Dynamic Subcarrier Assignment for IRS-assisted Multiuser MISO-OFDMA Systems

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Abstract

This paper investigates an intelligent reflecting surface (IRS) assisted multiuser multiple-input single-output orthogonal frequency division multiple access (MISO-OFDMA) system. We consider joint optimization of subcarrier assignment and beamforming in the multiuser MISO-OFDMA system to maximize the average sum rate in the downlink. In addition, we propose an alternating optimization for beamforming at the access point and passive phase shifters at the IRS. Numerical results show that the proposed dynamic subcarrier assignment outperforms random subcarrier assignment with quality-of-service constraints.

I. Introduction

Recently, intelligent reflecting surface (IRS) has been proposed as a potential solution to meet the increasing requirement on higher spectral and energy efficiency for future wireless networks [1]. By carefully adjusting the refection phase and/or amplitude of a large number of passive elements, IRS can alter the wireless propagation environment by constructing appropriate signal path between the transceivers. Compared to traditional methods such as active beamforming and relaying, IRS can program the signal propagation by an intelligent control without any complex signal processing, signal decoding, and amplification. As a result, IRS has motivated active research in addition to other wireless techniques, e.g., non-orthogonal multiple access, wireless power, physical layer security, full-duplex radio, and so on [2], [3].

In this paper, we consider an IRS-assisted downlink communication system from the access point (AP) to multiple users employing orthogonal frequency division multiple access (OFDMA). In an OFDMA system, random subcarrier assignment (SA) to users may lead to significant performance degradation due to multiuser inference (MUI) in the case of a large number of users. Therefore, we study a joint optimization of the dynamic SA and beamforming in the IRS-assisted multiuser MISO-OFDMA system to maximize the average sum rate under quality-of-service constraints. In addition, by leveraging alternating optimization and inner approximation, we propose an efficient algorithm to find an optimal solution for active and passive beamforming.

II. System Model

Fig. 1 illustrates an IRS-assisted multiuser MISO-OFDMA system, where an AP with N antennas serves K users in the cell. An IRS composed of M elements is connected a controller, which adjust the reflection coefficients. The channel model can be described by three links from the AP to each user, i.e., AP-user direct link, AP-IRS and IRS-user reflection link. For OFDMA, K users should be assigned to N_c subcarriers. As a random subcarrier assignment may cause excessive MUI, we propose a novel dynamic subcarrier

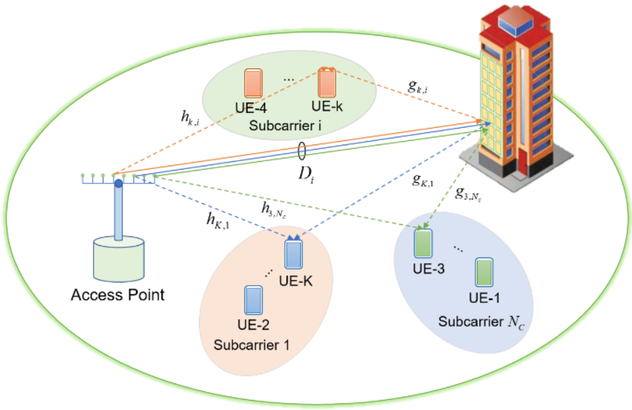

Fig. 1. IRS-assisted multiuser MISO-OFDMA system.

assignment scheme for the IRS-assisted multiuser MISO-OFDMA system. The users will be allocated to subcarriers based on the subcarrier selection coefficients $\alpha_{k,i}$, $k = 1, 2, \ldots, K$, $i = 1, 2, \ldots, N_c$, which are optimization variables. Specifically, if $\alpha_{k,i} = 1$, the k-th user is assigned to the i-th subcarrier, and $\alpha_{k,i} = 0$, otherwise. Accordingly, the transmit signal before inverse discrete Fourier transform (DFT) can be expressed as

$$x_i = \sum_{k=1}^{K} w_{k,i}\sqrt{\alpha_{k,i}}\, s_k\,, \quad i = 1, 2, \ldots, N_c, \tag{1}$$

Where s_k is the transmit data for user k with $E\{s_k s_k^H\} = 1$ and $w_{k,i}$ is the corresponding beamforming vector. The signal is appended with cyclic prefix (CP) before transmission. At the receiver, DFT operation and CP removal are subsequently performed on the received signal. As a result, the received signal via the direct AP-user channel and AP-IRS-user channel can be expressed as

$$\begin{aligned} y_{k,i} &= [\boldsymbol{h}_{k,i}^H + \boldsymbol{g}_{k,i}^H \boldsymbol{\Phi} \mathbf{D}_i] \mathbf{w}_{k,i}\sqrt{\alpha_{k,i}}\, s_k + [\boldsymbol{h}_{k,i}^H \\ &+ \boldsymbol{g}_{k,i}^H \boldsymbol{\Phi} \mathbf{D}_i] \textstyle\sum_{j=1, j\neq k}^{K} \mathbf{w}_{j,i}\sqrt{\alpha_{j,i}}\, s_j + n_{k,i}, \end{aligned} \tag{2}$$

where $\boldsymbol{h}_{k,i}$, $\mathbf{D}_i$, and $\boldsymbol{g}_{k,i}$ are the baseband equivalent channels from the AP to user, from the AP to the IRS, and from the IRS to user, respectively. $n_{k,i}$ denotes the additive white Gaussian noise at user k. A diagonal matrix $\mathbf{\Phi} = \mathrm{diag}(\phi_1, \ldots, \phi_M)$ stands for the reflection coefficients of the IRS, where $\phi_m = \kappa_m e^{j\theta_m}$ is the reflection coefficient of the m-th IRS element, and $\theta_m \in [0, 2\pi)$ and $\kappa_m \in [0,1]$, $m = 1,2,\ldots,M$ denote the phase shift and the amplitude reflection coefficient of the m-th element of the IRS, respectively.

Ⅲ. Problem Formulation

Based on (1), the signal-to-interference plus-noise ratio (SINR) on the i-th subcarrier for user k can be written as

$$\gamma_{k,i}(\mathbf{w}, \boldsymbol{\alpha}, \mathbf{\Phi}) \triangleq \frac{\left|\left[\boldsymbol{h}_{k,i}^H + \boldsymbol{g}_{k,i}^H \mathbf{\Phi} \mathbf{D}_i\right] \mathbf{w}_{k,i}\right|^2 \alpha_{k,i}}{\sum_{j/k}^{K} \left|\left[\boldsymbol{h}_{k,i}^H + \boldsymbol{g}_{k,i}^H \mathbf{\Phi} \mathbf{D}_i\right] \mathbf{w}_{j,i}\right|^2 \alpha_{j,i} + \sigma_{k,i}^2} \quad (3)$$

Accordingly, the optimization problem for maximizing the average sum rate can be formulated as

$$\max_{\mathbf{w}, \boldsymbol{\alpha}, \mathbf{\Phi}} \sum_{k=1}^{K} \sum_{i=1}^{N_c} \frac{1}{K} \log_2(1 + \gamma_{k,i}), \quad (4)$$

$$s.t. \quad \alpha_{k,i} \in \{0,1\},\ k = 1,2,\ldots,K, i = 1,2,\ldots,N_c,$$

$$\sum_{i=1}^{N_c} \log_2(1 + \gamma_{k,i}) \geq R_{QoS},$$

$$\sum_{k=1}^{K} \sum_{i=1}^{N_c} \|\mathbf{w}_{k,i}\|^2 \leq P_{\mathrm{AP}}^{\max}, |\phi_m| \leq 1,\ m = 1, 2, \ldots, M,$$

$$0 < \sum_{k=1}^{K} \alpha_{k,i} \leq \left\lfloor \frac{K}{N_c} \right\rfloor + 1 \text{ and } \sum_{i=1}^{N_c} \alpha_{k,i} \leq 1.$$

To find a solution, we consider inner approximation method to transform the non-convex problem (4) into a convex problem and use alternating optimization between passive beamforming and active beamforming. The proposed algorithm will be referred to as Alg.1.

IV. Simulation Results

Random subcarrier assignment can cause excessive MUI in multiuser MISO-OFDMA system, especially when a large number of users are allocated to the same subcarriers. In contrast, the proposed dynamic subcarrier assignment can avoid such undesirable allocations. Fig. 2 shows the convergence behavior of the random allocation (RA) and proposed dynamic allocation (Alg. 1). The main simulation parameters are tabulated in Table I. The average sum rate tends to converge in a few tens of iterations. It is clearly seen that Alg.1 provides higher sum rate than the RA scheme. In addition, higher power budget at the AP results in higher average sum rate.

V. Conclusion

In this paper, we considered an IRS-assisted multiuser MISO-OFDMA system and investigated the alternative optimization of the IRS passive beamforming along with active beamforming at the AP and dynamic subcarrier assignment to maximize the average sum rate under the quality-of-service constraint on the user rates. Effectiveness of the proposed scheme and optimization method was validated via numerical results, which showed that dynamic subcarrier assignment significantly improves the average sum rate, as compared to the random assignment.

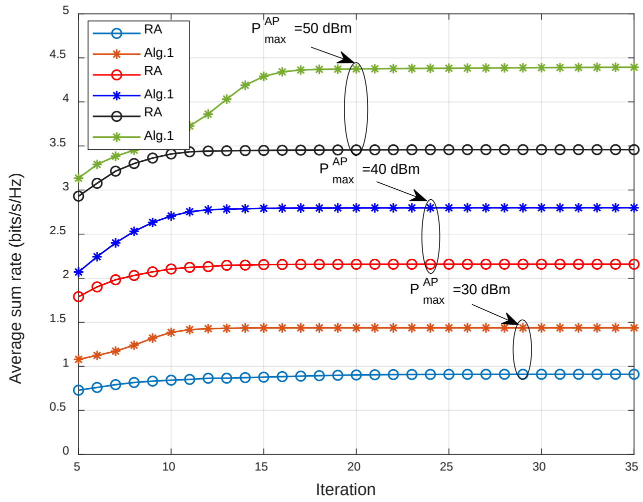

Fig. 2. Convergence behavior of RA and Alg. 1 in terms of the average sum rate with $K = 10$, $N = 2$, $M = 2$ and $N_c = 4$.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Carrier Frequency	1.9 GHz
Bandwidth	10 MHz
AP location	(0m, 0m, 30m)
IRS location	(75m, 50m, 50m)
Coverage	100m
Noise power spectral density	-170 dBm/Hz

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References

[1] Q. Wu and R. Zhang, “Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network,” *IEEE Commun. Mag.*, vol. 58, no. 1, pp. 106-112, Jan. 2020.

[2] Z. Ding and H. V. Poor, “A simple design of IRS-NOMA transmission,” *IEEE Commun. Lett.*, vol. 24, no. 5, pp. 1119-1123, May 2020.

[3] X. Yu, D. Xu, and R. Schober, “Enabling secure wireless communications via intelligent reflecting surfaces,” in *Proc. IEEE Global Commun. Conf. (GLOBECOM) 2019*, Waikoloa, HI, USA, Dec. 2019, pp. 1-6.