbf{g}_{l,n}|^2 p_{l,n,1} + \sum\limits_{\substack{m=1\\m\neq n}}^{N}|\mathbf{h}_{l,l,n,2}\mathbf{g}_{l,m}|^2 p_{l,m} + \sum\limits_{\substack{z=1\\z\neq l}}^{L}\sum\limits_{m=1}^{N}|\mathbf{h}_{z,l,n,2}\mathbf{g}_{z,m}|^2 p_{z,m} + \sigma^2} \tag{12}$$

where $p_{z,m}$ represents the total power allocated to m-th cluster in z-th cell. The strong user in the n-th cluster needs to decode the weak user signal with poor channel status before decoding his own signal. The weak user signal will be demodulated at the strong user with the SINR given in Eq. 13.

If the signal of the weak user in the n-th cluster is successfully demodulated, that is $log(1 + SINR_{l,n,1}^{l,n,2}) > R_{l,n,2}$, where $R_{l,n,2}$ is given by

$$SINR_{l,n,1}^{l,n,2} = \frac{|\mathbf{h}_{l,l,n,1}\mathbf{g}_{l,n}|^2 p_{l,n,2}}{|\mathbf{h}_{l,l,n,1}\mathbf{g}_{l,n}|^2 p_{l,n,1} + \sum\limits_{\substack{m=1\\m\neq n}}^{N}|\mathbf{h}_{l,l,n,1}\mathbf{g}_{l,m}|^2 p_{l,m} + \sum\limits_{\substack{z=1\\z\neq l}}^{L}\sum\limits_{m=1}^{N}|\mathbf{h}_{z,l,n,1}\mathbf{g}_{z,m}|^2 p_{z,m} + \sigma^2} \tag{13}$$

$$R_{l,n,2} = log(1+\frac{|\mathbf{h}_{l,l,n,2}\mathbf{g}_{l,n}|^2 p_{l,n,2}}{|\mathbf{h}_{l,l,n,2}\mathbf{g}_{l,n}|^2 p_{l,n,1} + \sum\limits_{\substack{m=1\\m\neq n}}^{N} |\mathbf{h}_{l,l,n,2}\mathbf{g}_{l,m}|^2 p_{l,m} + \sum\limits_{\substack{z=1\\z\neq l}}^{L}\sum\limits_{m=1}^{N} |\mathbf{h}_{z,l,n,2}\mathbf{g}_{z,m}|^2 p_{z,m} + \sigma^2}) \tag{14}$$

Then the strong user in the n-th cluster will subtract the weak user signal from the received signal. At this time, the strong user's received signal in the l-th cluster can be expressed as

$$\begin{aligned} y_{l,n,1} = {} & \mathbf{h}_{l,l,n,k}\mathbf{g}_{l,n}\sqrt{p_l, n, 1}s_{l,n,1} + \sum_{\substack{m=1\\m\neq n}}^{M_u} \mathbf{h}_{l,l,n,k}\mathbf{g}_{l,m}x_{l,m} \\ & + \sum_{m=M_u+1}^{N} \mathbf{h}_{l,l,n,k}\mathbf{g}_{l,m}x_{l,v} + \sum_{\substack{z=1\\z\neq l}}^{L}\sum_{m=1}^{N} \mathbf{h}_{z,l,m,k}\mathbf{g}_{z,m}x_{z,m} + n_{l,n,1} \end{aligned} \tag{15}$$

Thus it's received SINR can be expressed as

$$SINR_{l,n,1} = \frac{|\mathbf{h}_{l,l,n,1}\mathbf{g}_{l,n}|^2 p_{l,n,1}}{\sum\limits_{\substack{m=1\\m\neq n}}^{N} |\mathbf{h}_{l,l,n,1}\mathbf{g}_{l,m}|^2 p_{l,m} + \sum\limits_{z=1,z\neq l}^{L}\sum\limits_{m=1}^{N} |\mathbf{h}_{z,l,n,1}g_{z,m}|^2 p_{z,m} + \sigma^2} \tag{16}$$

For HSR, the SINR expression is as follows

$$SINR_v = \frac{\sum\limits_{z=1}^{L}\sum\limits_{m=M_u+1}^{N} |\mathbf{h}_{z,v}\mathbf{g}_{z,v}|^2 p_{z,m,v}}{\sum\limits_{z=1}^{L}\sum\limits_{m=1}^{M_u} |\mathbf{h}_{z,v}\mathbf{g}_{z,m}|^2 p_{z,m} + \sigma^2} \tag{17}$$

3 Coordinated Regularized Zero Forcing Precoding

In this paper we use Coordinated Regularized Zero Forcing precoding (CRZF) to design the downlink precoding vectors. The CRZF means that the BS in each cell not only applies RZF to the channels of the users in own cell but also considers its interfering channels to users in the adjacent cell, thus mitigating or suppressing the interference it caused to those users.

It is worth noting that in the MIMO-NOMA model we proposed, the channels processed by each BS includes the channels of local users that is divided into M_u clusters, the interfering channels from the BS to other cell users, and the channels from the BS to the MR. That is to say, each BS processes the interference of $M_uL + 1$ users using the precoding matrix.

The transmitter needs to decide whether the channel of the strong user or the channel of the weak user in the same cluster is used to generate the precoding vector, the selected user can completely eliminate the interference from other clusters and the other users whose channel is not used to generate the precoding vector cannot. In order to correctly implement SIC, we select strong users with better channel state to generates the precoding vector.

Let $\hat{\mathbf{h}}_{l,z,n}$ denote the estimation of the CSI of the strong user located at n-th cluster in z-th cell acquired by the l-th BS and used to generate precoding vector. Consider the Doppler shift of HSR, the MR receiver uses Eq. 2 to predict the channel state after delay, which includes precoding matrix generation and information transmission delay, and returns it to BS, such that the BS can precode for the real MR channel. By the same way, the CSI of MR acquired by the l-th BS is $\hat{\mathbf{h}}_{l,v}$. Note that the channel estimation here refers to small-scale fading, and the channel estimation available for the l-th BS can be expressed as follows:

$$\hat{\mathbf{H}}_l = [\mathbf{T}_1, \cdots, \mathbf{T}_z, \cdots, \mathbf{T}_L, \cdots, \mathbf{T}_v]^H \in \mathbb{C}^{(LM_u+1)\times N_t} \tag{18}$$

Where $\mathbf{T}_z = \left[\hat{\mathbf{h}}_{l,z,1}^H, \cdots, \hat{\mathbf{h}}_{l,z,M_u}^H\right]$ represents the estimate of CSI for all clusters in the z-th cell acquired by the l-th BS. Considering the CRZF precoding scheme, the precoding matrix is:

$$\hat{\mathbf{G}}_l = \hat{\mathbf{H}}_l^H \hat{\mathbf{W}}_l / \sqrt{\xi_l} \tag{19}$$

where, $\hat{\mathbf{W}}_l = \left(\hat{\mathbf{H}}_l \hat{\mathbf{H}}_l^H + \alpha_l \mathbf{I}_{(LM_u+1)}\right)^{-1} \in \mathbb{C}^{(LM_u+1)\times(LM_u+1)}$, the regularization parameter for the l-th BS is denoted by α_l, ξ_l is a normalization scalar to fulfill the power constraint which given below:

$$\xi_l = \| \hat{\mathbf{W}}_l \|_F^2 / N_t. \tag{20}$$

The precoding vector generated by the l-th BS and transmitted to the n-th cluster of l-th cell is the n-th column of $\mathbf{G}_l$:

$$\mathbf{g}_{l,n} = \hat{\mathbf{g}_{l,n}} / \sqrt{\xi_l} \tag{21}$$

where $\hat{\mathbf{g}}_{l,n}$ is the n-th column of $\hat{\mathbf{H}}_l^H \hat{\mathbf{W}}_l$. The precoding vector generated by the l-th BS and sent to HSR is the $M_u + 1$ column of $\mathbf{G}_l$:

$$\mathbf{g}_{l,v} = \hat{\mathbf{g}_{l,v}} / \sqrt{\xi_i} \tag{22}$$

where $\hat{\mathbf{g}}_{l,v}$ is the $LM_u + 1$ column of $\hat{\mathbf{H}}_l^H \hat{\mathbf{W}}_l$.

4 System Performance Analysis

This section first presents the capacity performance analysis of the proposed cooperative MIMO-NOMA system serving both high-speed railway and local users, including the rates of local strong user, weak user, and HSR, and total system capacity performance analysis. Then, we give a comparison of the HSR rate in the proposed system model and the HSR rate that can be provided in the traditional MIMO-NOMA and MIMO-OMA schemes. We prove that the rate of HSR of the proposed scheme is strictly better than the rate that the traditional MIMO-NOMA scheme can provide for HSR, that is to say, the proposed system model for HSR and local users can effectively improve the rate of HSR at almost no loss of local user rate.

4.1 Performance of the Proposed Solution

According to the Eqs. 12 and 16 the strong user rate and the weak user rate in the n-th cluster in the l-th cell of the proposed system model are given by:

$$R_{l,n,1} = \log_2(1 + SINR_{l,n,1}) \tag{23}$$

$$R_{l,n,2} = \log_2(1 + SINR_{l,n,2}) \tag{24}$$

The rate of HSR R_v:

$$\log\left(1 + SINR_v\right) = \log(1 + \frac{\sum\limits_{z=1}^{L}\sum\limits_{m=M_u+1}^{N} \left|\mathbf{h}_{z,v}\mathbf{g}_{z,v}\right|^2 p_{z,m,v}}{\sum\limits_{z=1}^{L}\sum\limits_{m=1}^{M_u} \left|\mathbf{h}_{z,v}\mathbf{g}_{z,m}\right|^2 P_{z,m} + \sigma^2}) \tag{25}$$

The total rate of local users in cell l is:

$$R_l = \sum_{n=1}^{M_u} \left(R_{l,n,1} + R_{l,n,2}\right) \tag{26}$$

The total rate of local users and high-speed railway in cell l is: $R_l + R_v$. The total rate of local users for the entire system is:

$$\sum_{l=1}^{L} R_l = \sum_{l=1}^{L}\sum_{n=1}^{N} \left(R_{l,n,1} + R_{l,n,2}\right) \tag{27}$$

4.2 Comparison with MIMO-NOMA

In this part, we give a comparison of the HSR rate in the proposed system scheme under the same resource allocation and the HSR rate that can be provided in the traditional MIMO-NOMA, which proves that the rate of proposed scheme is strict better than the rate of the traditional MIMO-NOMA solution for HSR. According to the principle of proposed model above, it is assumed that the power allocated to MR from each antenna serving for MR is $p_{l,n,v}$. Then the total power allocated by a BS to the HSR is $N_v p_{l,n,v}$. Then it is also assumed that the same power allocated to the MR in the traditional MIMO-NOMA scheme.

In the traditional MIMO-NOMA system, the rate that can be provided to HSR is given by Eq. 28.

$$R_{con\_v}^{NOMA} = log(1 + \frac{\left|\mathbf{h}_{l,v}\mathbf{g}_{l,n}\right|^2 p_{l,n,v}}{\sum\limits_{\substack{m=1 \\ m \neq n}}^{N} \left|\mathbf{h}_{l,v}\mathbf{g}_{l,m}\right|^2 p_{l,m} + \left|\mathbf{h}_{l,v}\mathbf{g}_{l,n}\right|^2 p_{l,n,1} + \sum\limits_{\substack{z=1 \\ z \neq l}}^{L}\sum\limits_{m=1}^{N} \left|\mathbf{h}_{z,v}\mathbf{g}_{z,m}\right|^2 p_{z,m} + \sigma^2}) \tag{28}$$

Since it is difficult to completely eliminate inter-cluster interference. Then $\sum_{m=1,m\neq n}^{N}|\mathbf{h}_{l,v}\mathbf{g}_{l,m}|^2 p_{l,m} > 0$ and $\sum_{\substack{z=1\\z\neq l}}^{L}\sum_{m=1}^{N}|\mathbf{h}_{z,v}\mathbf{g}_{z,m}|^2 p_{z,m} > 0$. Then there are HSR rate:

$$R_{con\_v}^{NOMA} < \log(1+\frac{|\mathbf{h}_{l,v}\mathbf{g}_{l,n}|^2 N_v p_{l,n,v}}{|\mathbf{h}_{l,v}\mathbf{g}_{l,n}|^2 p_{l,n,1}+\sigma^2}) \tag{29}$$

For the rate of HSR in our proposed scheme Eq. 25, since the precoding matrix is generated by directly utilizing the channel of the HSR, and the Doppler shift of the HSR is considered, the generated precoding vector can completely eliminate the inter-cluster interference. Then $\sum_{l=1}^{L}\sum_{m=1}^{M_u}|\mathbf{h}_{l,v}\mathbf{g}_{l,m}|^2 p_{l,m} = 0$. The high-speed railway rate can be written as below

$$\log(1+\frac{\sum_{l=1}^{L}\sum_{m=M_u+1}^{N}|\mathbf{h}_{l,v}\mathbf{g}_{l,v}|^2 p_{l,m,v}}{\sigma^2}). \tag{30}$$

For equal power comparison, assuming L = 1, each antenna is assigned the same power, then

$$\begin{aligned}&\log(1+\frac{\sum_{m=M_u+1}^{N}|\mathbf{h}_{l,v}\mathbf{g}_{l,v}|^2 p_{l,m,v}}{\sigma^2})\\&\quad=\log(1+\frac{|\mathbf{h}_{l,v}\mathbf{g}_{l,v}|^2 N_v p_{l,m,v}}{\sigma^2}) > \log(1+\frac{|\mathbf{h}_{l,v}\mathbf{g}_{l,n}|^2 N_v p_{l,n,v}}{|\mathbf{h}_{l,v}\mathbf{g}_{l,n}|^2 p_{l,n,1}+\sigma^2})\end{aligned} \tag{31}$$

$$R_v > R_{con\_v}^{NOMA} \tag{32}$$

4.3 Compared with MIMO-OMA Scheme

A scheme based on conventional MIMO-OMA can be described as follows. The MIMO-OMA transmission consists of K time slots. During each time slots, M users one from each cluster, are served simultaneously based on the same manner as described for MIMO-NOMA, as a result, during the first time slot, the 1-st user in the n-th cluster will served, In this way, the rate available to high-speed railway is given by

$$R_v^{OMA} = \frac{1}{2}\log(1+\frac{|\mathbf{h}_{l,v}\mathbf{g}_{l,v}|^2 N_v p_{l,v}}{\sum_{\substack{m=1\\m\neq n}}^{N}|\mathbf{h}_{l,v}\mathbf{g}_{l,m}|^2 p_{l,m,1}+\sum_{\substack{z=1\\z\neq l}}^{L}\sum_{m=1}^{N}|\mathbf{h}_{z,v}\mathbf{g}_{z,m}|^2 p_{z,m}+\sigma^2}) \tag{33}$$

It is worth noting that the 1/2 in front of (33) is because a conventional MIMO-OMA system with N transmit antennas requires two time slots to support 2M users, while the proposed cooperated MIMO-NOMA system with N transmit antennas can support 2M users during a single time slot. Similarly, inter-cluster interference can be assumed $\sum\limits_{\substack{m=1\\m\neq n}}^{N}\left|\mathbf{h}_{l,n,1}\mathbf{g}_{l,m}\right|^2 p_{l,m,1}=0$ and inter-cell interference are $\sum\limits_{\substack{z=1\\z\neq l}}^{L}\sum\limits_{m=1}^{N}\left|\mathbf{h}_{z,v}\mathbf{g}_{z,m}\right|^2 p_{z,m}=0$, then:

$$R_v^{OMA}=\frac{1}{2}\log(1+\frac{\left|\mathbf{h}_{l,v}\mathbf{g}_{l,v}\right|^2 N_v P_{l,v}}{\sigma^2}) \tag{34}$$

$$R_v=\log(1+\frac{\sum\limits_{m=M_u+1}^{N}\left|\mathbf{h}_{l,v}\mathbf{g}_{l,v}\right|^2 p_{l,m,v}}{\sigma^2})=\log(1+\frac{\left|\mathbf{h}_{l,v}\mathbf{g}_{l,v}\right|^2 N_v p_{l,m,v}}{\sigma^2})>R_v^{OMA} \tag{35}$$

In summary, we prove that in the case of assigning the same system resources to HSR, the rate of HSR in the proposed system model is strictly greater than that of traditional MIMO-NOMA and MIMO-OMA. So we can say that the proposed system model for high-speed railway and local users can effectively improve the rate of high-speed rail users.

5 Numerical Results

In this section, we present the simulation result of the proposed system and compare it with traditional MIMO-OMA and MIMO-OMA schemes. Figure 2 compares the HSR's maximum achievable rate achieved by proposed MIMO-NOMA scheme to that achieved by MIMO-NOMA and MIMO-OMA scheme for varying transmit power. For proposed scheme Fig. 2 considers the case in which there are four local users grouped into two clusters, with two local users in each cluster, and a MR. We can see that the HSR rate of proposed scheme is always higher than the other two and the gap become lager as the transmit power increase. Figure 2 confirms the accuracy of the analytical results developed in Sect. 5 that proposed MIMO-NOMA can outperform MIMO-NOMA and MIMO-OMA, particularly at high SNR.

Figure 3 demonstrates the rate of the HSR, strong user and weak user in the proposed MIMO-NOMA system. As can be seen from the figure, the rate of HSR is higher than that of the strong user at the same distance to base station, because the number of antennas serving high-speed rail users is more than that of strong users, and the high-speed rail users are served by two BSs simultaneously, which proves that our proposed MIMO-NOMA scheme is effective for increasing the speed of high-speed rail users.

Figure 4 Shows the total cell capacity achieved by proposed MIMO-NOMA, traditional MIMO-NOMA and MIMO-OMA scheme when the number of users and transmit antennas are different. From Fig. 4, it can be found that MIMO-NOMA scheme also absolutely outperforms MIMO-OMA in system capacity. In addition, one can also find that the total cell capacity of proposed scheme is slightly lower than that of the MIMO-NOMA solution with the growth of

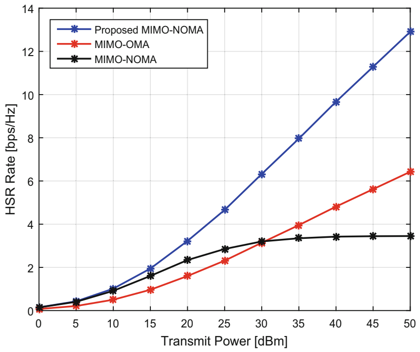

Fig. 2. HSR rate of proposed MIMO-NOMA, MIMO-NOMA and MIMO-OMA

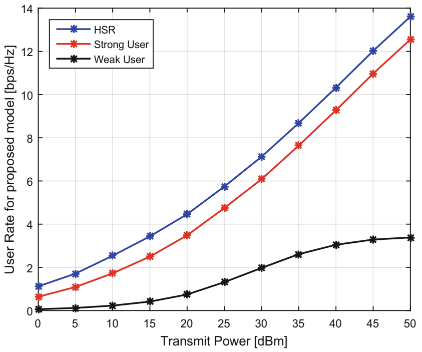

Fig. 3. Rate of strong user, weak user and HSR in proposed MIMO-NOMA scheme

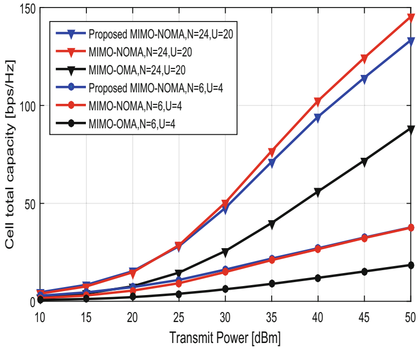

Fig. 4. Cell total capacity in our proposed system.

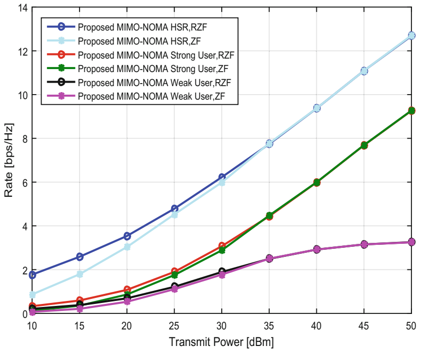

Fig. 5. HSR rate with RZF and ZF is applied in proposed system.

the number of transmit antennas, it is because that the BS can allocate more antennas to MR to enhance the rate of HSR when antennas increase, which result of the total cell capacity a little decrease. Obviously it is worthwhile to sacrifice the total capacity for a huge increase in HSR rate.

Figure 5 shows the rate of HSR when RZF and ZF is applied in proposed system which well prove the compensation effect of RZF in the low SNR regime.

6 Conclusion

In this paper, we propose a novel system model to provide service for HSR and local users at the same time in downlink MIMO-NOMA system. The CRZF precoding is applied to eliminate inter-cluster and inter-cell interference with considering Doppler shift of HSR and delay of transmission CSI when generate precoding matrix. We theoretically prove that the high-speed rate in the proposed scheme is strictly superior to the MIMO-NOMA and MIMO-OMA schemes. At last, simulation is performed to prove the theoretical derivation in the paper.

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