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Reflective Group Number Based Index Modulation for Intelligent Reflecting Surface Assisted Wireless Communications

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Abstract—Thanks to the characteristic that the signals can be reflected to a pre-defined orientation, intelligent reflecting surface (IRS) is becoming a promising technology to improve the efficiency of wireless communications. In this paper, a reflective group number based index modulation (RGNIM) scheme is proposed by exploiting the activating states of the reflecting elements of the IRS, where different group number of activated IRS elements can carry additional information in the reflective domain. The bit error ratio (BER) performance is then theoretically analysed under the imperfect channel estimation by adopting the maximum likelihood (ML) detection approach. Simulation results validate and evaluate the BER performance of the RGNIM assisted system, which also demonstrate that RGNIM scheme outperforms the traditional IRS aided index modulation scheme.

Index Terms—Reflective group number based index modulation (RGNIM), intelligent reflecting surface (IRS), modulation scheme

I. INTRODUCTION

In the era of 6G, more and more wireless devices are swarming into the modern cities, which is posing a challenge on the spectrum efficiency of the wireless communication network [1]. The limited communication resources result in a more crowded network, where the interference among network users is becoming more serious. The quality of service (QoS) of the wireless communication, such as the throughput and the latency performance, is consequently degraded. Moreover, due to the rapid development of modern cities, buildings are becoming more and more dense. Hence, there are rarely line-of-sight (LOS) wireless communication links between base station (BS) and devices. The inevitable channel fading may seriously degrade the communication efficiency of the network.

Intelligent reflecting surface (IRS) [2] [3] has been studied for many years, which is considered as a promising technology in the future 6G. An IRS comprises of lots of reflecting elements, each of which is capable of reflecting wireless

signals with an adjustable phase shift. With the aid of IRS, the above-mentioned problem can be readily relieved. For instance, an IRS can be implemented on the wall of a building, which may eliminate blind spots and provide direct communication links between the BS and devices. The IRS is also capable of approximately adjusting the reflecting phase shift to reshape the received signals at the receiver and reduce the interference caused by other devices.

Plenty of works have focused on the design of the IRS assisted wireless communication system. Pan *et. al* [4] provided a comprehensive overview of recent advances on IRS-aided wireless systems from the signal processing perspective, including channel estimation and transmission design. Zhang *et. al* [5] proposed two deployment strategies of IRS, namely distributed deployment and centralized deployment, while the capacity regions of both the deployments were derived. Mei *et. al* [6] studied a wireless network aided by multiple IRSs, where the average-signal-to-average-interference-plus-noise ratio (ASAINR) is analysed to evaluate the system performance. Moreover, simultaneous wireless information and power transfer (SWIPT) can also benefit from IRS [7], while the energy harvesting efficiency is largely improved.

Apart from the assistance of the IRS, index modulation [8] is another approach to improve the spectrum efficiency. With the aid of index modulation, additional information can be carried by activating different indices of the communication resources, such as antennas [9], time slots [10] and carriers [11]. Index modulation can also be adopted in an IRS assisted system. Basar *et. al* [12] studied the IRS aided space-shift-keying (SSK) and spatial modulation (SM) scheme, while the bit error probability of both schemes were analysed theoretically. Ma *et. al* [13] studied the IRS aided SM by utilizing both the transmit and receive antennas indices, while the antennas selection algorithm is designed for the sake of improving

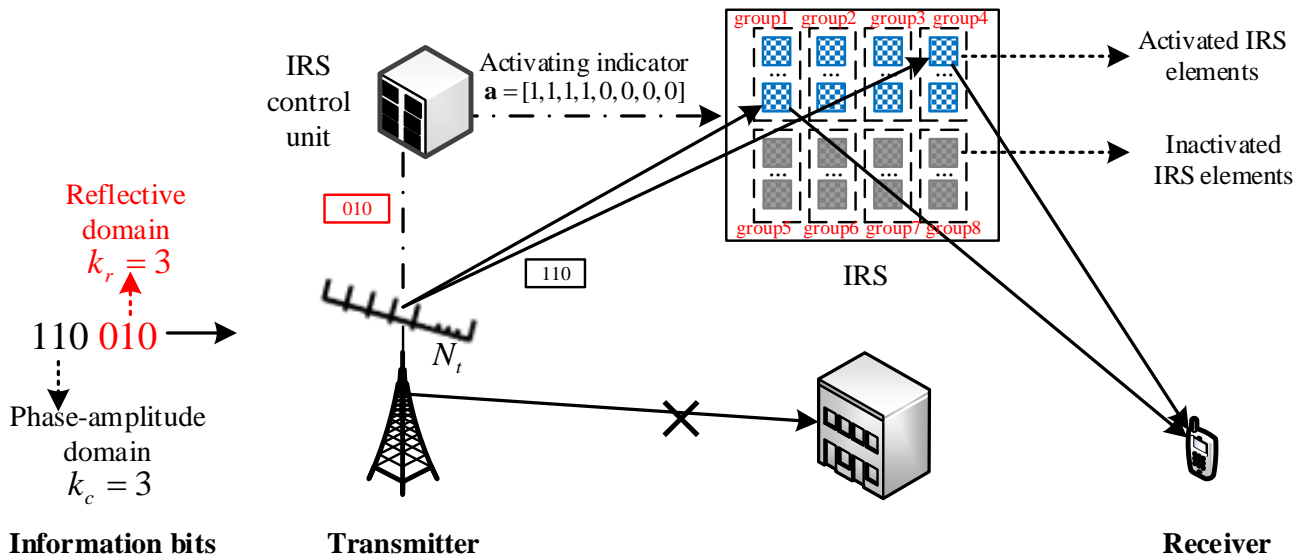


Fig. 1. System model of the RIM assisted system.

the average BER performance. Yuan *et. al* [14] proposed a receive quadrature reflecting modulation scheme. The IRS is partitioned to reflect the in-phase and quadrature component of signals, while each half forms a beam to a receive antenna whose index carries the bit information.

In the IRS assisted system, all the reflecting elements can be activated or de-activated for the reflection of the wireless signals, while different activation states of the reflecting elements result in different receive signal phase or strength. Motivated by this, we are able to modulate additional information on different activated indices of reflecting elements, namely reflective index modulation (RIM). By detecting the receive power of the wireless signal, the receiver is able to recover the information in the reflective domain. With the aid of RIM, the advantage of IRS can be fully exploited. Compared to conventional modulation schemes such as M -QAM, only a lower order modulation scheme in the phase-amplitude domain is required for achieving the same data rate. Up to now, there are less works studying RIM in an IRS assisted system. Hussein *et. al* [15] firstly proposed the RIM scheme in a 5G system, where all the reflecting elements are separated into groups, while only one different group is de-activated when different reflective information is transmitted. However, since the activated number of IRS elements are always the same, it will be difficult to recover the information in the reflective domain. Therefore, in order to reduce the demodulation errors in the reflective domain and further reduce the total BER, we propose a reflective group number based index modulation (RGNIM) scheme, where different reflective information corresponds to different group number of the

activated IRS elements. Our contribution is then summarised as follows:

- We propose a novel RGNIM scheme by exploiting the activation states of the reflecting elements of the IRS. Additional information in the reflective domain is carried by activating different group number of reflecting elements. The fundamental principle of RGNIM as well as the demodulation approach are also provided.
- The bit error ratio (BER) performance of the RGNIM assisted system is theoretically analysed under the imperfect channel estimation.
- The BER performance of the RGNIM assisted system is validated and evaluated by the Monte Carlo based simulation.

Notations: In this paper, \mathbb{C} denotes the set of complex numbers, $\mathcal{R}(\cdot)$ represents the operation of taking the real part of a complex number. $|x|$ represents the absolute value of a complex number x , while $\|\mathbf{x}\|$ represents the 2-norm of the vector \mathbf{x} . Moreover, x^* denotes the conjugation of the complex number x .

II. SYSTEM MODEL

We study a RGNIM assisted point-to-point system, which consists of a transmitter, a receiver and a IRS, as shown in Fig. 1. The transmitter is equipped with N_t antennas, while the receiver is equipped with a single antenna due to the limitation of the hardware size. The IRS comprises N_s low-cost reflecting elements, which are capable of manipulating and modifying the incoming electromagnetic waves phases. Each element can be switched between the active and the inactive states. In the

inactive state, the element would not reflect wireless signals. A control unit is connected to the IRS for the activation and deactivation of all the reflecting elements. It's assumed that the direct communication link between the transmitter and the receiver does not exist, due to the shelter of buildings or trees.

The block fading channels are assumed between the transmitter and the IRS as well as between the IRS and the receiver, which are denoted as $\mathbf{H}_{ts} \in \mathbb{C}^{N_s \times N_t}$ and $\mathbf{h}_{sr} \in \mathbb{C}^{1 \times N_s}$, respectively. Similar to the assumption in [16], the channel state information (CSI) \mathbf{H}_{ts} is perfect, while \mathbf{h}_{sr} is assumed to be imperfect, which can be expressed as

$$\mathbf{h}_{sr} = \rho \hat{\mathbf{h}}_{sr} + \sqrt{1 - \rho^2} \Delta \mathbf{h}, \quad (1)$$

In Eq.(1), ρ is the channel estimation accuracy parameter, $\hat{\mathbf{h}}_{sr}$ represents the estimated CSI between the IRS and the receiver, $\Delta \mathbf{h}$ represents the channel estimation error, which is independent with $\hat{\mathbf{h}}_{sr}$. The elements in $\Delta \mathbf{h}$ are independent with each other and are Gaussian distributed having the variance of $\sigma_h^2 = d_{sr}^{-\alpha}$, where d_{sr} is the distance between the IRS and the receiver and α is the pathloss exponent. Note that when $\rho = 1$, \mathbf{h} is perfectly estimated. The IRS phase shifter is denoted as

$$\Phi = \begin{bmatrix} \beta_1 e^{j\theta_1} & 0 & \cdots & 0 \\ 0 & \beta_2 e^{j\theta_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \beta_{N_s} e^{j\theta_{N_s}} \end{bmatrix}, \quad (2)$$

where β_i, θ_i are the reflecting magnitude and the phase response of the i -th IRS element, respectively.

A. Fundamental Principle of RGNIM

In the RGNIM assisted system, the data information is not only modulated in the conventional phase-amplitude domain, but also in the reflective domain:

- *Phase-amplitude domain.* Conventional modulation schemes such as M -QAM, M -PSK are conceived for the modulation in the phase-amplitude domain. Denoting the modulation order as M , $k_c = \log_2 M$ bits can be delivered during each transmission.
- *Reflective domain.* All the reflecting elements are separated into L groups, while each group has $N_l = N_s/L$ reflecting elements. The modulation scheme in the reflective domain is named as L -RGNIM. The data information in the reflective domain is carried by activating different numbers of reflecting element groups. The j -th IRS activating pattern is denoted as a indicator $\mathbf{a}_j = [a_{j,1}, a_{j,2}, \cdots, a_{j,L}]$, where $a_{j,l} = 1 (1 \leq l \leq j)$ indicates that the reflecting elements in the l -th group are activated and $a_{j,l} = 0 (j < l \leq L)$ otherwise. Since there are totally L different IRS activating patterns, $k_r = \log_2 L$ bits can be delivered during each transmission. The conventional

TABLE I
MODULATION PRINCIPLE OF 8-RGNIM.

| IRS pattern index | Reflective information bits | Activated group number | Activating indicator \mathbf{a} |
|-------------------|-----------------------------|------------------------|-----------------------------------|
| 1 | 000 | 1 | [1,0,0,0,0,0,0,0] |
| 2 | 001 | 2 | [1,1,0,0,0,0,0,0] |
| 3 | 011 | 3 | [1,1,1,0,0,0,0,0] |
| 4 | 010 | 4 | [1,1,1,1,0,0,0,0] |
| 5 | 110 | 5 | [1,1,1,1,1,0,0,0] |
| 6 | 111 | 6 | [1,1,1,1,1,1,0,0] |
| 7 | 101 | 7 | [1,1,1,1,1,1,1,0] |
| 8 | 100 | 8 | [1,1,1,1,1,1,1,1] |

Gray mapping rule is conceived for modulating the reflective information as the IRS activating indicator \mathbf{a} . TABLE I exemplifies the 8-RGNIM modulation principle in the reflective domain.

The transmitter should firstly deliver the reflective information to the IRS control unit, which then determines the activating states of all the reflecting elements during the current data transmission. It's assumed that the reflective information can be received at the IRS control unit without errors so that the IRS can be controlled perfectly. By jointly exploiting the phase-amplitude domain and the reflective domain, $k = k_c + k_r$ bits can be delivered during each transmission.

B. Signal model

Without loss of generality, it's assumed that M -QAM modulation scheme is conceived in the phase-amplitude domain, where the modulated baseband symbol is denoted as $b_m (m = 1, \cdots, M)$. According to [17], the conventional modulated symbol b_m can be expressed as $b_m = A_{I,m} + jA_{Q,m}$, where $A_{I,m}$ and $A_{Q,m}$ are the in-phase and quadrature amplitude of b_m , respectively. Given the average transmit power P_s , the amplitude set of $A_{I,m}$ and $A_{Q,m}$ is expressed as $(A_{I,m}, A_{Q,m}) \in \sqrt{\frac{3P_s}{2(M-1)}} \{1 - \sqrt{M}, 3 - \sqrt{M}, \cdots, \sqrt{M} - 3, \sqrt{M} - 1\}$, while the minimum Euclidean distance between the constellation point is $\xi = 2\sqrt{\frac{3P_s}{2(M-1)}}$.

The joint modulated symbol by considering M -QAM and L -RGNIM is expressed as $s_{m,j}$, when the symbol b_m is transmitted and the j -th IRS activating pattern \mathbf{a}_j works. In the j -th IRS activating pattern, only the first j groups of reflecting elements are activated, while the corresponding IRS phase shifter matrix Φ_j is expressed as

$$\Phi_j = \Phi * \begin{bmatrix} \mathbf{I}_{jN_l \times jN_l} & \mathbf{0}_{jN_l \times (L-j)N_l} \\ \mathbf{0}_{(L-j)N_l \times jN_l} & \mathbf{0}_{(L-j)N_l \times (G-j)N_l} \end{bmatrix}, \quad (3)$$

where $\mathbf{I}_{jN_l \times jN_l}$ is the identity matrix having the size of jN_l .

When the joint modulated symbol $s_{m,j}$ is transmitted, the

received signal $y_{m,j}$ in the baseband can be expressed as

$$\begin{aligned} y_{m,j} &= \mathbf{h}_{sr} \Phi_j \mathbf{H}_{ts} \mathbf{w} b_m + z \\ &= \rho \hat{\mathbf{h}}_{sr} \Phi_j \mathbf{H}_{ts} \mathbf{w} b_m + \sqrt{1 - \rho^2} \Delta \mathbf{h} \Phi_j \mathbf{H}_{ts} \mathbf{w} b_m + z \\ &\triangleq \rho g_j b_m + \sqrt{1 - \rho^2} \Delta \mathbf{h} \mathbf{g}_j b_m + z, \end{aligned} \quad (4)$$

where \mathbf{w} is the beamforming vector at the transmitter, z accounts for the additive white Gaussian noise (AWGN) as well as the interference at the receive antenna having the variance of σ_a^2 , $g_j \triangleq \hat{\mathbf{h}}_{sr} \Phi_j \mathbf{H}_{ts} \mathbf{w}$ and $\mathbf{g}_j \triangleq \Phi_j \mathbf{H}_{ts} \mathbf{w}$.

In order to recover the joint modulated symbol $s_{m,j}$, a maximum likelihood (ML) detector is conceived for jointly demodulating the data information in both the phase-amplitude domain and the reflective domain. The demodulation process can be expressed as

$$(\bar{m}, \bar{j}) = \arg \min_{\substack{m' \in [1, \dots, M] \\ j' \in [1, \dots, L]}} (|y_{m,j} - g_{j'} b_{m'}|^2), \quad (5)$$

where \bar{m} is the estimated index of the conventionally modulated symbol, \bar{j} is the estimated index of the IRS activating pattern, m' and j' are the trial index in the phase-amplitude domain and the reflective domain, respectively.

III. PERFORMANCE ANALYSIS

In this section, we aim to analyse the bit error ratio (BER) performance of the RGNIM assisted system by adopting the ML detection approach.

A. Pairwise Error Probability

Firstly, we define the pairwise error probability (PEP) between two joint symbols $s_{m,j}$ and $s_{n,i}$ ($m \neq n, i \neq j$) as $\tau(s_{m,j} \rightarrow s_{n,i})$, which is the probability that the Euclidean distance between the received signal $y_{m,j}$ and $s_{m,j}$ is larger than that between $y_{m,j}$ and $s_{n,i}$, when $s_{m,j}$ is transmitted. Then, $\tau(s_{m,j} \rightarrow s_{n,i})$ can be expressed as

$$\begin{aligned} &\tau(s_{m,j} \rightarrow s_{n,i}) \\ &= \Pr [|y_{m,j} - g_j b_m|^2 > |y_{m,j} - g_i b_n|^2] \\ &= \Pr \left[\left| \sqrt{1 - \rho^2} \Delta \mathbf{h} \mathbf{g}_j b_m + z + (\rho - 1) g_j b_m \right|^2 \right. \\ &\quad \left. > \left| \sqrt{1 - \rho^2} \Delta \mathbf{h} \mathbf{g}_i b_n + z + \rho g_j b_m - g_i b_n \right|^2 \right]. \end{aligned} \quad (6)$$

Since $\Delta \mathbf{h}$ is a Gaussian distributed vector independent with the noise z , $\sqrt{1 - \rho^2} \Delta \mathbf{h} \mathbf{g}_j b_m + z$ is also Gaussian distributed. Denoting $\lambda_{m,j} = \sqrt{1 - \rho^2} \Delta \mathbf{h} \mathbf{g}_j b_m + z$, we have $\lambda_{m,j} \sim \mathcal{CN}(0, \sigma_{m,j}^2)$, where $\sigma_{m,j}^2 = (1 - \rho^2) \|\mathbf{g}_j\|^2 |b_m|^2 \sigma_h^2 + \sigma_a^2$.

Further, Eq. (6) is reformulated as

$$\begin{aligned} &\tau(s_{m,j} \rightarrow s_{n,i}) \\ &= \Pr [|\lambda_{m,j} + (\rho - 1) g_j b_m|^2 > |\lambda_{m,j} + \rho g_j b_m - g_i b_n|^2] \\ &= \Pr \left[\underbrace{2\mathcal{R}((\lambda_{m,j})(g_i b_n - g_j b_m)^*)}_{LHS} \right. \\ &\quad \left. > |\rho g_j b_m - g_i b_n|^2 - |(\rho - 1) g_j b_m|^2 \right], \end{aligned} \quad (7)$$

where $\mathcal{R}(x)$ represents the real part of the complex number x . According to the statistical characteristic of $\lambda_{m,j}$, the Left-Hand-Side (LHS) of Eq. (7) obeys a Gaussian distribution of $\mathcal{N}(0, |g_i b_n - g_j b_m|^2 \sigma_{m,j}^2 / 2)$. Therefore, Eq.(7) can be further expressed as

$$\tau(s_{m,j} \rightarrow s_{n,i}) = Q \left(\frac{|\rho g_j b_m - g_i b_n|^2 - |(\rho - 1) g_j b_m|^2}{|g_i b_n - g_j b_m| \sqrt{2\sigma_{m,j}^2}} \right), \quad (8)$$

where

$$Q(x) = \int_x^{+\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt. \quad (9)$$

Similarly, the PEP $\tau(s_{m,j} \rightarrow s_{m,i})$ between the joint symbol $s_{m,j}$ and $s_{m,i}$ ($i \neq j$) as well as the PEP $\tau(s_{m,j} \rightarrow s_{n,j})$ between the joint symbol $s_{m,j}$ and $s_{n,j}$ ($m \neq n$) is derived as

$$\begin{aligned} \tau(s_{m,j} \rightarrow s_{m,i}) &= Q \left(\frac{|b_m| (|\rho g_j - g_i|^2 - |(\rho - 1) g_j|^2)}{|g_i - g_j| \sqrt{2\sigma_{m,j}^2}} \right), \\ \tau(s_{m,j} \rightarrow s_{n,j}) &= Q \left(\frac{|g_j| (|\rho b_m - b_n|^2 - |(\rho - 1) b_m|^2)}{|b_m - b_n| \sqrt{2\sigma_{m,j}^2}} \right) \end{aligned} \quad (10)$$

B. BER Performance

Denoting the alphabetical set of the joint modulated symbols as $\mathcal{S} = \{s_{m,j} | m \in \{1, \dots, M\}, j \in \{1, \dots, L\}\}$, the decoding BER at the receiver is expressed as

$$\epsilon = \frac{1}{k|\mathcal{S}|} \sum_{s_{m,j} \in \mathcal{S}} \sum_{\substack{s_{n,i} \in \mathcal{S} \\ s_{n,i} \neq s_{m,j}}} d(s_{m,j}, s_{n,i}) \Pr(s_{m,j} \rightarrow s_{n,i}), \quad (11)$$

where $d(s_{m,j}, s_{n,i})$ represents the Hamming distance between the information bits carried by the joint modulated symbol $s_{m,j}$ and $s_{n,i}$, $\Pr(s_{m,j} \rightarrow s_{n,i})$ represents the probability that the transmitted joint modulated symbol $s_{m,j}$ is mis-demodulated as $s_{n,i}$. According to [17], when the signal-noise ratio (SNR) is not very low, the mis-demodulation probability $\Pr(s_{m,j} \rightarrow s_{n,i})$ can be approximated as the PEP $\tau(s_{m,j} \rightarrow s_{n,i})$. Therefore, the BER can be further approximated as

$$\epsilon \approx \frac{1}{k|\mathcal{S}|} \sum_{s_{m,j} \in \mathcal{S}} \sum_{\substack{s_{n,i} \in \mathcal{S} \\ s_{n,i} \neq s_{m,j}}} d(s_{m,j}, s_{n,i}) \tau(s_{m,j} \rightarrow s_{n,i}), \quad (12)$$

By decomposing the joint modulation scheme into two domains, we are able to obtain the BER in the conventional phase-amplitude domain and the reflective domain as

$$\epsilon_c = \frac{1}{k_c |\mathcal{S}|} \sum_{s_{m,j} \in \mathcal{S}} \sum_{\substack{s_{n,i} \in \mathcal{S} \\ m \neq n}} d_c(s_{m,j}, s_{n,i}) \tau(s_{m,j} \rightarrow s_{n,i}),$$

$$\epsilon_r = \frac{1}{k_r |\mathcal{S}|} \sum_{s_{m,j} \in \mathcal{S}} \sum_{\substack{s_{n,i} \in \mathcal{S} \\ i \neq j}} d_r(s_{m,j}, s_{n,i}) \tau(s_{m,j} \rightarrow s_{n,i}), \quad (13)$$

where $d_c(s_{m,j}, s_{n,i})$ and $d_r(s_{m,j}, s_{n,i})$ are the Hamming distance between the information bits carried by $s_{m,j}$ and $s_{n,i}$ in the conventional phase-amplitude and reflective domain, respectively.

IV. SIMULATION RESULTS

A. Parameter Setting

In this section, the BER performance of the RGNIM assisted system is evaluated by the Matlab aided simulation. The transmitter is equipped with $N_t = 4$ antennas, while the number of the IRS reflecting elements is set to $N_s = 64$. The distance d_{ts} between the transmitter and the IRS and that d_{sr} between the IRS and the receiver are set to $d_{ts} = d_{sr} = 100m$. Each element $H_{i,j} \in \mathbf{H}_{ts}$ and $h_i \in \mathbf{h}_{sr}$ satisfy $H_{i,j} \sim \mathcal{CN}(0, d_{ts}^{-\alpha})$ and $h_i \sim \mathcal{CN}(0, d_{sr}^{-\alpha})$. The power of the AWGN and the interference is set to $\sigma_a^2 = -50$ dBm. The transmit beamforming vector is set as $\mathbf{w} = \frac{1}{\sqrt{N_t}} * [1, \dots, 1]$, while the reflecting magnitude of the IRS is set to $\beta_1 = \dots = \beta_{N_s} = 1$. In order to ensure that the multiple reflected wireless signal from the IRS can be superimposed positively, the phase shift θ_i is set to

$$\theta_i = -\angle \left(\sum_{j=1}^{N_t} \mathbf{H}_{ts,i,j} \mathbf{w}_i \right) - \angle \hat{\mathbf{h}}_{sr,i}, \quad (14)$$

where $\mathbf{H}_{ts,i,j}$ represents the element at the i -th row and the j -th column in \mathbf{H}_{ts} , $\hat{\mathbf{h}}_{sr,i}$ represents the element at the i -th column in $\hat{\mathbf{h}}_{sr}$, whereas $\angle x$ denotes the phase of the complex number x . Without specific statement, the channel estimation accuracy parameter is set to $\rho = 0.99$.

B. Numerical Results

The theoretical BER analysis of the RGNIM assisted system is validated in Fig. 2, where the 4-QAM and 8-PSK conventional modulation schemes are conceived by jointly considering 4-RGNIM and 2-RGNIM modulation schemes, respectively. The data rate is $k = 4$ bit/channel use. The simulation results are obtained by the Monte Carlo based simulation, where there are totally 10^8 information bits transmitted to the receiver. Observe from Fig. 2 that the theoretical results of the total BER ϵ , the phase-amplitude BER ϵ_c and the reflective BER ϵ_r match well with the simulation results. Therefore, in order

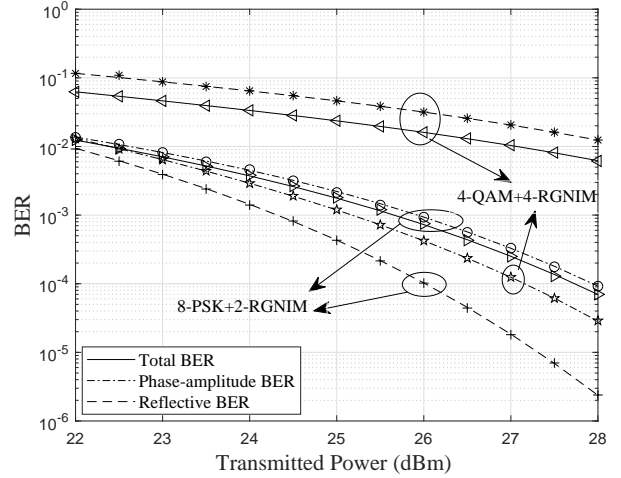


Fig. 2. Validation of theoretical analysis of BER. The lines are theoretical results and the dots are simulation results.

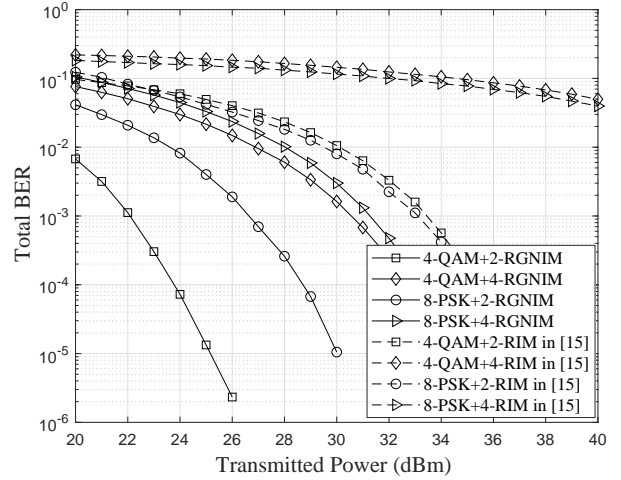


Fig. 3. Total BER comparison of RGNIM to RIM in [15].

to reduce the complexity, the theoretical results are used to evaluate the BER performance of RGNIM assisted system in the latter simulations. Moreover, the BER of the 8-PSK+2-RGNIM scheme outperforms that of the 4-QAM+4-RGNIM scheme. Especially, a lower order of the phase-amplitude modulation scheme results in a lower phase-amplitude BER, while a lower order of the reflective modulation scheme results in a lower reflective BER.

Fig. 3 compares the total BER performance between our RGNIM scheme and the RIM scheme in [15], in which different $(L - 1)$ groups of IRS elements are activated for modulating various reflective information. The 4-QAM and 8-PSK conventional modulation schemes are conceived by jointly considering 4-RGNIM and 2-RGNIM modulation schemes, respectively. Observe from Fig. 3 that our RGNIM outperforms the RIM in [15]. Moreover, a higher data rate results in a higher BER, since the Euclidean distance between two

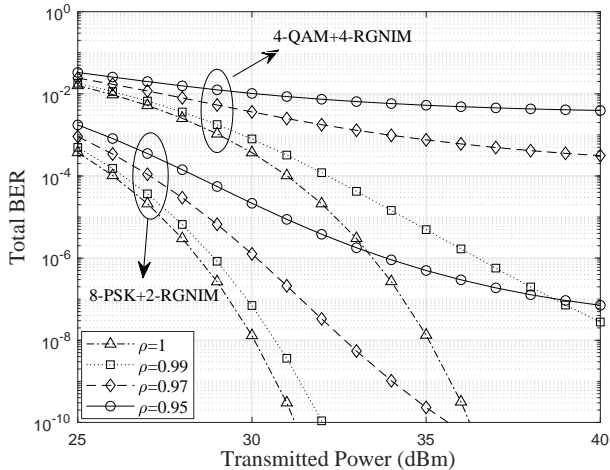


Fig. 4. Impact of imperfect channel estimation on total BER of the RGNIM assisted system.

adjacent joint modulated symbols are smaller.

Fig. 4 evaluates the impact of the imperfect channel estimation on the total BER of the RGNIM assisted system, where the 4-QAM+4-RGNIM and the 8-PSK+2-RGNIM joint modulation schemes are conceived. Observe from Fig. 4 that a smaller channel estimation parameter ρ results in a higher total BER for both the schemes. This is because that when ρ becomes smaller, the channel estimation error becomes larger, which has more influence on the joint demodulation and then reduces the correctness. When we continually increase the transmit power, the total BER with imperfect CSI gradually becomes flat, since the channel estimation error dominates the interference and the noise. Note that when $\rho = 1$, the CSI is perfectly estimated, which results in the lowest BER.

V. CONCLUSION

A reflective group number based index modulation scheme is proposed in this paper, where additional reflective information can be carried by activating different group number of the IRS elements. The BER performance of RGNIM is then theoretically analysed under the imperfect channel estimation. Simulation results validated our analysis, while also demonstrated that a higher data rate of the joint modulation scheme results in a higher BER.

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