NOMA-OFDM-IM for Random Access Uplink Transmission

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Abstract

In this work, non-orthogonal multiple access (NOMA) is combined with orthogonal frequency division multiplexing (OFDM) and index modulation (IM) for a random access uplink transmission scenario. The user entities send data by using IM to convey data bits through activated sub-carrier indices alongside the conventional M-ary modulation symbols. Additionally, depending on the channel condition of the users a rotation of the constellation is decided for multichannel ALOHA, which makes the signals of different users orthogonal to each other. This eliminates the need for successive interference cancellation (SIC) at the base station (BS) for multiuser signal detection, lowering computational complexity. The proposed scheme is investigated in terms of error performance through simulation.

Ⅰ. Introduction

OFDM-IM, or Orthogonal Frequency Division Multiplexing with Index Modulation, operates by dividing the existing subcarriers into various subblocks. It leverages the indices of activated subcarriers to convey supplementary information bits, alongside the data transmitted through signal constellations within each respective subblock. [1]. However, since only a fraction of the subcarriers is employed for modulation, the overall system spectral efficiency (SE) is compromised.

In uplink NOMA, the decoding process involves employing successive interference cancellation (SIC) for each user's signal. However, as the number of users increases, this method tends to result in elevated errors. Consequently, the available resources can only accommodate a restricted number of users. [2]. In the realm of beyond 5G technologies, there has been significant focus on combining NOMA and OFDM-IM. This integration is garnering attention as it aims to attain an optimal balance between spectral efficiency and error performance [3] [4]. However, the number of detection and cancellation operations in SIC is proportional to the number of superimposed users, which leads towards computational complexity. With a notion to reduce the complexity we propose NOMA-OFDM-IM with constellation rotation for multichannel ALOHA uplink transmission.

In this paper, a combination of NOMA and OFDM-IM with constellation rotation is proposed for a multichannel ALOHA uplink scenario. The transmission of information involves the activation of specific sub-carriers through IM and the utilization of M-ary modulation symbols on those activated sub-carriers. The modulation constellations goes through a constellation rotation devised utilizing the channel conditions of the users. User-transmitted signals, varying in channel gains, reach the base station (BS) for reception. The introduction of constellation rotation establishes orthogonality in the signal symbol space. Consequently, the need for SIC at the BS for decoding user signals is eliminated, enabling the direct detection of signals of multiple users. The combined effect of constellation rotation and diverse channel gains streamlines the overall signal detection process, leading to a reduction in computational complexity at the receiver.

Ⅱ. Proposed Methodology

Let us consider a randomly accessed uplink NOMA system based on OFDM, operating in frequency-selective Rayleigh fading channels. Users (U) independently generate OFDM-IM signals to transmit to the base station (BS) using the same frequency and time resource. The BS receives signals from multiple users as a composite signal. We assume that UE_1 is the closest and accordingly UE_U is the farthest user. The channel gains of $U_1 \rightarrow BS$, $U_2 \rightarrow BS, \ldots, U_U \rightarrow BS$ can be represented as $|h_1|^2, |h_2|^2, \ldots, |h_U|^2$ such that $|h_1|^2 > |h_2|^2 > \ldots > |h_U|^2$, respectively. Accordingly, their powers at the receiver (BS) are $P_1, P_2, \ldots, P_U$ such that $P_1 > P_2 > \ldots > P_U$. The CSI between the users and the BS is obtained by the users through overhearing the broadcast downlink common reference signals [5], and it is assumed that channel estimation is perfect.

Each of the users transmits a total of B_u bits, where $u \in (U_1, U_2, \ldots, U_U)$. The B_u bits are divided into g groups, each containing $b_u = B_u/g$ bits. The b_u bits are charted into sub-blocks of size $n = N/g$, where N is the total number of subcarriers. As the process of creating each sub-block is the same, the ε^{th} sub-block $j_u(\varepsilon)$ of u^{th} user is described for simplicity, $\varepsilon \in (1, 2, \ldots, g)$. Then, to create OFDM-IM sub-block, the bits are divided into two parts: b_{u}^{idx} and b_{u}^{sbl}. The former is to determine k active subcarriers in a sub-block employing a look-up table [6] and producing the active subcarrier indices as $I_u(e) = i_{u,1}(e), i_{u,2}(e), \ldots\ldots, i_{u,k_u}(e)$. And the latter ($\log_2 M$, M is modulation order) is to determine the vector of modulated symbols $c_u(e) = [c_{u,1}(e), c_{u,2}(e), \ldots\ldots, c_{u,ku}(e)]$. Then, we optimize a constellation rotation for multichannel ALOHA, which is to be applied to the modulation vector depending on the channel conditions of the users [7]. We assume that the users are distributed within a cell of radius D and there are R rotation levels. The number of levels is equal to the number of users to be served by a sub-block $(R = U)$.

If the distance between user u and the BS is d_u, the rotation level R_l can be chosen as follows.

$$R_l = (u|L_{l-1} < d_u \le L_l), \tag{1}$$

where, $L_0 = 0$ and $L_l = R\sqrt{l/_{R_l}}, l = 1,\ldots,R$. Now, we define the corresponding angle of rotation for each level as follows.

$$r_u = \frac{2\pi(u-1)}{R_l \times M}\circ, \tag{2}$$

where, $u = 1,\ldots,R_c$, and M is the order of modulation. This will enhance the minimum distance between the constellation points (Euclidean distance) of the composite multiuser signal at the BS.

The users create their signal blocks based on the $I_u(e)$ and $c_u(e)$. Eventually, the messages are transmitted through frequency-selective Rayleigh fading channels. At the receiving side, the signals of multiple users can be decoded directly by the BS. Exploiting the rotation of constellation makes the signal symbol of different users orthogonal to each other. As a result, the SIC is not required for the detection of the signals of multiple users. The composite received signal at the BS can be written as

$$y = \sum_{u=1}^{U} \sqrt{P_u}\, diag(\mathbf{h}_u)\mathrm{x}_u + \mathrm{w}, \tag{3}$$

where $diag(\mathbf{h}_u) = diag([h_u(1),\ldots,h_u(N)])$ and w are the channel matrix and noise vector for the users, respectively. The maximum likelihood (ML) based direct signal detection can be represented by the following equation.

$$\hat{x}_u = \underset{\mathrm{x}_u \epsilon \mathrm{X}_u}{\arg\min} ||y - \sqrt{P_u}\, diag(\mathbf{h}_u)\mathrm{x}_u||^2. \tag{4}$$

III. Result Analysis

Fig. 1 represents the error performance of the proposed scheme for different configuration setup. For simulation, the system is considered with $N = 64$ sub-carriers divided into $g = N/n = 16$ groups, each serving $U = 4$ users with $n = 4$ sub-carriers in each group. To achieve a data rate of 4 bps/Hz per sub-block, the legend can be interpreted as: $(n, k) \rightarrow k$ out of n subcarriers are activated in a sub-block and $M \rightarrow$ order of modulation. The system tends to perform slightly better with 4-PSK (higher order modulation) than with BPSK (lower order modulation), which is due to more subcarriers are activated with BPSK.

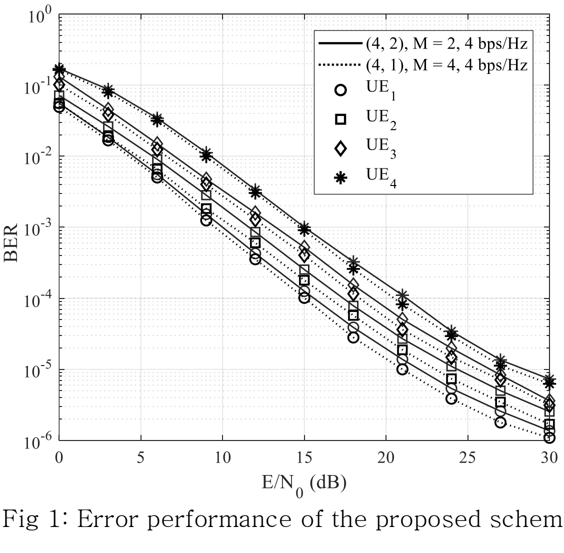

Fig 1: Error performance of the proposed scheme.

IV. Conclusion

The paper presents a NOMA-OFDM-IM scheme with rotation of constellations for multichannel ALOHA. An optimum error performance is shown through simulation for the proposed scheme. Comparison with the existing schemes in terms of error performance and computational complexity are to be explored at length in the future work.

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Reference

[1] E. Başar, Ü. Aygölü, E. Panayırcı and H. V. Poor, "Orthogonal Frequency Division Multiplexing with Index Modulation," in 2012 IEEE Global Communications Conference (GLOBECOM), 2012, pp. 4741–4746.

[2] L. Dai, B. Wang, Y. Yuan, S. Han, I. Chih-Lin, and Z. Wang, "Non-orthogonal multiple access for 5g: solutions, challenges, opportunities, and future research trends," IEEE Communications Magazine, vol. 53, no. 9, pp. 74–81, 2015.

[3] E. Arslan, A. T. Dogukan, and E. Basar, "Index modulation-based flexible non-orthogonal multiple access," IEEE Wireless Communications Letters, vol. 9, no. 11, pp. 1942–1946, 2020.

[4] M. B. Shahab, S. J. Johnson, M. Shirvanimoghaddam, M. Chafii, E. Basar, and M. Dohler, "Index modulation aided uplink noma for massive machine type communications," IEEE Wireless Communications Letters, vol. 9, no. 12, pp. 2159–2162, 2020.

[5] X. Jiang and F. Kaltenberger, "Channel reciprocity calibration in TDD hybrid beamforming massive MIMO systems," IEEE Journal of Selected Topics in Signal Processing, vol. 12, no. 3, pp. 422–431, 2018.

[6] E. Başar, Ü. Aygölü, E. Panayırcı, and H. V. Poor, "Orthogonal frequency division multiplexing with index modulation," IEEE Transactions on signal processing, vol. 61, no. 22, pp. 5536–5549, 2013.

[7] J. Choi, "Noma-based random access with multichannel aloha," IEEE Journal on Selected Areas in Communications, vol. 35, no. 12, pp. 2736–2743, 2017.