



Outage Performance Analysis of RIS Assisted RSMA Network with On-Off Control

Haiyan Huang¹, Dongjie Jiang¹, Nina Zhang², Linlin Liang³,
and Hongyan Zhang¹

¹ Lanzhou Jiaotong University, Lanzhou, Gansu 730070, China
huanghaiyan@mail.lzjtu.cn

² Shaanxi General Staff of PAP, Xi'an 710054, Shaanxi, China

³ Xidian University, Xi'an 710071, Shaanxi, China

Abstract. In order to make future wireless communication networks efficient in spectrum and energy, reconfigurable intelligent surface (RIS) has become a practical technology that can significantly improve the coverage and performance of wireless networks. In this paper, we discuss the application of RIS technology in Rate-Splitting Multiple Access (RSMA), where the base station (BS) sends superimposed signals to multiusers through RIS. To delve deeper into investigating the efficacy of RIS-aided RSMA networks, we adopt a On-Off control scheme and consider the system performance under imperfect successive interference cancellation (ipSIC) and perfect successive interference cancellation (pSIC) respectively. On this basis, we use ipSIC/pSIC to derive the outage probability expression of the k th user. Based on the outcome analysis, the diversity order of users exhibits a correlation with the quantity of reflective elements in the RIS and channel prioritization under pSIC conditions. In addition, increasing the quantity of RIS reflective units can make up for the decrease of system outage performance caused by residual interference, and further improve the outage performance of the system.

Keywords: Reconfigurable Intelligent Surface · Rate-Splitting Multiple Access · Imperfect SIC · On-Off Control

1 Introduction

As the field of wireless communication technology advances at a brisk pace, the urgency to amplify spectrum efficiency and augment network capacity has mounted considerably. [1]. To address this challenge, reconfigurable intelligent surfaces (RIS), a groundbreaking technology, have garnered significant attention due to their ability to intelligently manipulate the wireless propagation environment [2]. RIS, a two-dimensional structure comprised of numerous programmable

Supported by organization Lanzhou jiaotong University.

reflection units, possesses the ability to intelligently regulate the phase, amplitude, and polarization properties of wireless signals. This enables real-time adjustment of the RIS reflection mode, reducing signal attenuation and interference, thereby enhancing the spectrum efficiency and network capacity of the system. Furthermore, as a generalized multiple access (MA) technique, Rate-Splitting Multiple Access (RSMA) technology stands out in its proficiency in enhancing spectrum efficiency and user fairness, making it a promising contender for 6G wireless communication [3]. By splitting user messages and employing non-orthogonal transmission of both common messages and user-specific private messages [4], RSMA adeptly integrates two contrasting approaches to interference mitigation: comprehensively decoding disruptive signals and managing them as background noise, thereby bridging the gap between these seemingly opposed strategies.

In recent years, researchers have explored the combination of RIS assisted communication system and RSMA protocol. The author of [5] analyzed the outage probability of RIS assisted downlink NOMA systems. Taking into account the user's usage, the authors in [6] examined the discrete phase shift RIS reflection of RIS-assisted OMA or NOMA. When prioritizing users, a jointly optimization approach is employed to refine both the beamforming vector and the phase shift matrix, aiming to minimize the transmission power requirements, as demonstrated in [7]. Considering ipSIC in NOMA communication [8], the author analyzes the outage performance of the system. The authors of [9] designed a low-complexity joint optimization scheme for RIS assisted uplink RSMA systems, which significantly improves the maximum transmission delay. In [10], the RSMA system of RIS-aided cell-boundary and adjacent users is scrutinized, in which the outage performance expression is derived by considering the phase-shift-based switching technology. Yang [11] et al. considered the energy efficiency maximization of RIS-assisted RSMA communication by jointly optimizing RIS phase shift and BS beamforming.

It is noteworthy that while an outage analysis has been conducted for RIS-assisted NOMA systems in Reference [5], a comparable analysis for RSMA systems remains unresolved. In addition, the discrete phase shift of RIS-assisted NOMA and OMA systems is considered in [6], and the imperfect successive interference cancellation in NOMA systems is studied in [8]. The analysis of RSMA systems remains to be carried out. In [10] considers the RIS-integrated RSMA setup, but neglects to present the mathematical formalism for discrete phase modulation.

Drawing upon the aforementioned analysis, this paper delves into the RIS-assisted RSMA network. Considering the discrete phase modulation, user utilization rate and user ordering of RIS, the outage probability expression of the network is derived. The influence of imperfect continuous interference cancellation and discrete phase shift of RIS on the outage performance of the communication system is investigated.

2 System Model

According to the illustration in Fig. 1, the RIS-assisted RSMA communication model consists of three parts, including a base station (BS), RIS, and K end

users. It is assumed that each of the BS and users is endowed with a single antenna, where BS sends signals to K end users through the use of RIS. RIS is furnished with N reflection units, which are controllable through software focused on communication functionality. The complex channel coefficients for the BS-RIS link, as well as the RIS-users link, are expressed by h_i and g_{ik} respectively. Both h_i and g_{ik} follow the complex Gaussian distribution with the mean set to zero and the variance specified as σ^2 and are independent of each other. Given that the BS-users link is obstructed by tall buildings, resulting in a lack of direct interconnection, the communication channel between any two nodes within this environment is characterized by the Rayleigh fading model. The background noise of these wireless links is additive white Gaussian noise, with statistical properties including a mean of zero and a variance of N_0 .

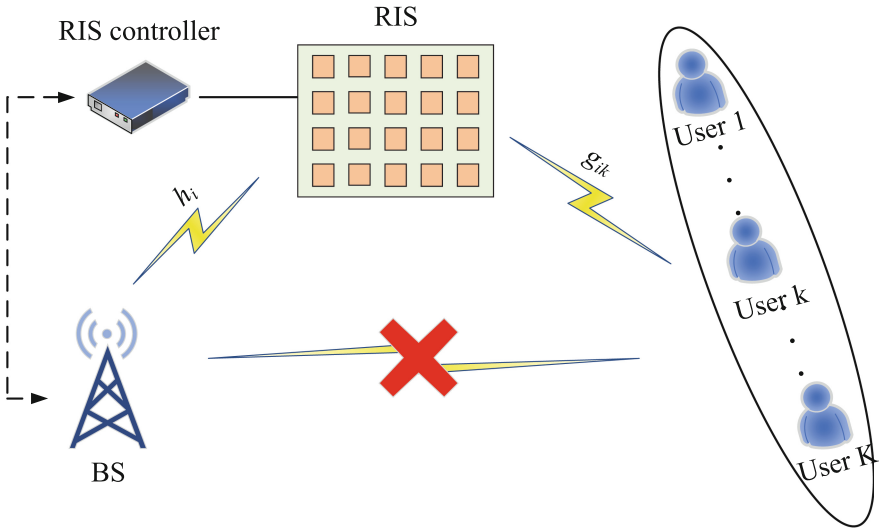


Fig. 1. RIS-assisted downlink RSMA network model.

The communication system assumes that the channel state information, the geographic coordinates of the BS, and the seamless feedback to the RIS can be implemented accurately. In order to facilitate the analysis, the effective cascade channel gain of the BS-RIS-user link is sorted: $|g_{i1}^H \Phi h_i|^2 \leq \dots \leq |g_{ik}^H \Phi h_i|^2 \leq \dots \leq |g_{iK}^H \Phi h_i|^2$, where $\Phi = \text{diag}(\beta e^{-j\theta_1}, \dots, \beta e^{-j\theta_i}, \dots, \beta e^{-j\theta_K})$ represents the phase shift matrix of RIS, and $\beta \in [0, 1]$ and $\theta_i \in [0, 2\pi)$ represent the fixed reflection amplitude and phase shift parameter of the k -th reflection unit of RIS, respectively. Without loss of generality, it is assumed that when the RIS is not within the frequency band, that is, the incident frequency does not fall within the designed unit's response band, the RIS is basically total reflection.

In the communication process, BS uses the RSMA protocol, and the superimposed signal sent to the end user includes a public message x_c and K mutually orthogonal private information x_k , $\{k \in 1, 2, \dots, K\}$ represents K different users. As a result, the signal that receives at the k -th user after RIS reflection is:

$$y_k = (g_{ik}^H \Phi h_i) \left(\sqrt{\alpha_c P_B} x_c + \sum_{i=1}^K \sqrt{\alpha_i P_B} x_i \right) + w_k \quad (1)$$

where P_B is the transmission power of the BS, α_c and α_i are the rate splitting factors of the base station sending public information and private information respectively. In order to meet the user fairness, the rate splitting factors of the public information and the k th user satisfy the relationship $\alpha_c + \sum_{i=1}^K \alpha_i = 1$, and $\alpha_c \geq \alpha_1 \geq \dots \geq \alpha_k \geq \dots \geq \alpha_K$. x_c , x_i represent the public information sent and the private information of K users respectively, and $E\{x_c^2\} = E\{x_i^2\} = 1$. w_k are additive Gaussian white noise with mean value of 0 and variance N_0 .

After receiving the superimposed signal sent by BS, user U_k first decodes the public message x_c , and then decodes his own private message x_k after deleting the public message x_c by SIC. When decoding x_c , all private messages will cause interference, and when x_k is decoded, the private information of other users will cause interference. Therefore, the signal to interference plus noise ratio (SINR) of U_k decoding public message and private messages can be expressed:

$$\Gamma_k^c = \frac{\alpha_c P_B |g_{ik}^H \Phi h_i|^2}{\sum_{i=1}^K \alpha_i P_B |g_{ik}^H \Phi h_i|^2 + N_0} \quad (2)$$

$$\Gamma_k^p = \frac{\alpha_k P_B |g_{ik}^H \Phi h_i|^2}{\sum_{\substack{i=1 \\ i \neq k}}^K \alpha_i P_B |g_{ik}^H \Phi h_i|^2 + \varpi P_B |h_{iru}|^2 + N_0} \quad (3)$$

where $\varpi \in [0, 1]$ is the imperfect successive interference cancellation coefficient, $\varpi = 0$ denotes ipSIC and $\varpi = 1$ denotes pSIC.

For the convenience of analysis, Assuming the residual interference arising from the implementation of ipSIC follows a Rayleigh fading model, and the corresponding complex channel parameter is represented by h_{iru} , which obeys the complex Gaussian distribution with mean 0 and variance σ_{iru}^2 . In addition, in order to facilitate the next calculation, the probability density function(PDF) of $|h_{iru}|^2$ is:

$$f_{|h_{iru}|^2}(y) = \frac{1}{\sigma_{iru}^2} e^{\left(-\frac{y}{\sigma_{iru}^2}\right)} \quad (4)$$

3 On-Off Control Scheme

Considering that in the actual communication scenario, constantly changing the reflection elements of RIS to adjust and control the amplitude and phase of

the signal is conducive to improving the performance of the network. However, this alternative requires precise design specifications, as well as an expensive hardware configuration, which will lead to the cost of RIS becoming higher. For the sake of convenient analysis and implementation, a low-cost implementation is to apply switch control to the RIS-RSMA network to realize the amplitude and phase shift level of the RIS-assisted RSMA network [12], that is, each diagonal element in the phase shift matrix Φ is either 0 (off) or 1 (on). Meanwhile, increasing the number of reflection units remains a scalable and cost-effective solution.

RIS has N reflection units. Suppose $N = LQ$, where L and Q are both integers. Let $\Psi = \frac{1}{\sqrt{Q}}I_L \otimes 1_Q$, where I_L is the unit matrix of $L \times L$, 1_Q is the 1-vector of $Q \times 1$, Ψ_l denotes the l column of Ψ , and for $l \neq p$, $\Psi_l^H \Psi_p = 0$, $\Psi_l^H \Psi_l = 1$. Using On-Off control, a random column of Ψ_l can be selected to maximize the SINR of user U_k decoding. (2) and (3) can be rewritten as:

$$\tilde{\gamma}_k^c = \max_{\Psi_i} \frac{\alpha_c P_B |\Psi_l^H D_k h_i|^2}{\sum_{i=1}^K \alpha_i P_B |\Psi_l^H D_k h_i|^2 + N_0} \tag{5}$$

$$\tilde{\gamma}_k^p = \max_{\Psi_i} \frac{\alpha_k P_B |\Psi_l^H D_k h_i|^2}{\sum_{\substack{i=1 \\ i \neq k}}^K \alpha_i P_B |\Psi_l^H D_k h_i|^2 + \varpi P_B |h_{iru}|^2 + N_0} \tag{6}$$

where D_k is a diagonal matrix whose diagonal elements are obtained by g_{ik} .

Theorem 1. *In order to simplify the analysis of the outage performance of the system, the cascade channel gain of the RIS aided link is expressed as $|Z|^2 = |\Psi_l^H D_k h_i|^2$ by using the On-Off control scheme. At this point, the cumulative distribution function(CDF) of $|Z|^2$ can be written as:*

$$F_{|Z|^2}(z) = \frac{K!}{(K-k)!(k-1)} \times \sum_{b=0}^{K-k} \binom{K-k}{b} \frac{(-1)^b}{k+b} \left[1 - \frac{2}{\Gamma(Q)} \left(\frac{\sqrt{z}}{\sigma^2} \right)^Q K_Q \left(\frac{2\sqrt{z}}{\sigma^2} \right) \right]^{k+b} \tag{7}$$

Proof. According to [13], the PDF of the Rayleigh cascade channel $|Z|^2$ from BS to RIS to the user is:

$$f_{|Z|^2}(z) = \frac{2\sqrt{z}^{Q-1}}{\Gamma(Q) \sigma^{2(Q+1)}} \cdot K_{Q-1} \left(\frac{2\sqrt{z}}{\sigma^2} \right) \tag{8}$$

where $\Gamma(\cdot)$ denotes the Gamma function and $K_v(\cdot)$ denotes the second modified Bessel function of order v .

Based on the above assumptions, the effective cascade channel gain of the RIS auxiliary link using the switching control scheme is sorted to the user: $|\Psi_p^H D_1 g_{i1}|^2 \leq \dots \leq |\Psi_p^H D_k g_{ik}|^2 \leq \dots \leq |\Psi_p^H D_K g_{iK}|^2$. The CDF of the sorted

effective cascade channel gain $F_{|Z|^2}(z)$ has a specific correlation with unordered channel gain [7, 14]:

$$F_{|Z|^2}(z) = \frac{K!}{(K-k)!(k-1)} \sum_{b=0}^{K-k} \binom{K-k}{b} \times \frac{(-1)^b}{k+b} \left[\widehat{F}_{|Z|^2}(z) \right]^{k+b} \quad (9)$$

where $F_{|Z|^2}(z)$ is the cumulative distribution function of the unsorted cascaded channel gain.

From (7), the PDF of the unsorted concatenated channel is:

$$\widehat{f}_{|Z|^2}(z) = \frac{2\sqrt{z}^{Q-1}}{\Gamma(Q)\sigma^{2(Q+1)}} \cdot K_{Q-1}\left(\frac{2\sqrt{z}}{\sigma^2}\right) \quad (10)$$

By integrating the (9), the CDF of the unsorted cascaded channel is obtained:

$$\widehat{F}_{|Z|^2}(z) = \frac{2}{\Gamma(Q)\sigma^{2(Q+1)}} \int_0^z x^{\frac{Q-1}{2}} \cdot K_{Q-1}\left(\frac{2\sqrt{x}}{\sigma^2}\right) dx \quad (11)$$

Let $x = zy$, the Gauss-Laguerre quadrature formula is used for (10):

$$\widehat{F}_{|Z|^2}(z) = 1 - \frac{2}{\Gamma(Q)} \left(\frac{\sqrt{z}}{\sigma^2}\right)^Q K_Q\left(\frac{2\sqrt{z}}{\sigma^2}\right) \quad (12)$$

Finally, (11) is substituted into (8), and the CDF of the effective cascade channel after the RIS auxiliary link is sorted is obtained, and the proof is completed.

4 Outage Probability

In wireless communication, outage probability is an important performance metric to measure the reliability of communication links under certain conditions. The outage performance refers to the probability that the communication link is interrupted within a given period of time, which is contingent upon the mean SNR of the communication link, along with the specific model that characterizes its channel fading distribution

According to the principle of RSMA, there are two cases in the RIS-assisted RSMA communication network that may cause communication interruption: (1) U_k cannot successfully decode the public information x_c after BS sends the superimposed signal; (2) U_k successfully decodes public information x_c , but cannot successfully decode its own private information x_k . Therefore, the outage probability of user U_k is defined as:

$$\begin{aligned} OP &= \Pr\left(\widetilde{\Gamma}_k^c < \Gamma_{th_c}\right) + \Pr\left(\widetilde{\Gamma}_k^c > \Gamma_{th_c}, \widetilde{\Gamma}_k^p < \Gamma_{th_p}\right) \\ &= 1 - \Pr\left(\widetilde{\Gamma}_k^c > \Gamma_{th_c}, \widetilde{\Gamma}_k^p > \Gamma_{th_p}\right) \end{aligned} \quad (13)$$

where $\Gamma_{thc} = 2^{R_c} - 1$ and $\Gamma_{thp} = 2^{R_p} - 1$ are the threshold SINRs for the transmission of public and private messages, respectively, R_c and R_p are the target data rates at which they decode the messages, respectively. $\Pr(\cdot, \cdot)$ denotes the joint probability. By the concept of joint probability in [15], the outage probability of (12) can be further simplified as :

$$OP = F_{\tilde{\Gamma}_k^c}(\Gamma_{thc}) + F_{\tilde{\Gamma}_k^p}(\Gamma_{thp}) - F_{\tilde{\Gamma}_k^c, \tilde{\Gamma}_k^p}(\Gamma_{thc}, \Gamma_{thp}) \quad (14)$$

where $F_X(\cdot)$ is the cumulative distribution function of the variable X , and $F_{X,Y}(\cdot, \cdot)$ is the joint CDF of X and Y .

In the realm of wireless communication, attaining perfect SIC is often considered an idealized scenario. However, in practical communication settings, achieving such perfection becomes challenging due to various factors, including hardware limitations, channel estimation errors, and signal processing constraints. In the subsequent analysis, we provide outage probability expressions for both perfect SIC and imperfect SIC scenarios. Furthermore, in the following chapter, these two cases will be simulated and verified accordingly.

4.1 Imperfect SIC

Using the On-Off control scheme, and considering the existence of imperfect SIC to generate residual interference, (13) can be rewritten as:

$$OP = \prod_{l=1}^L F_{|Z|^2}(\tau_c) + \prod_{l=1}^L F_{|Z|^2} \left(\left(\varpi P_B |h_{iru}|^2 + N_0 \right) \tau_p \right) - \prod_{l=1}^L F_{|Z|^2} \left(\min \left\{ \tau_c, \left(\varpi P_B |h_{iru}|^2 + N_0 \right) \tau_p \right\} \right) \quad (15)$$

$$\text{where } \tau_c = \frac{\Gamma_{thc} N_0}{\left(\alpha_c - \sum_{i=1}^K \alpha_i \Gamma_{thc} \right) P_B}, \quad \tau_p = \frac{\Gamma_{thp}}{\left(\alpha_k - \Gamma_{thp} \sum_{\substack{i=1 \\ i \neq k}}^K \alpha_i \right) P_B}$$

In order to facilitate analysis and implementation, assuming that the marginal and joint statistics of $\tilde{\Gamma}_k^c$ and $\tilde{\Gamma}_k^p$ are the same for all l [10], the outage probability of (14) can be further written as:

$$OP_{ipSIC} = \left[F_{|Z|^2}(\tau_c) \right]^L + \left[F_{|Z|^2} \left(\left(\varpi P_B |h_{iru}|^2 + N_0 \right) \tau_p \right) \right]^L - \left[F_{|Z|^2} \left(\min \left\{ \tau_c, \left(\varpi P_B |h_{iru}|^2 + N_0 \right) \tau_p \right\} \right) \right]^L \quad (16)$$

where,

$$F_{|Z|^2}(\tau_c) = \Pr \left(\frac{\alpha_c P_B |Z|^2}{\sum_{i=1}^K \alpha_i P_B Z + N_0} \leq \Gamma_{thc} \right) = \Pr \left(|Z|^2 \leq \tau_c \right) \\ = \frac{K!}{(K-k)!(k-1)!} \sum_{b=0}^{K-k} \binom{K-k}{b} \times \frac{(-1)^b}{k+b} \left[1 - \frac{2}{\Gamma(Q)} \left(\frac{\sqrt{\tau_c}}{\sigma^2} \right)^Q K_Q \left(\frac{2\sqrt{\tau_c}}{\sigma^2} \right) \right]^{k+b} \quad (17)$$

Similarly,

$$\begin{aligned}
 & F_{|Z|^2} \left(\left(\varpi P_B |h_{iru}|^2 + N_0 \right) \tau_p \right) \\
 &= \int_0^\infty f_{|h_{iru}|^2}(y) F_{|Z|^2} \left(\left(\varpi P_B y + N_0 \right) \tau_p \right) dy \\
 &= \int_0^\infty \frac{1}{2\sigma_{iru}^2} e^{-\frac{y}{2\sigma_{iru}^2}} \frac{K!}{(K-k)!(k-1)} \sum_{b=0}^{K-k} \binom{K-k}{b} \\
 &\times \frac{(-1)^b}{k+b} \left[1 - \frac{2}{\Gamma(Q)} \left(\frac{\sqrt{(\varpi P_B y + N_0) \tau_p}}{\sigma^2} \right)^Q K_Q \left(\frac{2\sqrt{(\varpi P_B y + N_0) \tau_p}}{\sigma^2} \right) \right]^{k+b} dy \tag{18} \\
 &\approx \frac{K!}{(K-k)!(k-1)} \sum_{a=1}^A \sum_{b=0}^{K-k} \binom{K-k}{b} \times \frac{(-1)^b W_a}{k+b} \\
 &\times \left[1 - \frac{2}{\Gamma(Q)} \left(\frac{\sqrt{(2\varpi P_B \sigma_{iru}^2 \xi_a + N_0) \tau_p}}{\sigma^2} \right)^Q K_Q \left(\frac{2\sqrt{(2\varpi P_B \sigma_{iru}^2 \xi_a + N_0) \tau_p}}{\sigma^2} \right) \right]^{k+b}
 \end{aligned}$$

where $W_a = \frac{(A!)^2 \xi_a}{[L_{A+1}(\xi_a)]^2}$ is the weight of Gauss-Laguerre quadrature formula, ξ_a is the zero point of Laguerre polynomial $L_A(\xi_a)$, $a = 1, 2, 3, \dots, A$, A is the complexity trade-off accuracy, and when $A \rightarrow \infty$, the above formula takes the equal sign.

In summary, by substituting (16), (17) into (15), formulations for the outage probability in the case of ipSIC is:

$$OP_{ipSIC} = \begin{cases} [F_Z(\tau_c)]^L, & (\varpi P_B |h_{iru}|^2 + N_0) \tau_p < \tau_c \\ [F_Z \left((\varpi P_B |h_{iru}|^2 + N_0) \tau_p \right)]^L, & (\varpi P_B |h_{iru}|^2 + N_0) \tau_p > \tau_c \end{cases} \tag{19}$$

4.2 Perfect SIC

Available with Sect. 4.1, ideally, the outage probability expression of the system to achieve perfect SIC is:

$$\begin{aligned}
 OP_{pSIC} &= [F_Z(\tau_c)]^L + [F_Z(\hat{\tau}_p)]^L - [F_Z(\min\{\tau_c, \hat{\tau}_p\})]^L \\
 &= \begin{cases} [F_Z(\tau_c)]^L, & \hat{\tau}_p < \tau_c \\ [F_Z(\hat{\tau}_p)]^L, & \hat{\tau}_p > \tau_c \end{cases} \tag{20}
 \end{aligned}$$

where $\hat{\tau}_p = N_0 \tau_p$,

$$\begin{aligned}
 F_Z(\hat{\tau}_p) &= \Pr \left(\frac{\alpha_k P_B |Z|^2}{\sum_{\substack{i=1 \\ i \neq k}}^K \alpha_i P_B |Z|^2 + \varpi P_B |h_{iru}|^2 + N_0} \leq \Gamma_{th_p} \right) = \Pr \left(|Z|^2 \leq \hat{\tau}_p \right) \\
 &= \frac{K!}{(K-k)!(k-1)} \sum_{b=0}^{K-k} \binom{K-k}{b} \times \frac{(-1)^b}{k+b} \left[1 - \frac{2}{\Gamma(Q)} \left(\frac{\sqrt{\hat{\tau}_p}}{\sigma^2} \right)^Q K_Q \left(\frac{2\sqrt{\hat{\tau}_p}}{\sigma^2} \right) \right]^{k+b} \tag{21}
 \end{aligned}$$

5 Performance Analysis

In this section, we delve deeper into the theoretical framework by conducting specific simulation experiments. These experiments aim to empirically validate the theoretical expressions and further examine the intricate impacts of two key factors: the number of reflection elements and the imperfect implementation of successive interference cancellation on the outage performance of the system. Set the complexity trade-off accuracy $A = 5$, BS transmission power $P_B = 10 \text{ dB}$.

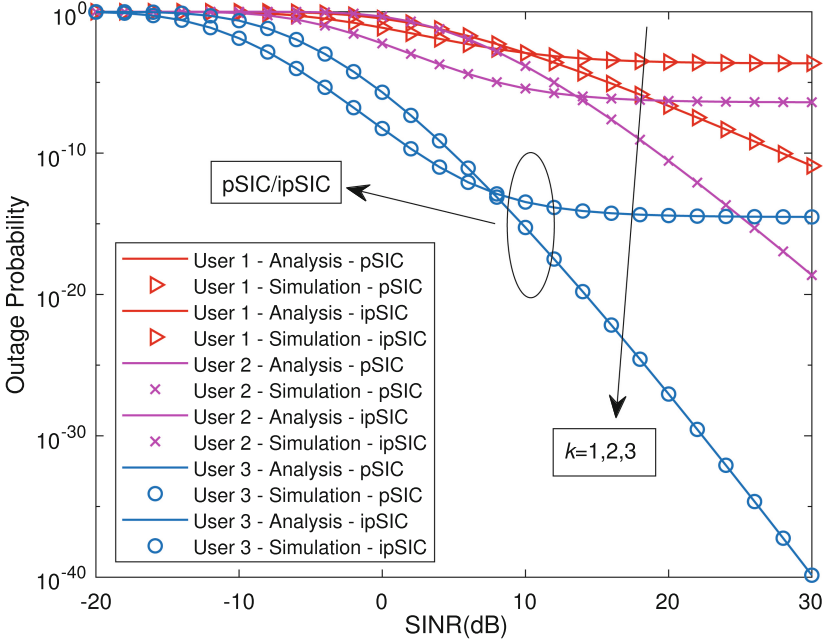


Fig. 2. Outage probability of various users vs the transmit SINR.

Figure 2 plot the relationship between the outage probability of users and the SINR in the instance of ipSIC and pSIC. Set $N = 5, K = 3, Q = 1$, the normalized power of residual interference $E\{|h_{iru}|^2\} = -10 \text{ dB}$, the rate splitting factor of public information and private information of each user are set to $\alpha_c = 0.4, \alpha_1 = 0.3, \alpha_2 = 0.2, \alpha_3 = 0.1$ respectively. The graph in Fig. 2 demonstrates that the outage probability simulation values of multi-user in two cases coincide with the theoretical analysis, which corroborates the precision of the theoretical expression. An increase in SINR corresponds to a decrease in the system’s outage capability. Secondly, in the case of pSIC, the outage probability curve decreases more than that of ipSIC, indicating that the RIS-RSMA network with pSIC has better outage performance.

The relationship between the outage probability of the system and SINR is depicted in Fig. 3 for users located far from the BS, considering different numbers of elements in the RIS under ipSIC and pSIC scenarios. In the simulation, set $K = 3, k = 1, Q = 1, \alpha_c = 0.4, R_1 = 0.5, E\{|h_{iru}|^2\} = -10\text{ dB}$. Take $N = 5, 10, 15$ respectively. Similarly, it can be observed from Fig. 3 that the simulation value of the outage performance of the system coincides perfectly with the theoretical value, and decreases with the increase of SINR. The results show that when RIS reflection units N is increased, the outage capacity of the system can be improved in both cases of ipSIC and pSIC.

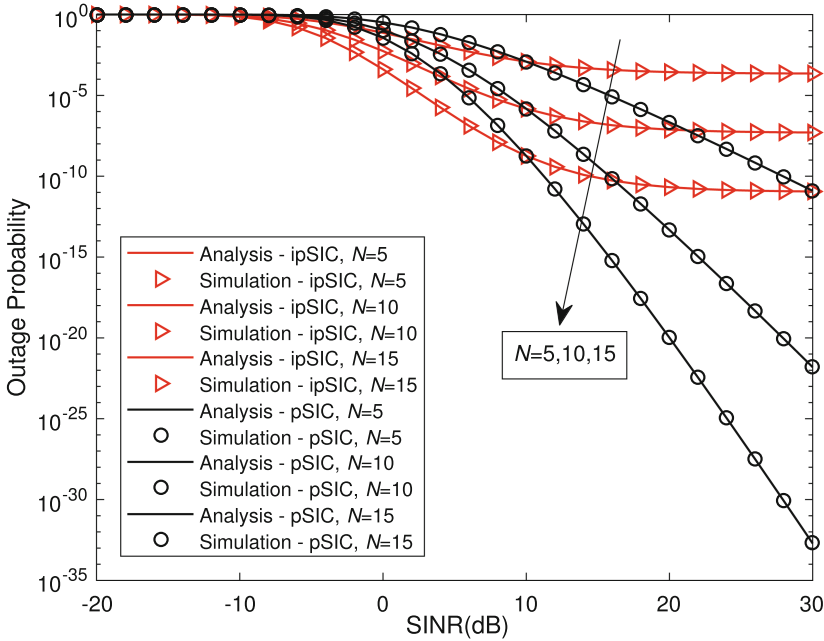


Fig. 3. Outage probability of various N vs the transmit SINR.

Figure 4 illustrates the connection between the outage probability of each user and the SINR of multiple users in the case of ipSIC and changing the residual interference size. In the simulation, we configure the parameters as follows: $N = 5, K = 3, Q = 1, \alpha_c = 0.4$. The rate splitting factor of three users is $\alpha_1 = 0.3, \alpha_2 = 0.2, \alpha_3 = 0.1$. The residual interference normalized power $E\{|h_{iru}|^2\} = -10, -8, -6\text{ dB}$ is taken respectively.

As can be seen from Fig. 4, when considering the user sorting, the user ($k = 3$) closer to the BS has better outage performance than the user ($k = 1, 2$) farther away from the BS, which is owing to the fact that near users have a higher diversity order. Secondly, taking residual interference into account, as the SINR value

of the RIS-RSMA network with ipSIC is large, the outage performance of the system tends to be constant, that is, the slope of the outage probability curve tends to be 0. At this time, the diversity order of the system is 0, as the residual interference power intensifies, the system's outage probability diminishes correspondingly. Consequently, it holds paramount importance to take into account the effect of ipSIC on the practical performance metrics of RIS-NOMA network deployments.

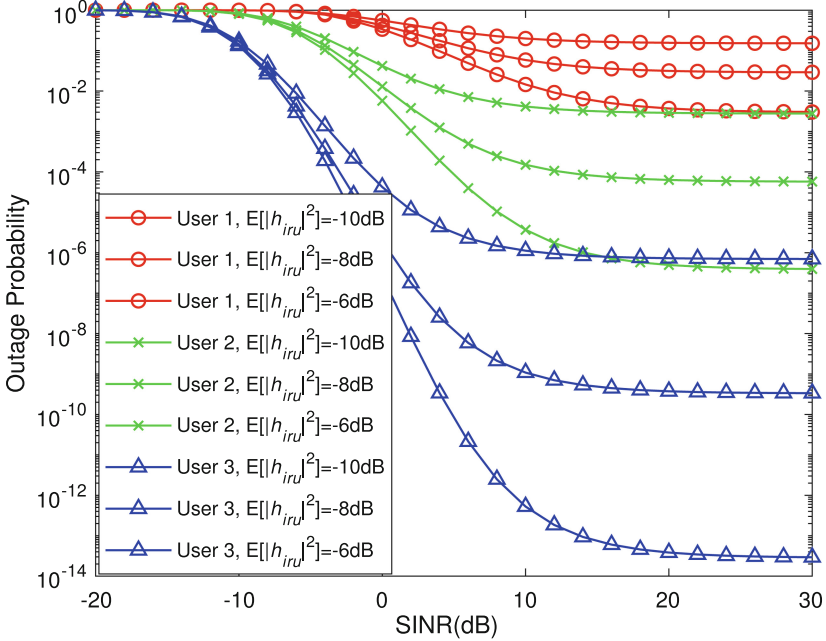


Fig. 4. Outage probability of various residual interference power vs the transmit SINR.

6 Conclusion

In many studies, the analysis of outage performance in the presence of residual interference in RIS-assisted RSMA communication systems is still insufficient, and most studies do not consider the effective cascaded channel gain for user ordering and the discrete phase shift parameter of RIS. In this paper, the existence of residual interference in the communication system is discussed in depth, and the communication scenario of RIS using On-Off control scheme is considered. Through performance analysis, it is indicated that the quantity of reflection units and residual interference of RIS make a marked difference to the overall communication performance. Although the residual interference has a certain impact on the system's performance, by increasing the number of RIS reflection elements, the system can obtain higher diversity gain, so as to effectively offset

the influence of residual interference and further improve the outage probability of the system. In addition, another promising research direction in the future is to design a combined beamforming and power allocation strategy, which will significantly improve the performance of RIS-RSMA.

Funding. This work was supported by the Tianyou Youth Talent Lift Program of Lanzhou Jiaotong University; the National Natural Science Foundation of China under grant 61901201, 62001359; the Key Research and Development Project of Lanzhou Jiaotong University (ZDYF2304).

References

1. Liu, Y., et al.: Evolution of NOMA toward next generation multiple access (NGMA) for 6G. *Journal* **4**(40), 1037–1071 (2022)
2. Li, Z., Yuan, W., Li, B., Wu, J., You, C., Meng, F.: Reconfigurable-intelligent-surface-aided OTFS: transmission scheme and channel estimation. *Journal* **10**(22), 19518–19532 (2023)
3. Katwe, M., Singh, K., Clerckx, B., Li, C.-P.: Rate-splitting multiple access and dynamic user clustering for sum-rate maximization in multiple RISs-aided uplink mmWave system. *Journal* **70**(11), 7365–7383 (2022)
4. Mao, Y., Dizdar, O., Clerckx, B., Schober, R., Popovski, P., Poor, H.V.: Rate-splitting multiple access: fundamentals, survey, and future research trends. *Journal* **24**(4), 2073–2126 (2022)
5. Sadia, H., Abbas, Z.H., Hassan, A.K., Abbas, G.: Outage probability analysis of reconfigurable intelligent surface (RIS)-Enabled NOMA Network. In: 10th International Conference on Wireless Networks and Mobile Communications (WINCOM), pp. 1–6. Istanbul, Turkiye (2023)
6. Zheng, B., Wu, Q., Zhang, R.: Intelligent reflecting surface-assisted multiple access with user pairing: NOMA or OMA? *Journal* **24**(4), 753–757 (2020)
7. Fu, M., Zhou, Y., Shi, Y.: Intelligent reflecting surface for downlink non-orthogonal multiple access networks. In: IEEE Globecom Workshops (GC Wkshps), pp. 1–6. Waikoloa, HI, USA (2019)
8. Gu, J., Wang, M., Duan, W., Zhang, L., Zhang, H.: Imperfect SIC for NOMA communications under Nakagami-m fading: comparison of RIS and Relay. In: 20th International Conference on the Design of Reliable Communication Networks (DRCN), pp. 17–23. Montreal, QC, Canada (2024)
9. Hu, J., Liu, G., Ma, Z., Xiao, M., Fan, P.: Low-complexity resource allocation for uplink RSMA in future 6G wireless networks. *Journal* **13**(2), 565–569 (2024)
10. Bansal, A., Singh, K., Clerckx, B., Li, C.-P., Alouini, M.-S.: Rate-splitting multiple access for intelligent reflecting surface aided multi-user communications. *Journal* **70**(9), 9217–9229 (2021)
11. Yang, Z., Shi, J., Li, Z., Chen, M., Xu, W., Shikh-Bahaei, M.: Energy efficient rate splitting multiple access (RSMA) with reconfigurable intelligent surface. In: IEEE International Conference on Communications Workshops (ICC Workshops), pp. 1–6. Dublin, Ireland (2020)
12. Ding, Z., Vincent Poor, H.: A simple design of IRS-NOMA transmission. *Journal* **24**(5), 1119–1123 (2020)

13. Liu, H., Ding, H., Xiang, L., Yuan, J., Zheng, L.: Outage and BER performance analysis of cascade channel in relay networks. *Journal* **34**(8), 23–30 (2014)
14. Yue, X., Qin, Z., Liu, Y., Kang, S., Chen, Y.: A unified framework for non-orthogonal multiple access. *Journal* **66**(11), 5346–5359 (2018)
15. Papoulis, A., U. Pillai, S.: *Probability, Random Variables, and Stochastic Processes*. 4th edn. McGraw-Hill, New York, NY, USA (2002)