Stacked Programmable Digital Metasurfaces assisted Holographic MIMO Power Domain Non-Orthogonal Multiple Access for 6G Communication and beyond

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Abstract

Recently, tremendous research has been done to develop reconfigurable intelligent metasurfaces (RIS) owing to their capability to enhance signal to noise ratio (SNR). Therefore, RIS emerges as a candidate to replace relay in terms of performance and cost efficiency. However, existing works consider a single layer RIS and mutually independent channel. This study proposed Stacked Programmable Digital Metasurfaces (SPDM) to assist power domain non-orthogonal multiple access (NOMA) to enhance achievable sum-rates. In contrast with RIS, SPDM utilizes a stacking architecture to enhance spatial

I. Introduction

Reconfigurable intelligent surfaces (RIS) emerge as a strong candidate to be realized in 6G and beyond due to its capability to reflect incoming signal to the users, resulting in coverage enhancement. However, the limitation of RIS is that it has a static structure (discrete phase shifter and elements) causing a restriction in placement flexibility and limitation of spatial diversity. In [1], proposed a programmable digital coding metasurface (PDCM) to assist holographic multiple input multiple output (HMIMO). Unlike the conventional RIS, PDCM works with continuous elements like holography which enable it to pass through different patterns of wave pattern from HMIMO. Based on the characteristics of PDCM that works with continuous surface, in [2] proposed a novel stacking PDCM (SPDM) to assist holographic MIMO for beyond 6G communication. Therefore, SPDM architecture becomes a future of enhanced RIS to assist wireless communications in 6G and beyond. The use-case of the novel stack SPDM architecture is shown in [3], where a stacking architecture of SPDM with holographic MIMO to reduce side-lobe and increase achievable rates through spatial diversity. The superiority of stacking architecture and SPDM are further utilized to assist semantic communication in [4]. And finally, in [5], stacking SPDM is utilized to assist MIMO OFDM-IM to enhance spectral efficiency.

To deliver a higher data-rate with additional degree of freedom (DoF) of stacking SPDM leads to a various integration of existing multiple access to enhance key performance index (KPI). Motivated by the integration of stacking SPDM with existing multiple access, this study proposed an SPDM assisted HMIMO power domain non-orthogonal multiple access (NOMA) to enhance spectral efficiency. In contrast with existing works, this study utilizes 3 users NOMA with S data streams. For the sake of paper simplicity, the power allocation for data steam and each user are utilizing a famous-classical water filling method. In addition, a channel is perfectly estimated between Tx-Rx.

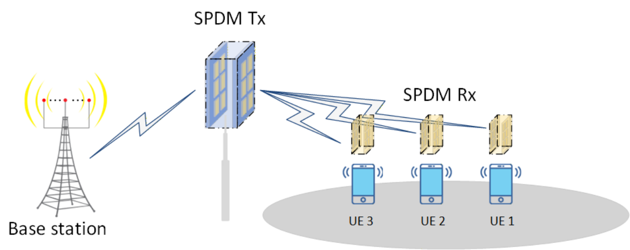

Figure 1. Proposed System of SPDM-HMIMO NOMA

II. Proposed System and Problem Formulation

Consider downlink communication with SPDM based transmission and receiver with M and N meta-atoms, respectively. Following the 1-Dimensional cartesian coordinates, we can write the meta-atoms formation for each layer as follows:

$$\begin{aligned} r_{m,\tilde{m}} &= r_{e,t}\sqrt{(m_z-\tilde{m}_z)^2+(m_x-\tilde{m}_x)^2}, \\ t_{\tilde{n},n} &= t_{e,r}\sqrt{(\tilde{n}_z-n_z)^2+(\tilde{n}_x-n_x)^2}, \end{aligned} \quad (1)$$

where r and t denoted a distance between meta atoms m and n, respectively. Furthermore, we can write M = [1, ⋯, m, ⋯, M] and N = [1, ⋯, n, ⋯, N]. Following the Rayleigh-Sommerfeld diffraction theory, we can express the EM wave that diffracted to each layer as follows:

$$w^l_{m,\tilde{m}} = \frac{A_t \cos\chi^l_{m,\tilde{m}}}{r^l_{m,\tilde{m}}}\left(\frac{1}{2\pi r^l_{m,\tilde{m}}} - j\frac{1}{\lambda}\right)e^{j2\pi r^l_{m,\tilde{m}}/\lambda}, l \in \mathcal{L}, \quad (2)$$

where X is the angle between propagation and normal angle of layer l-th layer; r is the distance between meta-atom m; λ is wavelength. Considering S stream of data, we employ W matrix as the transmission coefficient. Utilizing the combination of W and phase shifter $\boldsymbol{\Phi}$, the transmit precoding written as follows:

$$\mathbf{P} = \mathbf{\Phi}^L \mathbf{W}^L \cdots \mathbf{\Phi}^2 \mathbf{W}^2 \mathbf{\Phi}^1 \mathbf{W}^1 \in \mathbb{C}^{M \times S}. \quad (3)$$

where P yields the precoding matrix for all layers of transmit metasurface with dimension (M x S). In addition, we consider spatial correlation between Tx and Rx as follows:

$$\mathbf{G} = \mathbf{R}_{\mathrm{Rx}}^{1/2} \tilde{\mathbf{G}} \mathbf{R}_{\mathrm{Tx}}^{1/2} \in \mathbb{C}^{N \times M}, \quad (5)$$

The total capacity for all data streams and K NOMA users is written as follows:

$$C = \sum_{k=1}^{K} \sum_{s=1}^{S} \log_2 \left(1 + \frac{p_{s,k} \gamma_{s,k}^2}{\sum_{l=1}^{K-1} p_{s,k} \gamma_{s,l}^2 + \sigma^2} \right), \quad (6)$$

where p is the power allocation for each data stream and user, while γ is the instantaneous SNR for each data stream and user.

III. Result

Consider 3 users NOMA with power allocation [0.75, 0.1825, 0.0675] with distance [350, 200, 150] meters for all users.

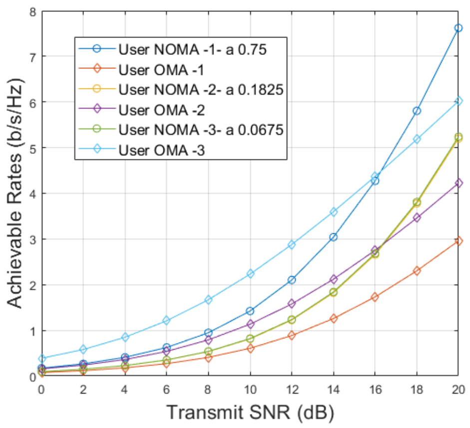

Figure 2. Result of achievable data rates and different transmit SNR

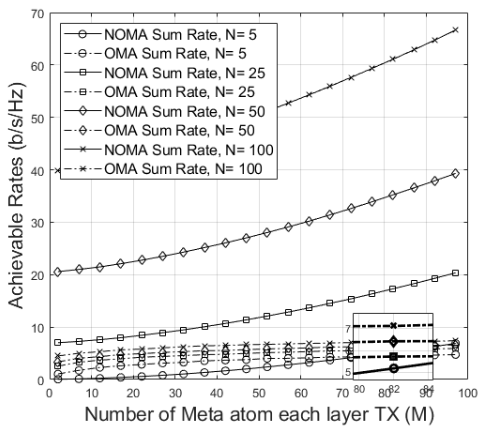

Figure 3. Result of achievable rates with different number meta-atom in the transmitter side and receiver side.

IV. Conclusion

This paper considers SPDM-based NOMA transmission to enhance achievable data-rates. Compared to traditional OMA scheme, NOMA outperforms in terms of data-rates. Furthermore, SPDM-NOMA improved over different numbers of meta-atoms. In addition, for different transmit SNR, OMA outperform user 1 NOMA for low-SNR case. Further join optimization of power allocation and phase shifter is needed to enhance the contribution of this study.

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