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SLR as Non-Orthogonal Multiple Access in 5G Systems

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Abstract – In the fifth generation (5G), the traditional restrictions that limit the capacity of wireless communication must be overcome. Non-orthogonal multiple access (NOMA) is a promising solution capable of overcoming these constraints to meet the requirements of 5G. The multiple-input multiple-output (MIMO) scheme that employs beamforming precoding technology can achieves NOMA. In this letter, we proposed non-unity beamforming precoding based on maximum signal to leakage ratio (SLR) algorithm as NOMA for multi-user MIMO (MU-MIMO) system. Then, we will compare between the proposed scheme and the classical SLR-based on beamforming precoding algorithm. This paper evaluates the symbol-detection performance for proposed and classical MU-MIMO beamforming over a Rayleigh fading channel and Rician fading channel. Simulation results show that the proposed scheme has better performance than the classical scheme. And the Rician fading channel has performance improvement until with low Rician factor value, compared to a Rayleigh channel.

Keywords – *5G, NOMA, SLR, MU-MIMO, Fading.*

I. INTRODUCTION

The current radio access technology is facing challenges to meet the requirements of technological advances represented by the fifth generation (5G), e.g., 10-fold increase in connection density, i.e., 〖10〗^6 connections per square kilometers [1] and increase in the volume of mobile traffic, e.g., beyond a 500-1000-fold increase in mobile traffic [2]. Therefore, new solutions must be identified and developed that can make significant gains in the capacity and quality of service to the user to continue to ensure the sustainability of radio access technologies [3] [4]. Non-orthogonal multiple access (NOMA) has recently received significant attention as a promising candidate to improve spectral efficiency [5]-[9]. The real motivation to propose NOMA in fifth-generation is that the NOAM can use the spectrum more effectively by opportunistically exploring channel stat information (CSI) of users [10]. In previous generations, radio access was represented by traditional multiple access systems that provide multiple users access to and share system resources simultaneously such as FDMA, TDMA, CDMA, and OFDMA [2]. The comparison between NOMA and traditional multiple access systems reveals a fundamental difference in power domain, since it allows transmitter to transmit signals to multi user simultaneously using the same code and frequency radio resources but with different power levels [6]-[8]. The key advantage of NOMA is to explore the extra power domain to further increase the number of supportable users. In particular, NOMA allocates less power to users with better channel conditions, and allocates better power level to users with lower channel conditions to supports them [11].

In multi-user MIMO (MU-MIMO) scenarios, numerous users in the same cells in the same time or frequency slots share the same base station (BS) and try to contact it. In this situation, many co-channels occur. According to the participation fact of reuse the sources in MU-MIMO systems, the system suffers from multi-user interference. The main challenge in MU-MIMO communications is that the transmitter has the ability to coordinate transmissions from all of its antenna elements, while the users are typically unable to coordinate with each other [12]. Therefore, the operation of multi-user interference cancellation is often done on the BS side.

Linear precoding at the wireless communications station, which is installed at a fixed location, and decoding at the user approaches are necessary to solve this problem [13]. In order to mitigate the co-channel interference that occurs at users, the designer must create a transmitter that can send information to several users via beamforming vectors. Particularly, there has been significant attention given to MU-MIMO systems as a future technology for LTE Advanced, which promises to provide optimal execution to wireless communication systems [14]. It should be mentioned that at any time a sender of a MIMO system has no information about the CSI, neither multi-user diversity nor spatial multiplexing can be achieved [15]. On the other hand, if the CSI of all mobile stations is available at the transmitter, then the precoder is capable of fully removing CCI. By removing CCI, each user can communicate with the transmitter over an interference-free, single-user channel [16].

Therefore, through an imperfect feedback channel, reconnaissance of limited CSI and employment of CSI are critical points for a MIMO system [15]. CSI is very important, because when it is fully available at the BS, the MIMO system performs best in numerous ways via using the precoding method. For example, to mitigate symbol interference, precoding can be used with spatial diversity and spatial multiplexing provided by the MIMO system. Besides high gain coding, if space–time codes can be combined with precoding, maximum gain diversity is available [17].

The signal-to-leakage ratio (SLR) algorithm can get the beamforming technique. This algorithm can design a beamforming precoding matrix based on maximizing the SLR. This means that it maximizes the useful power of received signals at the mobile station, while minimizing the overall interference power caused by the user at all other co-channel mobile stations [18]. The SLR algorithm maximizes the desired signal power for each mobile station. Unfortunately, it also takes no action to lower CCI, making it an interference-limited system with high SNRs [19].

This study proposes a NOMA scheme consider an alternative approach based on the concept of SLR to design transmits beamforming vectors. In the classical MU-MIMO beamforming system based on SLR, the design procedure for precoding weight need to the proportionality constant, which it is chosen to normalize the norm of the precoding to unity [20]. Compare this solution to the proposed scheme; it is no need to this step in BS.

Extensive simulations in the MU-MIMO system have been carried out over Rayleigh (in the NLOS environment) and Rician fading channels (in the LOS environment). The simulation results demonstrate that the proposed scheme outperforms classical schemes. Furthermore, it can reduce the BS complexity.

The rest of the paper is organized as follows. The system model is introduced in Section II. Section III provides downlink channel model. In Section IV, we review the precoding design. Section V provides proposed scheme. In Section VI, we provide and discuss the simulation. Finally, Section VII concludes the paper..

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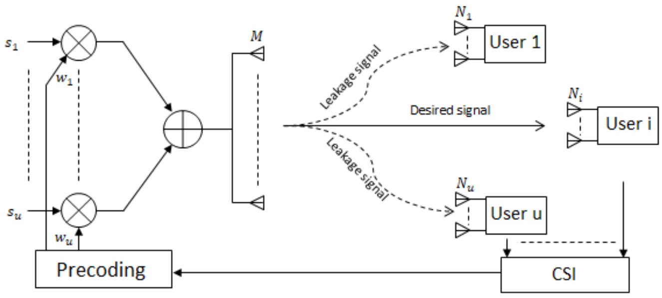

Fig. 1 Block diagram of the MU-MIMO beamforming system use NOMA.

II. SYSTEM MODEL

In MU-MIMO system we have considered an environment of U geographically sparse mobile stations as multi-user (MU) communicates with the MIMO base station (BS) which has M antennas. In such this environment system, each mobile station is independent and employing N_i antennas of user i. These users will receive their own signal, as shown in Fig.1. The total users' antennas number defines as;

$$N_T = \sum_{u=1}^{U} N_u \quad (1)$$

Also, this system has an operation condition which is $N_T \leq M$ with the independent channels of flat fading. The meant message signal for the ith user is the scalar s_i. Thereby, the transmitted symbol vector to U users is:

$$S = [s_1, s_2, \ldots, s_U]^T \quad (2)$$

In the second step, we denote to precoding matrix step as:

$$W = [w_1, w_2, \ldots, w_U] \quad (3)$$

where $w_i \in C^{N_i x M}$ is the joint beamforming coefficients for ith user.
Then the transmitted symbol vector is multiplied by the precoding matrix as third step to produce precoding data as:

$$X = \sum_{u=1}^{U} w_u s_u = WS \quad (4)$$

It is assumed that signals **WS** $\in C^{M\,\mathrm{x}1}$ are broadcast over the channels denoted as:

$$H = [H_1{}^T, H_2{}^T, \ldots, H_U{}^T]^T \quad (5)$$

where $H_u \in C^{N_u\,\mathrm{x}\,M}$ describes the channel coefficients between the N_u receiver antenna at the uth user and BS antennas as follows:

$$H_u = \begin{bmatrix} h_u^{(1,1)} & \ldots & h_u^{(1,M)} \\ \vdots & \ddots & \vdots \\ h_u^{(N_u,1)} & \ldots & h_u^{(N_u,M)} \end{bmatrix} \quad (6)$$

where $h_u^{(n,m)}$ denotes the channel coefficient between the BS, which has the mth transmitter array antenna, and the uth user, which has the nth receiver array antenna.
Thus, the received signals at the receivers' antennas are:

$$\boldsymbol{y} = [y_1{}^T, y_2{}^T, \ldots, y_U{}^T]^T = HWS + n \quad (7)$$

where $y_i \in C^{N_i\,\mathrm{x}\,1}$ represent the signal received at the ith recipient, while that for the additive noise is denoted by $n \in C^{UN_i \times 1}$. When each user has been carefully considered separately, we will find the received signal at an *i*th recipient as:

$$y_i = H_i \sum_{u=1}^{U} w_u s_u + n_i = H_i w_i s_i + H_i \sum_{u=1, u\neq i}^{U} w_u s_u + n_i \quad (8)$$

The H_i vector has complex Gaussian variable components with unit variance and zero mean. Moreover, the components of the additive noise n_i have a distribution as $N(0,\sigma_i^2)$ and are temporarily white and spatial. To describe the proposed scheme clearly, the original SLR-based precoding scheme [18] is reviewed in the precoding design section.

III.DOWNLINK CHANNAL MODEL

Due to LOS propagation the strongest propagation component of MIMO channel corresponds to deterministic component (also referred to as specular components). On the other hand, all the other components are random components (due to NLOS also referred to as scattering components) [21]. The broadcast channel distribution has been following the Rayleigh channel distribution which is Gaussian distribution with a variance of σ^2 and zero mean. That means there is no component of LOS (K= 0): $\sigma = \sqrt{\frac{1}{K+1}}$. On the other hand, when there is any component of LOS (For K > 0) the broadcast channel distribution has been following the Gaussian distribution with a variance of σ^2 and mean of q or Rician distribution when K increases as: $q = \sqrt{\frac{K}{K+1}}$, $\sigma = \sqrt{\frac{1}{K+1}}$

Therefore, in this work, channel matrix of MIMO system is tends to be described as [22]:

$$H = \sqrt{\frac{K}{K+1}}\, H_d + \sqrt{\frac{1}{K+1}\, H_r} \quad (9)$$

where H_d representing the component of the normalized deterministic channel matrix, while H_r representing the component of random channel matrix, with $||\, H_d\, ||^2 = N_T\, M$, $E\{\, |[H_r]_{i,j}|^2\}= 1$, $i = 1{:}\, N_T$, $j = 1{:}\, M$[22]. While K is known as factor of the Rician channel which is the relation between the component of the specular power c^2 and the component of scattering power $2\sigma^2$, displayed as [21]:

$$K = \frac{\|H_d\|^2}{E\{|[H_r]_{i,j}|^2\}} = \frac{c^2}{2\sigma^2} \quad (10)$$

IV. PRECODING DESIGN

Precoding can be used in MIMO to mitigate or cancel the user interference. For lower complexity, we concentrate on linear precoding methods in this work. SLR is linear precoding method. To design SLR it need to CSI. Therefore, we suppose that the CSI of the wireless communication network in the cell is recognized to BS in Frequency-division duplexing (FDD) or Time-division duplexing (TDD) systems. In FDD systems, BS can get the downlink CSI by feedback of the users at same cell. While in TDD systems, according to channel reciprocity, BS can correctly guess the downlink CSI duo to the uplink CSI.

- SLR Precoding

The original SLR-based precoding scheme is reviewed in [18]. Recall that SLR is defined as the ratio of received signal power at the desired user to received signal power at the other terminals (the leakage power) plus noise power without considering receive matrices. This scheme computes the maximum beamforming precoding (w_i^o) of each user from the maximum SLR of these users [18] as follows:

$$SLR = \frac{||H_i w_i||^2}{\sum_{u=1.\ u\neq i}^{U} ||H_u w_i||^2} \quad (11)$$

Then

$$w_i^o = arg\ \ max\ \frac{||H_i w_i||^2}{\sum_{u=1.\ u\neq i}^{U} ||H_u w_i||^2} \quad (12)$$

where $||H_i w_i||^2$ represents the required signal power of user *i*, while $\sum_{u=1.\ u\neq i}^{U} ||H_u w_i||^2$ represents the total leakage power from the total power of user *i* as an interference to the other users. By substituting $\widetilde{H}_i = \sum_{u=1.\ u\neq i}^{U} H_u$ into (11), we can obtain

$$SLR = \frac{||H_i w_i||^2}{||\widetilde{H}_i w_i||^2} = \frac{w_i^* H_i^* H_i w_i}{w_i^* \widetilde{H}_i^* \widetilde{H}_i w_i} \quad (13)$$

Depending on [18] we can solve (13) as

$$\frac{w_i^* H_i^* H_i w_i}{w_i^* \widetilde{H}_i^* \widetilde{H}_i w_i} \leq \lambda_{max}\left(H_i^* H_i, \widetilde{H}_i^* \widetilde{H}_i\right) \quad (14)$$

where $\lambda_{\max}$ is the largest generalized eigenvalue. According to the SLR criterion, the precoding matrix w_i is designed based on the following metric:

$$w_i^o \propto max\ gen.eigenvector\left(H_i^* H_i, \widetilde{H}_i^* \widetilde{H}_i\right) \quad (15)$$

Depending on [18], the proportionality constant is chosen to normalize the norm of w_i^o to unity. At user *i*, the maximum-likelihood detection scheme will be used to estimate s_i from the received signal as follows [18]:

$$\tilde{y}_i = \frac{w_i^* H_i^*}{||H_i w_i||^2} y_i \quad (16)$$

Then

$$\tilde{y}_i = s_i + \frac{w_i^* H_i^* \sum_{u=1.\ u \neq i}^{U} H_i w_u s_u}{||H_i w_i||^2} + \frac{w_i^* H_i^*}{||H_i w_i||^2} n_i \quad (17)$$

V. PROPOSED SCHEME

Based on [23], the drawback of [18] is that when each user has multiple data streams, the effective channel gain for each stream can be severely unbalanced. If power control or adaptive modulation and coding cannot be applied, then the overall error performance of each user will suffer significant loss.

Therefore, unlike the original SLR scheme in [18], which gives the solution in Equation (15) dependent on *subject to* $\|w_u\|^2 = 1$, we apply total transmission power constraints (P_u) at the transmitter, which can be described as $E(\|w_u s_u\|^2) \leq P_u$. The symbol s_u satisfies the power constraint as $E_u = E(|s_u|^2) = 1$. Therefore, the same solution is chosen in Equation (15) but depend on [24]:

$$\textit{subject to}\ \|w_u\|^2 = {w_u}^H w_u \leq P_u / E_u \quad (18)$$

Note that the norm of w_u is irrelevant to the final solutions; in other words, the norm of w_u can be forced to be any value to achieve the best value for w_u under the power constraints.

VI. SIMULATION RESULTS

In this section, we present our evaluation of the signal-to-noise ratio (SNR) against the bit error rate (BER) as a scale of precoding efficiency. A typical MU-MIMO scheme was imitated to estimate the performance of the suggested MU-MIMO beamforming precoding scheme over a Rician fading channel in comparison to the same scheme over a Rayleigh fading channel.

The samples of these parameters are set up to 1000 with elements generated as zero-mean for Rayleigh fading channel while m-mean for Rician fading channel and unit-variance independent and identically distributed (i.i.d) complex Gaussian random variables. We simulate NOMA system, where the average BER is taken of SLR-based precoding approach at BS while the receiver was using a maximum-likelihood detection approach. BS transmits by M antennas to each user over the noise and flat fading channel while each user has employed N_u antennas to receive the signal. QPSK signal constellation has been used as a broadcast modulation in all simulations and the results are averaged through several channel investigations. For all receivers the noise variance per receive antenna is supposed the equal, $\sigma_1^2 = \ldots = \sigma_K^2 = \sigma^2$.

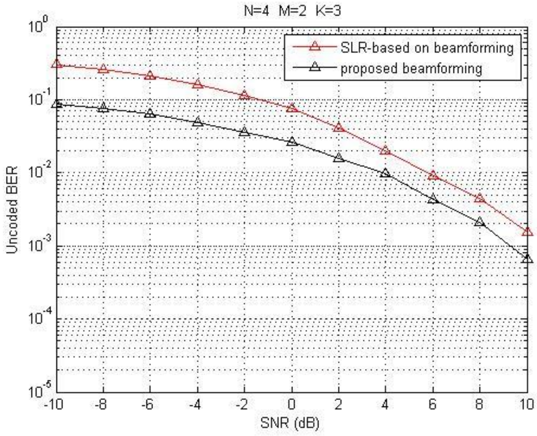

Fig.2 MU-MIMO system for M = 4, U = 3, Ni = 2.

Fig. 2 illustrates the comparison of the classical MU-MIMO beamforming system based on SLR and the proposed MU-MIMO beamforming system based on SLR with different power constraint.

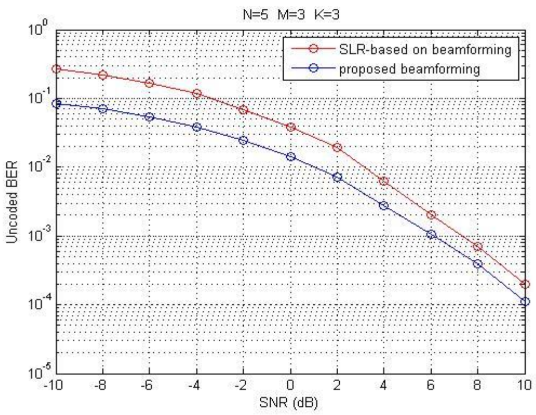

Fig.3 MU-MIMO system for M = 5, U = 3, Ni = 3.

While the classical MU-MIMO beamforming system based on SLR fails in a multi-user environment, to pass the proposed scheme (see Figures 2 and 3), the proposed scheme provides an acceptable BER with different numbers of antenna. For instance in Figure 3, the proposed scheme maintains an acceptable 10^{-2} uncoded BER for 3 simultaneously active users at a received per antenna SNR of 1dB.

Fig.2, in the case of the classical MU-MIMO beamforming system based on SLR, the performance of the system gradually and continuously improved with increases in the values of SNRs, although in the case of the proposed scheme, system performance was dramatically improved at significantly lower values of SNRs. Unfortunately, when the values of SNRs increased, performance improvement slowly stabilized even at high values of SNRs. That is because of noise and inter-user interference factors. For the proposed scheme, which supports inter-user interference and maximizes useful power, the system performed significantly better than the classical MU-MIMO beamforming system based on SLR scheme at low values of SNRs because the effect of noise was bigger than the effect of inter-user interference. Therefore, at low values of SNRs, the major factor limiting the performance of the system was the noise. On the other hand, the classical MU-MIMO beamforming system based on SLR scheme, which minimize multi-user interference, gradually approaching the performance of the proposed system at high values of SNRs because the effect of inter-user interference was greater than the effect of noise on the system. Therefore, at high values of SNRs, the major factor limiting the performance of the system was inter-user interference.

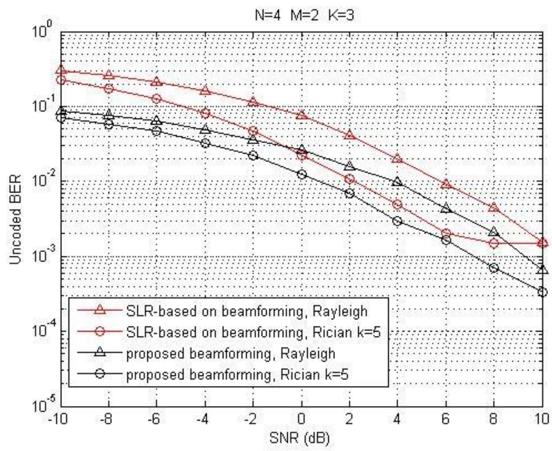

Fig.4 MU-MIMO system for M = 4, U = 3, Ni = 2 over Rayleigh and Rician channel.

To better understand the behavior of NOMA, it can be seen that the MU-MIMO beamforming system (in the case of both the classical MU-MIMO beamforming system based on SLR and the proposed scheme) over conventional channels produced adverse results with regard to BER Fig.4; the realistic channel gives a suitable BER in the existence of three dynamic users. To best comprehend the behavior of the suggested schemes, the BER was plotted for different values of K (K > 0), compared to the Rayleigh fading channel. Fig.4 illustrates that to achieve better performance; it needs good condition of users channel for the proposed scheme at all values of SNRs, while good condition of users channel for the classical MU-MIMO beamforming system based on SLR scheme at low values of SNRs and no need to good condition of users channel at high values of SNRs.

VII. CONCLUSION

This study proposes a NOMA scheme consider an alternative approach based on the concept of SLR to design transmits beamforming vectors with different power constraint. In proposed scheme, the complexity in the BS will be reduced by reduce the design procedure for beamforming precoding. When in the conventional SLR-beamforming scheme, the design precoding procedure need to the proportionality constant, which it is chosen to normalize the norm of the precoding to unity. Compare this solution with the proposed scheme; it is no need to this step in BS. Simulations were carried out over the Rayleigh fading downlink channel and then over the Rician fading channel. Simulation results demonstrated that the proposed scheme outperforms the classical SLR-based beamforming precoding schemes. The performance of the proposed scheme with different numbers of antennas was also observedCONCLUSION

The main conclusions of the study should be summarized in a short Conclusions section.

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