Performance of Double Reconfigurable Intelligent Surface Assisted Communication System

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***Abstract*—Since reconfigurable intelligent surface(RIS) enhances the spectral efficiency of wireless communication system, it is a promising technology in the future communication. However, if there are a lot of obstacles, single RIS cannot guarantee performance and double RIS experiences fading three times. So, this paper suggests double RIS assisted communication system with amplifier. Suggested RIS system is compared with conventional RIS system in terms of bit error rate and sumrate. Simulation result shows that the performance of suggested RIS system outperforms single RIS system by 4.7% and double RIS system without amplifier by 12.6%, in terms of sumrate.**

***Index Terms*—5G, MU-MISO, Reconfigurable intelligent surface(RIS), double RIS**

I. Introduction

Reconfigurable intelligent surface(RIS) has emerged as a promising technology to enhance the spectral efficiency of wireless communication system in future[1]. RIS is consisted of a single plane with passive reflective elements that phase and amplitude can be adjusted. Existing communication systems show limited performance when an obstacle such as a building exists between a transmitter and a receiver. However, the RIS-based communication system can overcome limitations of real environment because the signal sent from the transmitter is reflected by the passive reflection elements of the RIS and enters in the receiver. RIS-based communication system has a similar structure to cooperative communication such as amplify and forword and decode and forword, but it has advantages in terms of cost and energy efficiency by reducing the number of RF chains required in existing cooperative communication. However, if there are a lot of obstacles, single RIS cannot guarantee performance. This paper considers double RIS system. In this system, the signal reflected by the two RISs is transmitted through three channels(Base station to RIS1, RIS1 to RIS2, RIS2 to user). So, in this system, there is attenuation of the signal that occurs when the signal experiences fading several times. To solve this problem, this paper considers the structure of RIS2 including an amplifier. The energy consumption of RIS with amplifier and conventional RIS is 6 20mW[2] and 5mW[3]. The energy consumption of RIS with amplifier is slightly higher than conventional RIS , but better performance can be obtained.

A. Notation

Vectors and matrices are denoted with bold lower and bold upper letters, respectively. $\mathbf{a_i}$ and $\|\mathbf{a}\|$ refer to the i-th element and L2-norm of vector $\mathbf{a}$, respectively. $\mathbf{A}^{-1}$,$\mathbf{A}^T$, $\mathbf{A}^H$, $\|\mathbf{A}\|_F$ and $\lceil x \rceil$ refer to the inverse, transpose, conjugate transpose, frobenius norm of matrix $\mathbf{A}$ and ceiling function, respectively. $\mathbb{R}$ and $\mathbb{C}$ denote the real and complex number sets, respectively. $j = \sqrt{-1}$ denotes the imaginary unit. diag $(a_1, \cdots, a_N)$ refers to a diagonal matrix with diagonal elements with $a_1, \cdots, a_N$.

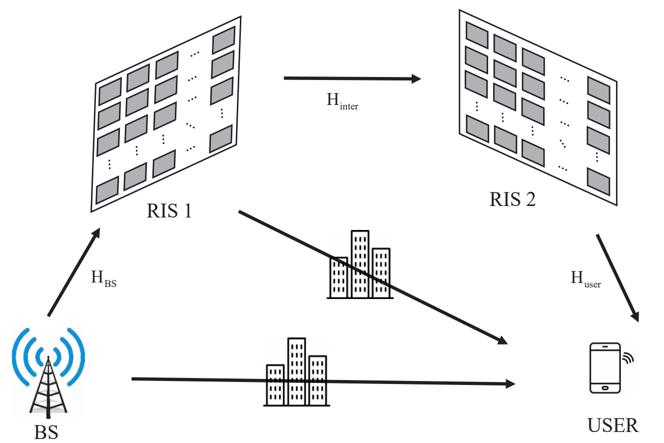

Fig. 1. Double RIS MISO communication system

B. Organization

Section II presents the system model for the double RIS assited system. Section III proposes scheme exploiting Singular Value Decomposition to optimize RIS reflective element with amplifier. Section IV presents simulation result for the proposed scheme compared to conventional scheme. And conclusions are presented in Section V.

II. System model

This paper considers double RIS MISO communication system of Fig 1. Base station(BS) with M antennas communicates with user with single antenna. The direct link between BS and user is blocked by obstacles, and then direct link can be ignored. Also the link between RIS1 to user is blocked by obstacles, and then this link can be ignored. N denotes total number of RIS passive reflective elements and N_1, N_2 are number of RIS 1, RIS 2 passive reflective elements with $N_1 + N_2 = N$

Let $\mathbf{H}_{BS} \in \mathbb{C}^{N_1 \times M}$, $\mathbf{H}_{inter} \in \mathbb{C}^{N_2 \times N_1}$ and $\mathbf{H}_{user} \in \mathbb{C}^{U \times N_2}$ are BS to RIS 1 channel, RIS 1 to RIS 2 channel and RIS 2 to user channel, respectively, with $U = [1, \cdots, U]$. Let $\theta_l = [\theta_{l,1}, \cdots, \theta_{l,N_l}] = [\beta_{l,1} e^{j\phi_{l,1}}, \cdots, \beta_{l,N_l} e^{j\phi_{l,N_l}}] \in \mathbb{C}^{N_l \times 1}$ denotes equivalent reflection coefficients of RIS 1 where $l \in [1,2], \beta_{l,n} \in [0,1]$ and $\phi_{l,n} \in [0, 2\pi)$ are RIS number, amplitude and phase of passive reflective element n at RIS l Thus, the received signal through double reflection channel between BS and user is given as follows,

$$\mathbf{Y} = \mathbf{H}_{user} \mathbf{\Theta}_2 \mathbf{H}_{inter} \mathbf{\Theta}_1 \mathbf{H}_{BS} X + \mathbf{N} \in \mathbb{C}^{U \times M}, \quad (1)$$

where $\mathbf{N} \in \mathbb{C}^{U \times M}$ denotes addictive white Gaussian noise(AWGN) matrix with independent and identically distributed(i.i.d.) entries of zero mean and variance σ^2. $\mathbf{\Theta}_l = diag(\theta_l) \in \mathbb{C}^{N_l \times N_l}$ and X denote diagonal reflection matrix of RIS l and pilot symbol, which is simply set as $X = 1$, respectively. And then, received signal can be expressed as follows,

$$\mathbf{Y} = \mathbf{H}_{user} \mathbf{\Theta}_2 \mathbf{H}_{inter} \mathbf{\Theta}_1 \mathbf{H}_{BS} + \mathbf{N} \in \mathbb{C}^{U \times M} \quad (2)$$

The signal-to-interference-plus-noise ratio(SINR) of active RIS at the u-th user can be expressed as follows,

$$\gamma_u = \frac{\|\mathbf{H}_{eff,u} \mathbf{w}_u\|^2}{\sum_{i=1, i \neq u}^{U} \|\mathbf{H}_{eff,u} \mathbf{w}_i\|^2 + \|\mathbf{H}_{active}\|^2 \sigma_a^2 + \sigma^2}, \quad (3)$$

where $\mathbf{H}_{eff,u}$, $\mathbf{H}_{active}$ and σ_a are $\mathbf{H}_{user,u} \mathbf{\Theta}_2 \mathbf{H}_{inter} \mathbf{\Theta}_1 \mathbf{H}_{BS}$, $\mathbf{H}_{user,u} \mathbf{\Theta}_2$ and noise power caused by amplifier. $\mathbf{W}$ denotes zero-forcing(ZF) transmit beamforming matrix $\mathbf{W} = \mathbf{H}_{eff}^H (\mathbf{H}_{eff} \mathbf{H}_{eff}^H)^{-1}$ and $\mathbf{W}$ should be normalized by the factor $\mathbf{W}_{factor}$ as follows,

$$\mathbf{W}_{factor} = \frac{\sqrt{p}}{\|\mathbf{W}\|_F}, \quad (4)$$

The sumrate $\mathbf{R}$ can be represented as follows,

$$\mathbf{R} = \sum_{i=1}^{U} log_2(1 + \gamma_u) \quad (5)$$

III. Propose scheme

In single RIS system, the received signal $\mathbf{Y}$ is $\mathbf{Y} = \mathbf{H}_{user} \mathbf{\Theta} \mathbf{H}_{BS} + \mathbf{N}$. Since $\mathbf{\Theta}$ is diagonal matrix ($\mathbf{\Theta} = diag(\theta)$), the received signal can expressed as $\mathbf{Y} = \theta diag(\mathbf{H}_{user}) \mathbf{H}_{BS} + \mathbf{N}$. To find optimized $\mathbf{\Theta}$, find the covariance matrix of $diag(\mathbf{H}_{user}) \mathbf{H}_{BS}$ and apply singular value decomposition(SVD) to that matrix.

$$\mathbf{T} = svd(\mathbf{H}(\mathbf{H})^H) = \mathbf{U} \sum \mathbf{V}^H, \quad (6)$$

where $\mathbf{H}$ is $diag(\mathbf{H}_{user}) \mathbf{H}_{BS}$. The phase of RIS reflective elements are optimized by exploiting V obtained from equation (5).

In double RIS system, phase of each RIS reflective element can be optimized as the above method. Then, by multiplying amplified value, RIS system with amplifier can be implemented as follows,

$$\theta = \eta exp(j\mathbf{V},) \quad (7)$$

where η denotes amplifier value. The algorithm of double RIS system with amplifier is shown in Algorithm 1.

Algorithm 1 Double RIS MISO System Assisted by Amplifier

INPUT: $\mathbf{H}_{BS}, \mathbf{H}_{inter}, \mathbf{H}_{user}, \eta$

OUTPUT: $\mathbf{\Theta}_1, \mathbf{\Theta}_2$

1: $\mathbf{Y} = \mathbf{H}_{user} \mathbf{\Theta}_2 \mathbf{H}_{inter} \mathbf{\Theta}_1 \mathbf{H}_{BS}$
2: $\mathbf{T}_1 = svd(\sum_{n=1}^{N} \mathbf{H}_n (\mathbf{H}_n)^H) = \mathbf{U}_1 \sum_1 \mathbf{V}_1^H$
3: $\mathbf{\Theta}_1 = \text{diag}(exp(j\angle(\mathbf{V}_1)))$
4: $\mathbf{Y}_u = \mathbf{H}_{user,u} \mathbf{\Theta}_2 \mathbf{H}_1$, $\mathbf{H}_1 = \mathbf{H}_{inter} \mathbf{\Theta}_1 \mathbf{H}_{BS}$
5: $\mathbf{T}_2 = svd(\sum_{u=1}^{U} \mathbf{G}_u (\mathbf{G}_u)^H) = \mathbf{U}_2 \sum_2 \mathbf{V}_2^H$
6: $\mathbf{\Theta}_2 = \text{diag}(exp(j\angle(\mathbf{V}_2)))$
7: $\mathbf{\Theta}_2 = \text{diag}(\eta exp(j\angle(\mathbf{V}_2)))$

IV. Simulation result

In this paper, it is assumed that M,U,N and N_1 are 64, 6, 64, 8, respectively. BS, RIS1, RIS2, user are located at (1m,0), (0,0.5m), (0,99.5m) and (1m,100m), respectively. Each channel is considered as small-scale and large-scale

TABLE I
Simulation Parameters

Parameters	Value
c	-30dB
path-loss exponent for $\mathbf{H}_{inter}$	3
path-loss exponent for $\mathbf{H}_{user}$, $\mathbf{H}_{BS}$	2.2
noise power(σ^2)	-80dBm
noise power of amplifier(σ_a^2)	-76dBm
amplifier power(η)	2
Transmit Power	30:5:50 dB
Rician factor(K)	10

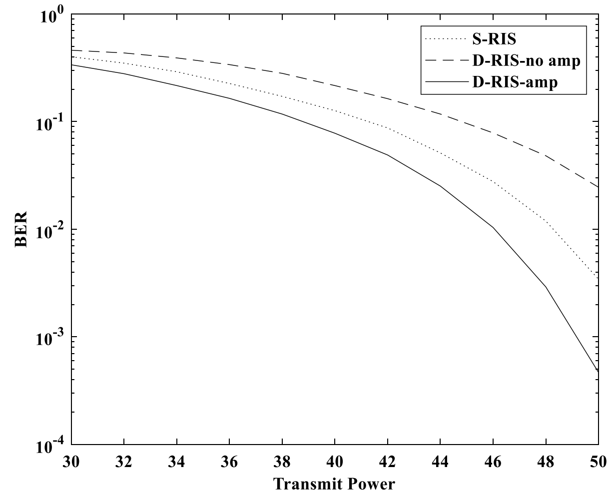

Fig. 2. BER vs Transmit Power(dBm)

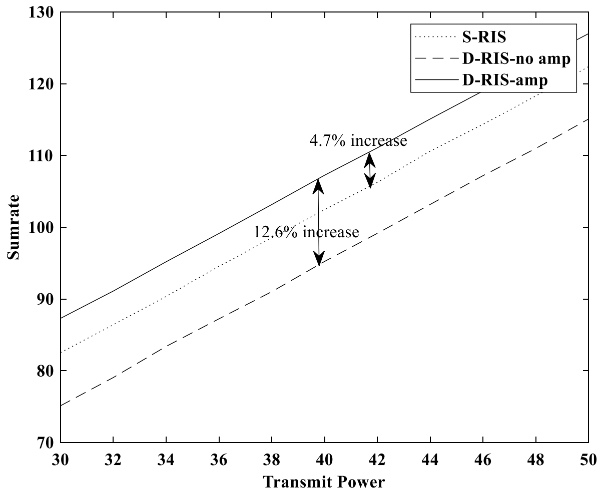

Fig. 3. Sumrate vs Transmit Power(dBm)

fading. The large-scale fading follows a distance-based path-loss model like $\mathbf{PL}(d_x) = c(d_x/d_0)^{-n}$, where c, d_x and n represent the path-loss exponent at a reference distance d_0, the distance between each node and the path-loss exponent. All of three channels have line-of-sight(LoS). Therefore, all channels experience small-scale fading that follows a Rician fading. Rician fading channel coefficients can represented as follows,

$$\mathbf{H} = \sqrt{\mathbf{PL}(d_x)}\left(\sqrt{\frac{K}{1+K}}\mathbf{H}_{LoS} + \sqrt{\frac{1}{1+K}}\mathbf{H}_{NLoS}\right), \tag{8}$$

where K, $\mathbf{H}_{LoS}$ and $\mathbf{H}_{NLoS}$ represent Rician factor, LoS channel and NLoS channel, respectively. NLoS channel follows a Rayleigh distribution with zero mean and unit variance. And remaining parameters are listed in Table 1.

In simulation results, S-RIS is communication system with single RIS and D-RIS-no amp, D-RIS-amp are communication system with double RIS that have no amp and just one amplifier at second RIS(RIS2), respectively. Figure 2 shows bit error rate(BER) vs transmit power for two systems. And Figure 3 shows sumrate vs transmit power for two systems. Both simulation results presents that double RIS with no amplifier is worse than single RIS. However, when double RIS has one amplifier, this system achieves higher performance than single RIS situation. This result means that although double RIS with no amplifier has lower performance than single RIS, it seems to be usable in a situation where obstacles block communication link between RIS and user. If an amplifier is exploited for double RIS, this system not only guarantees communication performance, but also outperforms single RIS.

V. Conclusion

In this paper, we compare the performance of single RIS, double RIS with no amplifier and one amplifier at RIS2. In the results, even though double RIS with no amplifier assisted communication system has lower performance than single RIS, it can be usable in situation where has a lot of obstacles. Double RIS with amplifier assisted communication system outperforms single RIS assisted communication system. In the future research, energy efficiency of RIS system with amplifier will be researched. Based on the research results, we will research a scheme that demonstrates good performance in terms of energy efficiency, BER and sumrate performance by limiting the number of amplifying RIS elements rather than amplifying the entire RIS elements.

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