Transmission Design and Component Allocation for STAR-RIS Assisted NOMA Systems with Direct Link

Yuan Ren, Wenzhe Cai, Xuewei Zhang, Suihu Yang
School of Communications and Information Engineering
Xi’an University of Posts and Telecommunications, Xi’an, 710121, China
E-mail: {renyuan, zhangxw, yangsuihu}@xupt.edu.cn, caizw@stu.xupt.edu.cn

Abstract—This paper investigates a simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS) assisted downlink non-orthogonal multiple access (NOMA) system, consisting of a base station (BS), a STAR-RIS, a transmission user and a reflection user, where STAR-RIS uses mode switching protocols. Under the proposed transmission model, the base station serves the two users via the STAR-RIS and a direct link exists from the base station to the reflection user. By using the Beaulieu series, the statistical property of the Nakagami-m fading cascaded channel is characterized. Based on this, closed-form expressions of outage probability and diversity order for the reflection user and transmission user are obtained, respectively. In addition, to ensure the maximum gain in system throughput, a component allocation scheme is proposed, and the optimal allocation interval between the transmission and reflection components is obtained. Numerical results verify the theoretical analysis and demonstrate the superiority of the proposed scheme in terms of outage probability and system throughput compared to existing schemes.

Index Terms—Simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS), non-orthogonal multiple access (NOMA), mode switching, outage probability, component allocation.

I. INTRODUCTION

With the rapid development of industrial Internet of things, the demand for massive connectivity, higher spectrum efficiency (SE) and energy efficiency (EE) of various wireless devices has gradually increased [1]. Reconfigurable intelligent surface (RIS) is a new technology in the upcoming sixth generation (6G) wireless communication systems, and has garnered significant research interest from both academia and industry [2]. The existing literature [3] proved the great advantages of RIS for improving SE, and EE in the considered networks. Deploying RIS in traditional communication systems can guarantee the quality-of-service (QoS) requirements of users in signal blind spots by creating line-of-sight (LOS) links to transmit signals without consuming extra radio frequency (RF) chains, which can get lower cost, lower power consumption, and higher SE.

The existing research works on RIS mainly focus on a purely reflective way, which limits the coverage of the served users to $180^\circ$, i.e., the base station (BS) and its served users should locate on the same side of the RIS and the BS cannot serve the users on the other side of the RIS. This results in incomplete coverage, which limits the application of RIS in practical systems. To this regard, a new type of RIS named simultaneously transmitting and reflecting RIS (STAR-RIS) [4] comes into being, which can magnify the coverage space from $180^\circ$ to $360^\circ$. Currently, STAR-RIS was designed to operate in three protocols, i.e., time switching (TS), energy splitting (ES) and mode switching (MS).

As one of the promising candidates for 6G, non-orthogonal multiple access (NOMA) supports massive device connections and higher SE [3]. Specifically, NOMA differs from traditional orthogonal multiple access in transmitting signals over the same time/frequency/code resources by power domain multiplexing, and adopts power allocation to achieve fairness among users. Consequently, the combination of STAR-RIS and NOMA is able to support the large-scale device connectivity and $360^\circ$ full coverage, which has become a promising research direction for 6G.

Recently, several research works focused on the analysis of STAR-RIS assisted NOMA downlink systems [5]–[7]. In [5], a joint power and discrete amplitude allocation scheme was investigated for STAR-RIS assisted NOMA system. In addition, in [6], the coverage of the STAR-RIS assisted NOMA system was studied, and the analysis showed that the coverage can be broadened under NOMA. To explore a more realistic deployment scenario, the authors in [7] investigated a STAR-RIS assisted NOMA system with a direct link between BS and the user, and the secrecy outage probability under this system was analyzed. It can be found that when a direct link exists between BS and the user, it not only has better outage performance but also has a higher diversity order. In the papers [5]–[7] above, STAR-RIS all used ES protocol. In the ES protocol, each component reflects signal and transmits signal at the same time, increasing the complexity and cost of the components, and it cannot adjust component allocation to the actual deployment environment. Therefore, when the number of components is fixed, users with poor channel conditions cannot improve performance through component allocation. On the contrary, in the MS protocol, all components are divided into two parts, i.e., one for signal reflection and the other for signal transmission. Lower manufacturing costs and more flexibility due to each component being responsible for only one function. Combining direct links with MS protocols

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produces higher system performance because the performance of users who cannot build the direct link can be improved by component allocation. To the best of our knowledge, the transmission design and component allocation for MS protocol based STAR-RIS assisted downlink NOMA systems with direct links have not been studied.

In this paper, we consider an MS protocol based STAR-RIS assisted downlink NOMA system with a direct link from BS to the reflection user, where the reflection user can be served by BS and STAR-RIS simultaneously and the transmission user can only be served by STAR-RIS. Due to the co-existence of cascaded channels and direct links in the transmission model, to reduce the complexity of channel coupling, the exact cascaded channels and direct links in the transmission model, the reflection user, where the reflection user can be served by assisted downlink NOMA system with a direct link from BS to

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The BS serves both two users through the MS protocol and divides the STAR-RIS carries out the MS protocol and divides the STAR-RIS components into two parts, \( S_r \) and \( S_t \), where \( S_r \) for reflection and consists of \( N_R \) components, \( S_t \) for transmission and consists of \( N_T \) components, \( N = N_R + N_T \). Hence, the transmission and reflection matrices of STAR-RIS are denoted as \( \Theta_R = \sqrt{P_R} \text{diag}(e^{j\theta_1}, e^{j\theta_2}, \ldots, e^{j\theta_{N_R}}) \) and \( \Theta_T = \sqrt{P_T} \text{diag}(e^{j\theta_1}, e^{j\theta_2}, \ldots, e^{j\theta_{N_T}}) \). Without loss of generality, the components in both \( S_r \) and \( S_t \) are ideal components with no energy consumption, and their amplitude coefficients are both one.

The BS serves both two users through the MS protocol and divides the STAR-RIS, creating links from BS to STAR-RIS (\( S_r \)), from BS to STAR-RIS (\( S_t \)), from STAR-RIS (\( S_t \)) to U_R, and from STAR-RIS (\( S_r \)) to U_T. Since there is severe congestion between the BS and the U_T, the BS can only provide direct service to the U_R, creating a direct link from the BS to the U_R. Subsequently, we denote the corresponding channel vectors as \( h_{SR} \in \mathbb{C}^{N_R \times 1} \), \( h_{ST} \in \mathbb{C}^{N_T \times 1} \), \( h_{RR} \in \mathbb{C}^{1 \times N_R} \), \( h_{RT} \in \mathbb{C}^{1 \times N_T} \), and \( h_{BR} \), where these channels are modeled as Nakagami-\( m \) distribution and the fading parameters are \( m_1, m_2, m_3, m_4 \) and \( m_5 \).

II. SYSTEM MODEL AND THE PROPOSED SCHEME

A. System Model

We consider an MS protocol based STAR-RIS assisted downlink NOMA system as shown in Fig. 1, where a BS utilizes NOMA protocol to serve two users U_R and U_T, where U_R is the reflection user and U_T is the transmission user. The BS serves two users through the STAR-RIS equipped with \( N \) components, where the U_R has a direct link to the BS and can also be served by the BS. Moreover, the BS and both two users are equipped with single antenna.

The STAR-RIS carries out the MS protocol and divides the STAR-RIS components into two parts, \( S_r \) and \( S_t \), where \( S_r \) for reflection and consists of \( N_R \) components, \( S_t \) for transmission and consists of \( N_T \) components, \( N = N_R + N_T \). Hence, the transmission and reflection matrices of STAR-RIS are denoted as \( \Theta_R = \sqrt{P_R} \text{diag}(e^{j\theta_1}, e^{j\theta_2}, \ldots, e^{j\theta_{N_R}}) \) and \( \Theta_T = \sqrt{P_T} \text{diag}(e^{j\theta_1}, e^{j\theta_2}, \ldots, e^{j\theta_{N_T}}) \). Without loss of generality, the components in both \( S_r \) and \( S_t \) are ideal components with no energy consumption, and their amplitude coefficients are both one.

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B. The Proposed Scheme

Based on the above system model, the superimposed signals \( \sqrt{a_R P_x} x_R + \sqrt{a_T P_x} x_T \) are transmitted to STAR-RIS and U_R simultaneously, where \( a_R \) and \( a_T \) are the corresponding power allocation factors with \( a_R > 0 \), \( a_T > 0 \), and \( a_R + a_T = 1 \). \( P_x \) is the transmission power, \( x_R \) and \( x_T \) are the normalized information symbols for U_R and U_T with \( \mathbb{E}\{ |x_R|^2 \} = \mathbb{E}\{ |x_T|^2 \} = 1 \). Based on the correlated phase shift design method [9], the received signals at U_R and U_T are given by

\[
y_{UR} = \left( \sum_{n=1}^{N_R} |h_{SR}^n| |h_{RR}^n| D_{SR} + |h_{BR}^n| D_{BR} \right) \times \sum_{i \in \{T,R\}} \sqrt{a_i P_x} x_i + n_R \tag{1}
\]

\[
y_{UT} = \sum_{n=1}^{N_T} |h_{ST}^n| |h_{RT}^n| D_{ST} \sum_{i \in \{T,R\}} \sqrt{a_i P_x} x_i + n_T \tag{2}
\]

where \( D_{SR} = d_{SR}^{a_{SR}} \times d_{RR}^{a_{RR}} \), \( D_{BR} = d_{BR}^{a_{BR}} \) and \( D_{ST} = d_{ST}^{a_{ST}} \times d_{RT}^{a_{RT}} \) are separately the product-distance-based path loss for U_R and U_T, where \( d_{SR}, d_{BR}, d_{RR} \) and \( d_{RT} \) are the distance from BS to STAR-RIS, from BS to U_R, from STAR-RIS to U_R, and from STAR-RIS to U_T, respectively. \( a_{SR}, a_{ST}, a_{BR}, a_{RR} \) and \( a_{RT} \) are the path loss exponents for each path, \( n_i \sim CN(0, \sigma^2) \) is additive Gaussian white noise with variance \( \sigma^2 \). According to [7], let \( a_{SR} = a_{ST} = a_{RT} = a_{RR} = \frac{a_{BR}}{2} = a \), \( d_{SR} \times d_{BR} = d_{RR}^2 \). So path loss \( D_{SR} = D_{BR} \). The received signal at U_R can be rewritten as

\[
y_{UR} = \left( \sum_{n=1}^{N_R} |h_{SR}^n| |h_{RR}^n| + |h_{BR}^n| \right) \times \sum_{i \in \{T,R\}} \sqrt{a_i P_x} x_i + n_R \tag{3}
\]
As per the principles of NOMA, the user with a better channel condition conducts SIC, and the other user decodes its signal directly. However, in practice, the user’s channel conditions are constantly changing. In this paper, we assume that $U_R$ has a higher priority and the decoding order is determined as $(U_R, U_T)$. Therefore, received signal-to-noise ratio (SNR) to decode $x_T$ at $U_R$ can be expressed as

$$r_{U_R}^{(U_T)} = \frac{a_T r_{in} D_{SR}^{2}}{\sum_{n=1}^{N_R} |h_{SR}^n| |h_{RR}^n| + |h_{BR}|^2} \cdot (4),$$

$\frac{a_T r_{in} D_{SR}^{2}}{\sum_{n=1}^{N_R} |h_{SR}^n| |h_{RR}^n| + |h_{BR}|^2} + 1$

where $r_{in} = \frac{\sigma}{\sqrt{2}}$ is the transmit SNR. After decoding and subtracting $x_T$, the received SNR to decode $x_R$ at $U_R$ can be expressed as

$$r_{U_R}^{(U_T)} = \frac{a_T r_{in} D_{SR}^{2}}{\sum_{n=1}^{N_R} |h_{SR}^n| |h_{RR}^n| + |h_{BR}|^2} \cdot (5).$$

During information decoding, $x_R$ is an interference signal for $U_T$, and the received SNR to decode $x_T$ can be expressed as

$$r_{U_T}^{(U_T)} = \frac{a_T r_{in} D_{SR}^{2}}{\sum_{n=1}^{N_T} |h_{ST}^n| |h_{RT}^n|} \cdot (6).$$

### III. Performance Analysis

In this section, a novel channel statistic method is analyzed to evaluate the outage probability, diversity order of $U_R$ and $U_T$. Finally, a closed-form expression for the system throughput is derived.

#### A. Channel Distribution Analysis

By observing (4)-(6), we first need to solve a complex channel characteristic problem, which is the distribution of the summation of $N$ double Nakagami-$m$ random variables.

We define a random variable $X = \sum_{n=1}^{N_T} g_n$, where $g_n = G_1 G_2$, $G_1 = |h_{SR}^n|$, $G_2 = |h_{RR}^n|$. When $G_1$ and $G_2$ are two non-identical and independent Nakagami-$m$ variables, $m_1 \neq m_3$, the cumulative distribution function (CDF) of $X$ can be obtained as [10]

$$F_X(x) = \frac{1}{2} - \sum_{n=1, odd}^{n_{max}} \frac{2 \Im(e^{-j\omega x} \Phi_X(\omega n))}{\pi},$$

where $n_{max}$ and $\omega$ are two controlled variables, denoting the balancing computational complexity and approximate accuracy, respectively. $\Im(.)$ denotes the imaginary part, $\Phi_X(\omega n)$ is the characteristic function of $X$, $\Phi_{g_n}(\omega n) = \int_{\frac{\omega}{2}}^{\omega} F_1 (m_1, m_3; \frac{1}{2}; \gamma_a) + \xi_a F_1 (\frac{1}{2} + m_1, m_3; \frac{1}{2}; \gamma_a)$, $\Phi_X(\omega n) = \int_{n_{max}}^{\omega} \Phi_{g_n}(\omega n)$, where $\gamma_a = \frac{m_3 - m_3}{\Gamma(m_1, m_3)}$, $\Gamma(.)$ is the gamma function and $F_1(.)$ is the Gauss hypergeometric function.

### B. Outage Probability

#### 1) Outage Probability of $U_R$:

When the received SNR $r_{U_R}$ and $r_{U_T}$ at $U_R$ are lower than $r_{th}$ and $r_{th'}$, respectively, the transmission outage will occur. Therefore, the outage probability of $U_R$ can be expressed as

$$P_{U_R} = 1 - \Pr \left( r_{U_R}^{(U_T)} \geq r_{th} U_R, r_{U_T}^{(U_T)} \leq r_{th'} U_T \right),$$

where $r_{th} = 2r_{th} - 1$ is the threshold of SIC and $r_{th'}$ is the target rate of $U_T$. When $a_T \leq a_T r_{th}$, it is clear that $P_{U_R} = 1$, when $a_T > a_T r_{th}$, substituting (4) and (5) into (8), let $\sum_{n=1}^{N_R} |h_{SR}^n| |h_{RR}^n| = H_B$ and $|h_{BR}| = H_B$, the outage probability of $U_R$ can be expressed as

$$P_{U_R} = 1 - \Pr (H_R - H_B + \tilde{y}_s),$$

where $\tilde{y}_s = \max \left\{ \sqrt{a_T r_{U_T}^{(U_T)}}^\frac{1}{2}, \sqrt{a_T r_{U_T}^{(U_T)}}^\frac{1}{2} \right\}.$

#### Proposition 1. The outage probability of $U_R$ is given as

$$P_{U_R} \approx A \sum_{m=1}^{M} \omega_m \sqrt{1 - x_m^2} (\tan \theta_m)^{2m-1} e^{-m_3} (\tan \theta_m)^2 \times F_X (a (\tan \theta_m) + b) \sec^2(\theta_m),$$

where $A = \frac{\pi}{4} \times 2(m_3)^{m_3} \pi x_m = \frac{\pi}{M}, x_m = \cos \left( \frac{2m-1}{2M} \pi \right), \theta_m = \frac{\gamma}{4} (x_m + 1)$. 

**Proof:** Because $U_R$ has a direct link to BS, a complex integral involving two random variables needs to be solved, let $X = H_R$, $y = H_B$, $a = -1$, $b = \tilde{y}_s$, (9) can be expressed as

$$P_{U_R} = 1 - \Pr (X \geq ay + b)$$

$$= 1 - \int_{0}^{\infty} f_y(t_1) [1 - F_X (at_1 + b)] dt_1, \quad (12)$$

where $f_y(t_1)$ is a function of $y$ concerning $t_1$. Since $y = H_B$ obeys the Nakagami-$m$ distribution, using its probability density function, (12) can be simplified as

$$P_{U_R} = 1 - \Pr (X \geq ay + b)$$

$$= \frac{2(m_3)^{m_3}}{T(m_5)} \int_{0}^{\infty} t^{m_3-1} e^{-m_3 t} F_X (at_1 + b) dt_1. \quad (13)$$

Then, the Chebyshev-Gauss quadrature can be utilized to approximate (13), the outage probability of $U_R$ can be derived as Eq. (11).

#### 2) Outage Probability of $U_T$:

When the received SNR $r_{U_R}^{(U_T)}$ at $U_T$ is lower than $r_{th}$, the transmission outage will occur, the outage probability of $U_T$ can be expressed as

$P_{U_T} = \Pr \left( r_{U_T}^{(U_T)} < r_{th} \right), \quad (14)$
when $a_T \leq a_R r_U^{th}$, it is possible to obtain $P_{U_T} = 1$, when $a_T > a_R r_U^{th}$, substituting (6) into (14), the outage probability of $U_T$ can be expressed as

$$P_{U_T} = \Pr (Y < C),$$

(15)

where $C = \sqrt{\frac{r_{U_T}}{r_m D_T (a_T - a_R r_U^{th})}}$. $Y = \left\lceil \sum_{n=1}^{N_T} l_n \right\rceil$, $l_n = |h_{n}^{th}| |h_{RT}^{th}|$. Using the same method as Proposition 1, the outage probability of $U_T$ can be derived as

$$P_{U_T} \approx F_Y (C).$$

(16)

C. Diversity Order

In this subsection, we can directly utilize the characteristic function to derive the diversity order by referring Proposition 4 in [11].

1) Diversity Order of $U_R$: According to Wolfram research in [12], Eq.(07.23.02.0004.01) for approximating $\Phi_X (wn)$.

When $jw \to \infty$, $\Phi_X (wn)$ can be obtained as

$$\Phi_X (wn) = N_n^{\psi} (\psi_1 \gamma_1^{-a_1 - m_1} + \psi_2 \gamma_2^{-a_2 - m_2})
+ N_n \left( \left( \frac{\psi_3 \gamma_3^{-a_3 - m_3} + \psi_4 \gamma_4^{-a_4 - m_4}}{2} \right) \right)^N_n,$$

(17)

where $\psi_1 = \sqrt{\pi} \Gamma (m_1 - m_1) / \Gamma (m_1 - m_1)$, $\psi_2 = \sqrt{\pi} \Gamma (m_1 - m_1) / \Gamma (m_1 - m_1)$, $\psi_3 = \sqrt{\pi} \Gamma (m_1 - m_1) / \Gamma (m_1 - m_1)$, $\psi_4 = \sqrt{\pi} \Gamma (m_1 - m_1) / \Gamma (m_1 - m_1)$. Finally, since the lower bound of the cascaded channel gain equals to $X^2$, diversity order at $U_R$ can be obtained as

$$d_{U_R} = N_R \min (m_1, m_2, m_3) + m_5,$$

(18)

2) Diversity Order of $U_T$: Since $U_T$ can only receive signals from STAR-RIS. Similar to the above analysis, we can obtain the diversity order at $U_T$ based on the characteristic function $\Phi_Y (wn)$ as

$$d_{U_T} = N_T \min (m_2, m_4).$$

(19)

D. System Throughput

The system throughput reflects the amount of information that can be carried in the current system. When the target rate is fixed, the system throughput can be obtained from the amount of data correctly received at $U_R$ and $U_T$, respectively. Therefore, the system throughput of the considered system is given by

$$R = \sum_{\chi \in \{R,T\}} (1 - P_{U_{\chi}}) R_{U_{\chi}}^{th}.$$  

IV. COMPONENT ALLOCATION SCHEME

In this section, aiming to find the optimal component allocation scheme can maximize system throughput. Using maximizing the system throughput as the objective function, by substituting (11) and (17) into (20) to obtain the objective function, the optimization problem can be modeled as

$$\max_{N_{T,R}} \left( 1 - A \sum_{m=1}^{M} \omega F_X (a (\tan \theta_m) + b) R_{U_R}^{th} + (1 - F_Y (C)) R_{U_T}^{th} \right)$$

s.t. \hspace{1cm} \begin{align*}
0 \leq N_R \leq N, N_R \in \mathbb{Z}, \\
0 \leq N_T \leq N, N_T \in \mathbb{Z}, \\
N_R + N_T = N, \\
\end{align*}$$

(21a)

where

$$\omega = \omega_m \sqrt{1 - \pi^2 m_2} (\tan \theta_m)^{2m_5 - 1} e^{m_5 (\tan \theta_m)^2} \sec^2 (\theta_m),$$

(22)

in (22a), there is no explicit representation of the optimization variables $N_R$ and $N_T$, according to $F_X (a (\tan \theta_m) + b)$ and $F_Y (C)$, optimization variables $N_R$ and $N_T$ are included in the characteristic functions $\Phi_X (wn)$ and $\Phi_Y (wn)$, respectively.

(22b) and (22c) indicate that both $N_R$ and $N_T$ belong to the interval $[0, N]$ and are integers, and according to the constraint (22d), $N_R$ and $N_T$ are negatively correlated with each other. Therefore, we can solve this optimization problem using one-dimensional linear search by fixing the total number of components $N$ and limiting the user target rate $R_{U_R}^{th}$.

Remark 1. This scheme can significantly increase the throughput performance and reduce the additional hardware overhead under the system. Due to the impact of user target rate on system throughput, we set three different sets of target rates $\{R_{U_R}^{th}, R_{U_T}^{th}\} = \{0.5, 1\}, \{1, 1\}, \{1, 0.5\}$ in the following to explore the optimal component allocation scheme. The optimal range of the ratio of the number of the transmission components and the reflection components $N_T/N_R = [1, 5/3]$.

V. NUMERICAL RESULTS

In this section, we validate the accuracy of the theoretical analysis of the proposed scheme by Monte-Carlo simulations. The proposed scheme is compared with the existing scheme in [9]. Unless otherwise stated, the system parameters are shown as follows [7]. The target rates are $R_{U_R}^{th} = R_{U_T}^{th} = 0.5$ bit per channel use (BPCU), the distances from BS to STAR-RIS, BS to $U_R$, STAR-RIS to $U_r$, and STAR-RIS to $U_T$ are $d_{SR} = 10$ m, $d_{BR} = 7$ m, $d_{IR} = 4.9$ m, $d_{RT} = 10$ m, respectively, the path loss exponent is $\alpha = 2.3$, the transmit power allocation factors are $a_T = 0.7$, $a_R = 0.3$, the transmit SNR is $r_m = 30$ dB, the Nakagami-$m$ fading parameters are $m_1 = m_2 = 3.3$, $m_3 = m_4 = 2$, $m_5 = 2.4$, the total number of components of STAR-RIS is $N = 32$, the reflection components are $N_R = 12$, the transmission components are $N_T = 20$, the controllable parameters $n_{max} = 300$, $w = 0.15$.

Fig. 2 depicts the outage probability versus the transmit SNR between different schemes. We considered two different component configurations of STAR-RIS, i.e., STAR-RIS 1 with $\{N = 32; N_R = 12, N_T = 20\}$ and STAR-RIS 2 with $\{N = 48; N_R = 18, N_T = 30\}$. It can be clearly seen that the theoretical analysis of outage probability for $U_T$ and $U_R$
matches well with the simulation results, which confirms that Beaulieu series is an efficient tool for analyzing cascaded channel channel statistics. With the increase of SNR, the curve of STAR-RIS 2 becomes steeper. This is because that more components can create more LOS links to improve signal enhancement. Because of the existence of direct link, this scheme is to ensure the performance of $U_R$. Moreover, component allocation for STAR-RIS improves the performance of $U_T$. Compared to the existing scheme [9], the proposed scheme has a great advantage in terms of outage performance.

Fig. 3 shows the system throughput versus the transmit SNR between the proposed and existing schemes. The proposed scheme is better than the existing scheme in [9] at all transmit SNR regions for the three different sets of target rates. When $R_{U_R}^{th} < R_{U_T}^{th}$, although our scheme reduces the performance of $U_T$, it achieves a larger performance improvement at $U_R$. This results in a higher throughput compared to [9]. On the contrary, when $R_{U_R}^{th} > R_{U_T}^{th}$, the performance of $U_T$ with poor channel conditions is significantly gained at this time, which greatly ensures the performance of the system. Finally, all curves exist a throughput ceiling due to the constraint in (20).

Fig. 4 plots the outage probability versus the transmission components with a total number of components of $N = 40$. It can be clearly seen that the outage probability of $U_R$. This and $U_T$ shows an opposite trend. Moreover, when the number of transmission components is 20, the number of transmission components is equal to that of reflection components, but the outage performance of $U_R$ is still better than that of $U_T$, once again proving the existence of $U_R$ direct links.

Fig. 5 describes the system throughput versus the transmission components with a total number of components of $N = 40$. We verify the component allocation range for the maximum gain in system throughput. When $R_{U_R}^{th} < R_{U_T}^{th}$, the system throughput reaches an optimal value at the number of transmission component of 25. Instead, at $R_{U_R}^{th} > R_{U_T}^{th}$, the system throughput reaches its optimal value when the number of transmission component is 20. When $R_{U_R}^{th} = R_{U_T}^{th}$, the system throughput does not differ much throughout the interval. Therefore, regardless of target rate sets of the users, the allocation of transmission and reflection components in the range of $N_T/N_R = [1, 0.5]$ can achieve the optimal throughput of the system.

VI. CONCLUSIONS

In this paper, we investigated an MS protocol based STAR-RIS assisted downlink NOMA system with a direct link from BS to the reflection user. A novel channel statistics was evaluated to evaluate the outage probability and diversity order of $U_R$ and $U_T$, and the throughput of the system. To maximize the throughput of the system, the optimal component allocation scheme was obtained for this system. Numerical results verified the correctness of our analysis, and the proposed scheme yielded significant gains in outage probability and system throughput.

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