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Analysis of Uplink NOMA with MIMO

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Abstract— ***This study centres on utilizing Multiple Input Multiple Output (MIMO) technology within communication networks for the construction and evaluation of the Uplink NOMA systems. Enhancing system capacity, reducing bit error rate (BER), and offering a comparison of MIMO and Single Input Single Output (SISO) technologies within the context of Uplink NOMA with MIMO are the main goals. In the suggested Uplink NOMA system, a (base station) BS is equipped with N antennas and using spatial resources it can accommodate 2N users. However, this sharing of spatial resources leads to user interference. Thus, we also suggest a set selection method and spatial multiplexing to increase sum capacity and decrease the interference. The set selection algorithm is used to reduce the interference among users, by selecting 2N users based on the orthogonality and disparity in gains of their channels.***

Index Terms— ***Multiple Input Multiple Output (MIMO), Non-Orthogonal Multiple Access (NOMA), Set Selection Algorithm, Spatial Multiplexing.***

I. INTRODUCTION

In modern communication systems, Non-Orthogonal Multiple Access (NOMA) is becoming more and more important, particularly with the introduction of 5G and beyond. First off, by allowing numerous users to share time and frequency resources simultaneously, NOMA dramatically improves spectral efficiency. With the demand for data services always rising, this improvement makes it possible to send more data over same bandwidth.

In addition, NOMA increases system capacity in comparison to conventional orthogonal multiple access (OMA) techniques by supporting more users concurrently within the allotted resources. Improved system performance and better use of network resources are the results of this expanded capacity.

In the realm of 5G mobile communication systems, researchers are investigating various approaches to enhance the total capacity, with Non-Orthogonal Multiple Access (NOMA) combined with Successive Interference Cancellation (SIC) emerging as a prominent candidate. [1][2]. By utilizing shared time and frequency resources, this strategy has the potential to perform better than conventional orthogonal multiple access (OMA) [3][4].

In addition to time and frequency, NOMA systems are also tapping into spatial resources. In the downlink (DL) situation, for example, NOMA has been merged with random beamforming (BF) techniques in recent works by Y. Hayashi et al. and K. Higuchi et al. [5].

Conversely, this research advocates for a multiuser beamforming system based on NOMA, employing a zero-forcing (ZF) beamforming scheme [6]. in order to avoid the disadvantages of random BF schemes, such as feedback costs and performance degradation.

The research conducted delved into NOMA across multiple cells within the UL (uplink) multi-antenna environment.

The study assumes that users which are in the same cell would be allocated resource blocks orthogonally [7].

N antennas on a base station (BS) can accommodate maximum of 2N users concurrently in a multi-antenna environment. This is achieved by proposing a NOMA-based UL system in [8]. By sharing space resources, the suggested UL NOMA system can increase sum capacity, however also causes interference between users. As a result, we also provide two methods to lessen the impact of interference resulting from the sharing of the space resource: an ideal power control technique to maximize the sum capacity and a set selection approach to minimize interference.

In this research paper, we propose an innovative approach to enhance the performance of uplink Non-Orthogonal Multiple Access (NOMA) systems with Multiple Input Multiple Output (MIMO) configurations. The primary objectives of our study are to increase the sum capacity of the system and to reduce the bit error rate. To accomplish our objectives, we employ multiple methodologies. Initially, we harness the power of Multiple Input Multiple Output (MIMO) technology to enable spatial multiplexing, facilitating simultaneous data transmission by multiple users within the same frequency band. By exploiting spatial diversity, this approach significantly enhances system capacity and spectral efficiency, aligning with the escalating demand for high data rates in modern communication networks. Additionally, we integrate a sophisticated set selection algorithm into our system design to effectively mitigate inter-user interference. This algorithm strategically selects user sets based on prevailing channel conditions and interference levels, thereby optimizing resource allocation and maximizing system capacity while minimizing degradation caused by interference.

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II. SYSTEM MODEL

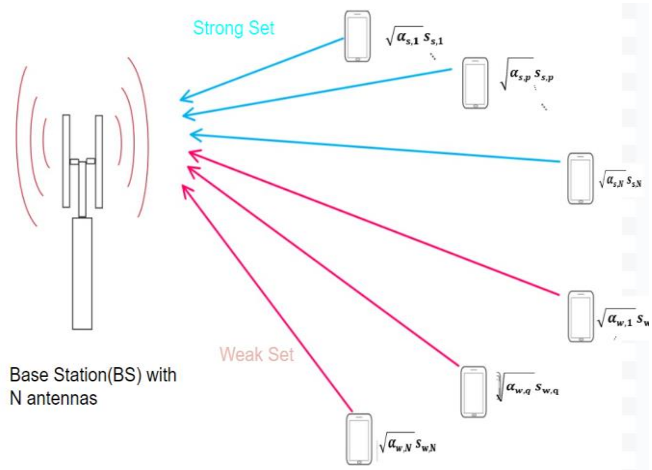

Fig. 1 Uplink NOMA - MIMO model

Fig. 1 shows the architecture of the uplink NOMA with MIMO system. We can see that base station (BS) is equipped with N antennas and number of users that are present in the cell are K where $K \geq 2N$. Because of the presence of antennas N at the base station, N groups of beamforming of multiantenna are established and Non-Orthogonal Multiple Access only permits

Total two number of users to share a resource. Consequently, the NOMA – MIMO systems can accommodate a total of 2N users, meaning that the total data rates of all users amount to 2N times. These N users are known as sets. The proposed Uplink NOMA – MIMO systems can support two or more sets with the help of superposition coding. We are presuming that BS can accommodate two sets of 2N users consecutively. The two sets are classified as strong set and weak set. The strong set comprises users with relatively higher channel gains, while the weak set consists of users with relatively lower channel gains. The channel matrices for the strong and weak sets, denoted as H_s and H_w respectively, are as follows.

$$\mathbf{H_s} = [h_{s,1}, h_{s,p} \ldots h_{s,N}],\ \mathbf{H_w} = [h_{w,1}, h_{w,q} \ldots h_{w,N}] \quad (1)$$

where $h_{s,p}$, $h_{w,q}$ represent the N x 1 uplink channel matrices corresponding to the p-th user in the strong set and the q-th user in the weak set, respectively, and p and q $\in \{1,2,.., N\}$.

The signals received from all the users in the uplink are represented by 'y'. This expression is based on the channels of users categorized into strong and weak sets which is as follows:

$$\mathbf{y} = \mathbf{H}_s\mathbf{x}_s + \mathbf{H}_w\mathbf{x}_w + \mathbf{n}_{awgn} \quad (2)$$

Where n_{awgn} stands for the additive white gaussian noise having power P_{awgn}, H_s and H_w are the strong and weak set channel matrix, respectively and x_w and x_s represent the Nx1 vector of weak and strong sets transmitted signal respectively.

The strong and weak set's transmitted signal vector is provided by

$$x_s = [\sqrt{\alpha_{s,1}}s_{s,1}\ \sqrt{\alpha_{s,p}}s_{s,p} \ldots \sqrt{\alpha_{s,N}}s_{s,N}]^{tr} \quad (3)$$

$$x_w = [\sqrt{\alpha_{w,1}}s_{w,1}\ \sqrt{\alpha_{w,q}}s_{w,q} \ldots \sqrt{\alpha_{w,N}}s_{w,N}]^{tr} \quad (4)$$

Where the matrix's transpose is represented by $(.)^{tr}$. The control power factors for q^{th} and p^{th} weak and strong sets users are represented by $\alpha_{w,q}$ and $\alpha_{s,p}$, respectively. Additionally, the signals from the q^{th} and p^{th} users in the weak as well as strong sets are denoted as $s_{w,q}$ and $s_{s,p}$, respectively.

A successive interference cancelation (SIC) technique is required as the signals sum from the strong and weak sets are received by the base station, as shown in (2) [4]. Initially, the users signal in the strong set are processed, considering signals from the weak set users as interference, akin to the process of uplink Successive Interference Cancellation (SIC). Signals from users in the weak set undergo successive interference cancellation (SIC) using the processed signals from users in the strong set. The interference caused by the users of weak sets affecting users in the strong set is known as inter-set interference. Alternatively, we can process the signals from users present in weak set without encountering interference, assuming flawless SIC in our study.

III. STRATEGIES

A. Spatial Multiplexing

Spatial multiplexing is a pivotal technique utilized in uplink NOMA systems with multi-antenna configurations employing MIMO technology. It allows for the simultaneous transmission of data from multiple users over the same frequency band by exploiting the spatial dimensions of the communication channel. In this context, each antenna at the base station serves as an independent communication stream, enabling parallel transmission paths for different users. This spatial diversity not only enhances the system's capacity but also improves spectral efficiency by maximizing the utilization of available resources. By employing spatial multiplexing, uplink NOMA systems can achieve higher data rates and improved performance compared to traditional single-antenna systems. Furthermore, spatial multiplexing enables the system to adapt dynamically to altering channel conditions, hence boosting robustness and dependability in varied operating settings. Overall, the integration of spatial multiplexing inside uplink NOMA systems leveraging MIMO technology represents a significant achievement in boosting the efficiency and performance of next-generation communication networks. Furthermore, the intrinsic diversity provided by spatial multiplexing enables greater resistance to fading and interference.

B. Set Selection Algorithm

Due to inter-set interference, user selection for the strong and weak sets in uplink NOMA systems using MIMO technology has a substantial impact on system performance.

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Users are chosen considering various factors, including the orthogonality of their channels and the users gains of the channels of weak set. The users' channels orthogonality is important for anticipating and reducing inter-set interference, without needing direct interference calculations. Reduced inter-set interference is seen by users with nearly orthogonal channels, increasing system capacity overall. In order to reduce interference, users with orthogonal channels are given preference when choosing who to include in the strong and weak sets.

Furthermore, the strong set's experience with inter-set interference is influenced by the weak set's users' channel gain as well as their own capacity. Although they could have less individual capacity, users with lower channel gains contribute less to inter-set interference. Users with median channel gains are taken into account by the algorithm when choosing the weak set in order to strike a compromise between reducing interference and preserving appropriate capacity levels. Table I provides a detailed description of the proposed set selection algorithm's process.

Table I. Set Selection Algorithm

Step 1) Set the number of antennas (M) and the total number of users (K) using their received CSI (channel state information) feedback. Subsequently, the transmitter creates the feedback set of CSI, denoted as S. $S = \{h_1, \ldots, h_K\}$, $i = 1$, $T_w = \varphi$, where 'i' and 'j' are used as indices for users, and Tw represents the set of users designated as the weak set, move on to step 2).
Step 2) After calculating each user's channel gain for the K users in the system, the transmitter orders the channel gains of the users in descending order. Sord = { |**h**k| | |**h**k| > |**h**k+1| } k ∈ {1, . . . , K}. Using the sorted channel gains from S_{ord}, the transmitter divides users into two categories: S_{high}, comprising those with the highest channel gains, and Slow, encompassing users with lower channel gains. $S_{high} = \{ \|h_1\|, \ldots, \|h_{[k/2]}\|\}$, $S_{low} = \{ \|h_{[k/2]+1}\|, \ldots, \|h_K\|\}$, The symbol [.] represents the floor function. The initial N users are chosen and stored in S_{high}. $\mathbf{H}_1 = \{\mathbf{h}_1, \ldots, \mathbf{h}_N \mid \mathbf{h}_o \in S_{high}, o = 1, \ldots, N\}$, and go to step 3).
Step 3) The Tx (transmitter) evaluates the orthogonality between the channels of users in the j-th user and the strong set in S_{low} when i is less than N and the size of the weak set ($\|T_w\|$). The user i-th will be placed by Tx (transmitter) in the weak set, if the correlation value is less than a predetermined threshold, ρ ($0 \leq \rho < 1$). $$h_i^* = \{h_i \| \frac{\|h_i . h_j\|}{\|h_i\|\|h_j\|} < \rho, \text{for } {}^\forall j, j = 1, \cdots, N \},$$ $T_w = T_w \cup \{h_i^*\}$, $S_{low} = S_{low} - \{h_i\}$. Increase i by 1 and repeat Step 3 after the i-th person has been added to the weak set. Step 3 can be repeated by increasing i if the correlation is greater than ρ. The method ends and defines the users in Tw as the weak set if |Tw| reaches N before i equals N. $\mathbf{H}_2 = \{h_o \mid h_o \in T_w, o = 1, \ldots, N\}$. If the size of the weak set $\|T_w\|$ is less than N and i equals N, move on to Step 4).
Step 4) If $\|T_w\| < N$ while $i < N$, the BS resorts to OMA, choosing the top N users from S_{low} as the weak set. $\mathbf{H}_2 = \{h_p \| h_p \in S_{ord}, p = [K/2] + 1, \ldots, [K/2] + N\}$, thus the algorithm is concluded by the base station.

IV. RESULTS

In this research, we exclusively concentrated on the performance evaluation of multiple-input multiple-output (MIMO) technology within the context of uplink non-orthogonal multiple access (NOMA) systems. We compared the cumulative capacity performance of these two transmission methods in our investigation. We can plainly see that MIMO technology routinely beats SISO in terms of sum capacity, as shown in Fig. 2. Across varied numbers of users, ranging from 20 to 60, the MIMO system consistently displays greater cumulative capacity values compared to its SISO equivalent. Due to its capacity to take advantage of spatial multiplexing gains and increase spectral efficiency by employing multiple antennas at the transmitter and receiver ends, MIMO has been shown to be superior. These results demonstrate how well MIMO approaches work to increase total capacity and spectral efficiency of uplink NOMA systems.

Fig. 2 Comparison of sum capacity for SISO and MIMO

The bit error rate (BER) performance in uplink NOMA with multiple antenna was investigated, and both single-input single-output (SISO) and multiple-input multiple-output (MIMO) technologies were thoroughly assessed throughout a range of signal-to-noise ratio (SNR) levels. We have compared the BER results between the two transmission systems using a set selection technique in our analysis framework. As opposed to SISO technology, MIMO technology has a lower bit error rate, as shown in Fig. 3, when averaging bit error rates at various SNR values ranging from 0 to 12 dB This significant error rate advantage of MIMO over SISO highlights the resilience and dependability of MIMO systems, especially in demanding wireless situations. Through utilizing the set selection algorithm's enabled spatial diversity and multiplexing advantages, MIMO exhibits increased resilience to channel defects, leading to higher communication dependability. These findings demonstrate how well MIMO approaches work to achieve higher BER performance and illustrate how well-suited they are for applications in contemporary wireless networks that require excellent data integrity and transmission quality.

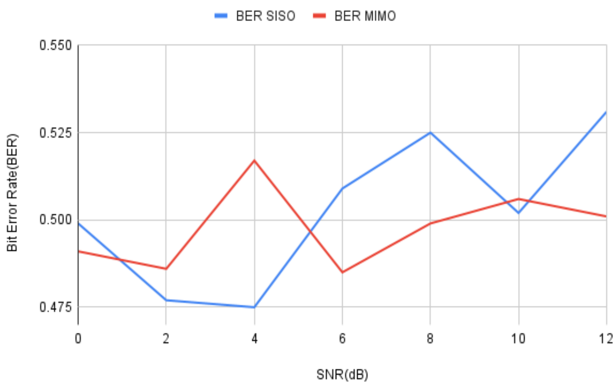

Fig 3. Comparison of bit error rate (BER) for SISO and MIMO

V. CONCLUSION

This work focuses on using MIMO technology to increase sum capacity and decrease bit error rate for uplink NOMA with multiple antennas. It also evaluates the advantages of MIMO over SISO technology for the same purposes. The suggested graphics demonstrate that bit error rate lowers and sum capacity rises using MIMO technology when compared to SISO technology. The set selection algorithm for bit error rate comparison and spatial multiplexing for sum capacity comparison in uplink NOMA with multiple antenna employing MIMO and SISO technologies are included in this work. In conclusion, MIMO technology is presented in this research with the goal of increasing total capacity and decreasing bit error rate. Its applicability to contemporary wireless networks that need excellent transmission quality and data integrity is highlighted.

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