Fully-Connected Active IRS based Cell-Free Massive MIMO for 6G Communication

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Abstract

Intelligent reflecting surface (IRS) has considered as a candidate for 6G communication since it is a low cost yet powerful devices to optimize the quality of the signal. An advanced version of IRS is power amplifier-equipped named active IRS and since it is attached in each IRS elements, it can be called fully-connected active IRS (FCAR). In this paper, FCAR is implemented in the cell-free massive MIMO scheme, which remove the cell boundaries in cellular network.

Ⅰ. Introduction

Intelligent reflecting surface (IRS) has considered as a candidate for 6G communication since it is a low cost yet the powerful enough to optimize the quality of the signal [1]. Recently, an advance version of IRS was introduced as active IRS and equipped with power amplifier in its elements. If the amplifier is attached to all elements, the active IRS can be called fully-connected active IRS (FCAR) [2].

Massive demands of network coverage has been has lead to the study of cell free massive MIMO (CF-mMIMO). Unlike conventional concept of cellular network, in CF-mMIMO, a high number of access points (AP)s and users are distributed in a large area without any cell boundaries [3].

Several studies have already explain about combination of IRS and CF-mMIMO. For example, in [4], the study about a multi-user downlink scenario in a CF-mMIMO system with imperfect channel state information was explained. In [5], the IRS-aided CF-mMIMO system and its max-min fairness problem was studied in order to maximize the minimum achievable rate. However, for the best knowledge of the authors, the previous work did not consider about active IRS in the CF-mMIMO scheme.

In this paper, we combine the FCAR with CF-mMIMO. According to [6], the combination of these two technologies is expected to have better performance than the conventional IRS-aided CF-mMIMO scheme in terms of achievable rate.

Ⅱ. System Models

In Fig. 1, the m -base stations (BS) with index $m = [1,..,M]$ can transmit signals to r-FCAR where $r = [1,..,R]$. From the FCAR, the signals are reflected with some power amplification towards the users which is denoted by $k = [1,\dots,K]$. In this study, we assume zero-forcing precoding applied in both BS and FCAR [3, 7]. Assuming some obstacles are found in the environment, the direct channel is not considered in the system. The communication channels from BS to the FCAR and FCAR to users are denoted by $\mathbf{H}_{m,r} = [H_{1,1},\dots,H_{M,R}] \in \mathbb{C}^{M\times R}$ and $\mathbf{G}_{r,k} = [G_{1,1},\dots,G_{R,K}] \in \mathbb{C}^{R\times K}$ respectively. Each user can be served by more than 1 FCAR.

According to [2], the structure of FCAR in the proposed system can be seen in Fig. 2. Since it is fully-connected, each FCAR element is consisted of power amplifier to strengthen the reflected signal. Besides that, phase-shifter and the patch are also needed as the basic components of IRS.

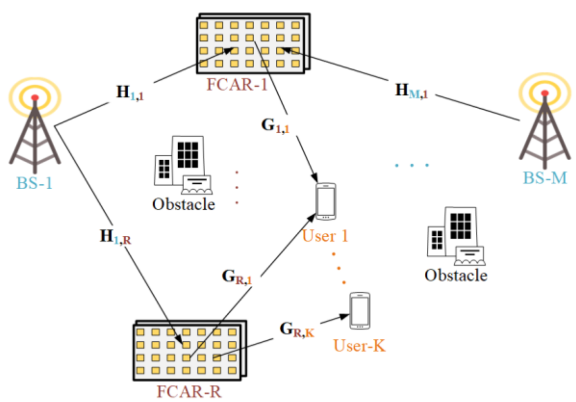

Figure 1. System model of FCAR CF-mMIMO.

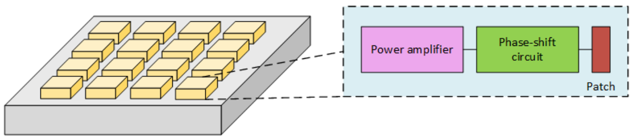

Figure 2. The components of FCAR.

III. Performance Analysis

The channels and received signal for m- BS and users k-users in downlink scheme can be written as follows

$$F_{m,k} = \sum_{m=1}^{M} \sum_{r=1}^{R} ((\mathbf{H}_{m,r}\boldsymbol{\Theta}\mathbf{G}_{r,k})\mathbf{x}_m) \quad (1)$$

$$y_k = \sqrt{P_{\mathrm{BS}}^{\mathrm{act}}}\rho\mathbf{F}_{m,k} + \rho\mathbf{G}_{r,k}\boldsymbol{\Phi}\mathbf{n}_r + n_{k,} \quad (2)$$

where $\sqrt{P_{\mathrm{BS}}^{\mathrm{act}}}$ denotes the transmit power of BS in FCAR CF-mMIMO where $\boldsymbol{\Theta} = \mathrm{diag}\{\rho_1 e^{j\theta_1}, \dots, \rho_N e^{j\theta_N}\}$ and $\rho_n > 1$ defines the reflection matrix in the IRS. $\mathbf{x}$ and n_k define transmitted signal, and additive white Gaussian noise, respectively. According to FCAR elements that implemented in the system, the signal to interference noise ratio (SINR) for k-user is defined as

$$\mathrm{SINR}_k = \frac{|\mathbb{E}\{\mathbf{F}_{m,k}\}|^2}{\sum_{k=1}^{K}\mathbb{E}\{|\mathbf{G}_{r,k}\boldsymbol{\Phi}|^2\}+\sigma^2}\sqrt{P_{\mathrm{BS}}^{\mathrm{act}}}\rho^2 . \quad (3)$$

As a result, the spectral efficiency of k-user can be written as

$$\mathrm{SE}_k = \log_2(1+\mathrm{SINR}_k) \ \text{bit/second/Heartz} . \quad (4)$$

IV. Conclusion

In this paper, the idea of fully-connected active IRS attached in the cell-free massive MIMO is explained. The combination of these two technologies are expected to improve the signal quality in the transmission.

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