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A Two Layer Precoding With Rate Splitting Method For Massive OFDM-MIMO Communications

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Abstract

In a Multi-user MIMO broadcast channel, to overcome the adverse effects of multiuser interference caused due to the imperfect CSIT, two rate splitting methods have been adopted. One is a Rate Splitting (RS) approach which splits one intended user's message into a common and a private part and another by exploiting the channel second order statistics and by generalizing the RS method which is known as Hierarchical Rate Splitting (HRS) approach. In order to reduce the computational complexity of increasing number of antennas in Massive MIMO and to increase the sum rate gain, a two layer precoding has been done. By concatenating the output data obtained after rate splitting by two layer precoding with the OFDM modulation technique that further enhances the sum rate gain and to achieve high and reliable data rate transmission in Massive MIMO broadcast channel under reduced CSI feedback. By comparing with the existing linear precoding schemes and conventional RS and HRS methods, the two layer precoding with rate splitting method with OFDM yields a better sum rate gain. OFDM in Massive MIMO increases the system capacity and high data rate transmission at a low bit error rate. The results are obtained which validates the significant sum rate gain of OFDM -RS and OFDM-HRS over other conventional broadcasting schemes under imperfect CSIT.

Keywords: *Massive MIMO, Rate Splitting, Two layer precoding, OFDM.*

1. Introduction

In MIMO wireless networks, the performance rate is affected by the multiuser interference once the Channel State information at the Transmitter (CSIT) is imperfect. Conventional multiuser broadcasting strategies like Zero-Forcing (ZF) beamforming, TDMA achieve the sum Degree-of-Freedom (DoF) in a two-user MISO broadcast channel when the CSIT error variance decays with signal-to-noise ratio (snr) as for some constant 0 < ep <1. But it is not practical in the case of linear precoding schemes to attain a high DOF performance under imperfect CSIT as ep ⟶ 0. And therefore imperfect CSIT is an impasse for multi-user broadcast channels and especially in Massive MIMO to find out its significant spectral and energy efficiency benefits with its increasing number of antennas. So it is very difficult to obtain a sum rate gain and high data rate transmission is impossible.

So in order to overcome the high DoF and to attain better sum rate gain at high data rates in multiuser broadcast channels, a rate splitting method has been adopted [1]. In Rate Splitting (RS) method, by splitting one selected user's message into two parts. One is a private part and another is a common part. The common part can be decoded by all the users as it is drawn from a public codebook under zero error probability. When the CSIT error variance (ep) is fixed and independent of SNR, linear precoding techniques with uniform power allocation lead to multiuser interference, which ultimately produces a rate ceiling at high Signal-to-Noise-Ratio (SNR) [5].

Generally more number of antennas provides more degree of freedom resulting in a larger throughput. And in Massive MIMO a large number of users are served simultaneously. But there will be difficulties in acquiring Channel State Information at the transmitter side and therefore challenging to support a large number of users. In FDD mode of operation, there is no such privileges. So pilot based channel estimation and uplink channel feedback are required. The advantages of Massive MIMO are not obtained as it is highly sensitive to CSIT qualities. CSIT might be imperfect due to many reasons like antenna miscalibration, imperfect channel estimation during the training phase and pilot contamination. The large number of antennas requires high dimensional matrix operations and the simple conventional multiuser BC techniques like BC-RZF, TDMA, MRC will become more difficult and a better performance of sum rate gain and benefits of massive MIMO like high DoF, high data rates and reliableness with low interferences is not achieved. And it is difficult to achieve the sum rate gain, high throughput at a low bit error rate in Massive MIMO. So a two layer precoding with rate splitting method has been adopted. It is used to reduce the computational complexity due to the increase in the number of antennas and to increase the sum rate gain in Massive MIMO.

The two layer precoding provides a tradeoff between energy maximization and aesthetic improvement between the users at reduced interference. Both RS and HRS methods are generalized in large scale array regime. RS can provide a rate performance beyond just operating the adaptive per-user power allocation. By optimizing the transmit beamforming and power allocation parameters for both RS with two layer precoding and conventional RS method multiuser broadcasting(BC) schemes like TDMA, BC-RZF, the RS with two layer precoding shows significant performances in sum rate gain and also reduces the complexity due to the increase in number of antennas in massive MIMO.

2. Proposed Work

For a better sum rate performances and to reduce the computational complexity due to the increase in the number of antennas in Massive MIMO, a two layer precoding with rate splitting method has been adopted. And for further increasing the sum rate gain and to obtain high data rate transmission at a low bit error rate, the output obtained after rate splitting with two layer precoding is fed to the OFDM modulation technique.

Main contributions of this paper includes:

- Two layer precoding with rate splitting method in MU-MIMO and Massive MIMO.
- Increases the sum rate gain.
- For complexity reduction due to increase in number of transmitting antennas.
- The output obtained after two layer precoding along with rate splitting method is fed to the OFDM modulation technique.
- Further increases the sum rate gain.
- High data rate transmission.
- Decreases BER and increases system capacity.

3. System Model

Consider a single cell multi-user massive MIMO system, where a single base station (BS) equipped with M antennas transmits messages to K(≤M) single-antenna users over a spatially correlated Rayleigh fading channel. In FDD mode, the downlink training becomes a major problem with increase in number of transmit antennas and thereby difficulty to attain good CSIT quality. For each channel use, linear precoding is employed at the BS to support simultaneous downlink transmissions to K users. The received signals can be expressed as,

$$\mathbf{y} = \boldsymbol{H}^{\boldsymbol{H}}\mathbf{x} + \boldsymbol{n} \quad (1)$$

where $\mathbf{x} \in \mathbb{C}^{M}$ is the linearly precoded signal vector subject to the transmit power constraint. $H = [h_1, \ldots \ldots h_k]$ is the downlink channel matrix, $\boldsymbol{n} \sim \boldsymbol{\mathcal{CN}}(\mathbf{0}, \boldsymbol{I_k})$is the additive white Gaussian noise(AWGN) vector and $\mathbf{y} \in \mathbb{C}^{\boldsymbol{K}}$ is the received signal vector at the K users.

4. Rate Splitting Approach

In order to overcome the multiuser interferences caused by the imperfect CSIT due to the increase in the number of transmitting antennas in Multiuser broadcast channels(BC) and in Massive MIMO, a rate splitting approach for transmission has been done. It elaborates precoder design with two layer precoding method, power allocation parameters and the asymptotic sum rate performances. And the performance of two layer precoding over conventional precoding without two layer precoding with various multiuser broadcasting schemes like TDMA, BC-RZF have been quantified.

In Rate Splitting (RS) approach, the message intended to one selected user among k users is split into two parts. One is a common part 's_c' and another a private part, 's1'. The common message can be decoded by all the users with zero error probability as it is drawn from a public codebook. The private message s1 and the private messages intended to other users are superimposed over the common message and is transmitted by linear precoding.

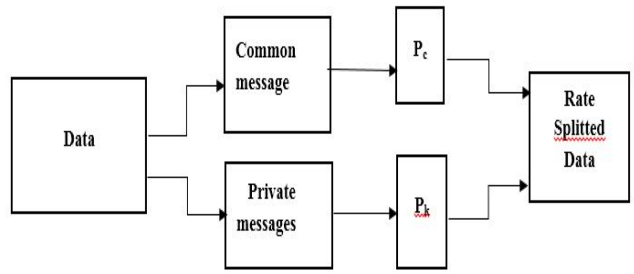

Fig. 1. Block Diagram of Rate Splitting Method

4.1 CSIT Model

Due to limited feedback, only an imperfect channel estimate is available at the BS which is modeled. The CSIT estimate is completely uncorrelated with the true channel. It can be modelled as,

$$\mathbf{h}_{\mathbf{k}}^{\wedge} = \mathbf{U}_{\mathbf{k}} \ \wedge_{\mathbf{k}}^{\frac{1}{2}} \ \mathbf{g}_{\mathbf{k}}^{\wedge} \quad (2)$$

whereas when error variance ep = 0, then it will be a perfect CSIT and on increasing ep =.1, .4 then the channel estimate will become imperfect.

4.2 Transmission Design

Considering a linearly precoded multiuser broadcasting with one tier precoder using two layer precoding technique. The transmitted signal '$\mathbf{x}$' and received signal '$\mathbf{y}_k$' of k^{th} user can be written as,

$$\mathbf{x} = \boldsymbol{W_s} = \sum_{\boldsymbol{k}=\mathbf{1}}^{\boldsymbol{K}} \sqrt{P_k}\ \boldsymbol{w}_k\ s_k \quad (3)$$

$$\boldsymbol{y_k} = \sqrt{\boldsymbol{P_k}}\, \boldsymbol{h}_{\boldsymbol{k}}^{\boldsymbol{H}} \boldsymbol{w_k} \boldsymbol{s_k} + \sum_{\mathrm{j}\neq \mathrm{k}}^{\mathrm{K}} \sqrt{\mathrm{P_j}}\ \boldsymbol{h}_{\boldsymbol{k}}^{\boldsymbol{H}} \boldsymbol{w_j} s_j + n_k \quad (4)$$

In the presence of imperfect CSIT with fixed error variance, the sum rate of BC with uniform power allocation is multiuser interference-limited at high SNR. In order to tackle the interference, one can adaptively schedule a smaller number of users to transmit as the SNR increases, which boils down to TDMA at extremely high SNR. However, such an adaptive scheduling is computationally heavy for a large number of users. And then the transmitted signal by RS approach can be written as,

$$\mathbf{x} = \sqrt{\boldsymbol{P_c}}\, \mathbf{w}_c\, s_c = \sum_{k=1}^{K} \sqrt{P_k}\, \mathbf{w}_k\, s_k \qquad (5)$$

where 'w_c' is the unit norm precoding vector of the common message (s_c).

5. Precoder Design

After creating two channels for common and private messages randomly, precoders are designed on the basis of reduced CSI feedback. The optimization is particularly complex in large scale systems. The precoder design in general can be written as,

$$\mathbf{W} = \xi\, \widehat{\mathbf{M}}\, \widehat{\mathbf{H}} \qquad (6)$$

where $\widehat{M} = \left(\widehat{H}\, \widehat{H}^H + M\, \varepsilon\, I_M\right)^{-1}$ and $\varepsilon = \sqrt{1/tr\left(\widehat{H}^H\, \widehat{M}^H\, \widehat{M}\widehat{H}\right)}$ that satisfies the transmit power constraints. Or simply, $\varepsilon = K/MP$.

5.1 Two Layer Precoding

In order to increase the sum rate gain and to reduce the computational complexity due to the increase in number of transmitting antennas in multiuser broadcast channels and Massive MIMO, the two layer precoding method has been adopted in the rate splitting (RS) approach. It splits the precoder design into outer and inner precoder separately due to the complexity in their joint optimization in two layer precoding. It provides a better separation with less errors while beamforming.

5.1.1 Outer Precoder Design

Using the different heuristic tactics, the outer precoder is constructed and simulate the rate performance of the system as a function of the outer precoder dimension, i.e., the number of statistical pre-beams. The outer precoder is based on the slow varying channel statistics like user covariances matrices. To construct the outer precoder we need to decompose the total channel covariance matrix through eigenvalue decomposition and is simulated in Matlab using singular value decomposition. And for a given matrix 'R' after decomposition, we obtain the three matrices and its corresponding eigenvalues and eigenvectors. By choosing the S largest eigenvalues among them and obtain an outer precoder matrix, U = [u_1, u_2, .., u_s] and performing the outer precoder matrix for both common message and private message separately. And then by multiplying them with their respective channels created for common and private to obtain the precoder weights for common and private messages.

5.1.2 Inner Precoder Design

The outer precoder matrix is fed to the inner precoder matrix and together by accumulating the Signal-to-Interference-Ratio (SINR) and power constraints, the precoder weights of common and private messages are obtained. The precoder weights are designed in such a way to maximize the achievable sum rate performances of common and private messages.

The precoder is designed in such a way to maximize the achievable rate of common message ($\mathbf{w}_c$). It is obtained as, $\log_2(1 + \gamma^c)$ with $\gamma^c = \min_k\{\gamma_k^c\}$ [1]. And different channel estimates become asymptotically orthogonal in the large scale array regime [6]. And then by designing the precoder $\mathbf{w}_c$, it can be written as,

$$\mathbf{w}_c = \sum_k a_k \ \hat{\mathbf{h}}_k \qquad (7)$$

which can be interpreted as weighted matched beamforming(MBF), where

$$\mathbf{a}_\mathbf{k}^* = \frac{1}{\sqrt{\mathrm{M}.\sum_{j=1}^{K} \frac{\pi_k(1-\tau_k^2)}{\pi_j(1-\tau_j^2)}}} \ , \forall_\mathbf{k} \quad (8)$$

6. Power Allocation

In Rate Splitting approach, a uniform power allocation to the private messages for both RS with two layer precoding method and conventional multiuser broadcasting schemes like TDMA, BC-RZF. Power allocation optimization can further enhances the sum rate performances on incorporating two layer precoding with rate splitting method. So it should be taken into account of how to allocate the power between private and common messages. The received signal, $\mathbf{y} = \boldsymbol{H}^{\boldsymbol{H}}\mathbf{x} + \boldsymbol{n}$, where x is linearly precoded signal vector subject to the transmit power constraint, $E\left[||\boldsymbol{x}||^2\right] \leq P$. And hence the power allocated to each messages is $P_c = P(1-t)$ and $P_k = {}^{Pt}/_K$ where t ∈ (0, 1] denotes the fraction of the total power that is allocated to the private messages. And in the decoding procedure, each user decodes first the common message ($\mathbf{s_c}$), by treating all private messages as noise. After eliminating the decoded common message by SIC, each user decodes their own private messages. By plugging (5) into (1), the Signal-to-Interference-plus-Noise-Ratios (SINRs) of the common message can be expressed as,

$$\gamma_k^c = \frac{P_k|\boldsymbol{h}_k^H \ \mathbf{w}_c|^2}{\sum_{j=1}^{K} P_j \ |h_k^H \boldsymbol{w}_j|^2 + 1} \qquad (9)$$

And the private message of user k is,

$$\gamma_k^p = \frac{P_k|\boldsymbol{h}_k^H \ \mathbf{w}_k|^2}{\sum_{j\neq k}^{K} P_j \ |h_k^H \boldsymbol{w}_j|^2 + 1} \qquad (10)$$

Under Gaussian signaling, the achievable rate of the common message is given as, $R_c^{RS} = \log_2(1 + \gamma^c)$, where $\gamma^c = \min_k\{\gamma_k^c\}$ and thereby it can be decoded by all the users. And the sum rate for the private messages can be expressed as,

$$R_p^{RS} = \sum_{k=1}^{K} R_k^{RS} = \sum_{k=1}^{K} \log_2(1 + \gamma_k^p) \qquad (11)$$

Then the total sum rate of RS can be calculated from this RS of common and private messages is given as,

$$\mathbf{R}_{\mathbf{Sum}}^{\mathbf{RS}} = \mathbf{R}_\mathbf{c}^{\mathbf{RS}} + \mathbf{R}_\mathbf{p}^{\mathbf{RS}} \qquad (12)$$

The optimal precoder $\mathbf{w}_c^*$ is given by (7) with $\{a_k^*\}$ in (8), by which all the K users experience the same SINR (9 and 10) with respect to the common message. Specially, the equally weighted matched beamforming with $a_k^* = 1/MK$ is optimal when the condition $\pi_k \ (1 - \tau_k^2) = \pi_j(1 - \tau_j^2), \ \forall \, k \neq j$ is satisfied. In order to obtain a more insightful and tractable asymptotic sum rate expression in the result we employ, $a_k^* = 1/MK$.

According to random matrix theory and the asymptotic SINR/rate approximations become more accurate for increasing number of transmit antennas. Meanwhile, the asymptotic approximations are feasible and tight for large but finite M, then an approximation $R_{sum}^{RS,o}$ of the sum rate of RS is obtained as,

$$R_{Sum}^{RS,o} = R_c^{RS,o} + R_p^{RS,o} \qquad (13)$$

The asymptotic approximations are feasible and tight for large but finite M. So the RS method is not suitable for the case when the number of transmitting antennas get increased as in the case of massive MIMO. So the RS method is best suitable for multiuser MIMO broadcasting channel where the receiving antennas is less than or equal to the transmitting antennas. So for massive MIMO, a novel rate splitting method is used.

7. Hierarchical Rate Splitting Approach

HRS exploits the knowledge of spatial correlation matrices and it make use of the channel second-order statistics, if known to the transmitter. When there are more number of transmitting antennas than the method is suitable as it consists of a large number of transmitting antennas at the base station (BS). This method is done by generalizing the RS method into group level clustering. By treating each group as a user and then the rate splitting method is done. It consists of an inner RS and an outer RS. Users in each group share the same spatial correlation matrix.

All the method is as same as RS approach but the only difference is in HRS method, all the users are grouped and the rate splitting is done at the group level by treating each group as a user. In HRS approach there are two kinds of common messages and private messages intended to each users. Treating each group as a single user, an outer RS would tackle the inter-group interference. By packing part of one user's message into a common codeword that can be decoded by all users. An inner RS would cope with the intra-group interference. By packing part of one user's message into a common codeword that can be decoded by multiple users in that group. Uniform power allocation is performed for the private messages similar to RS. And the same transmission scheme, precoder design and power allocation is done in HRS approach like rate splitting.

When users are clustered into groups according to the similarity of their channel covariance matrices, [7] proposed a two-tier precoding approach to achieve massive-MIMO-like gains with highly reduced-dimensional CSIT. More precisely, the outer precoder controls inter-group interference based on long-term CSIT (the channel covariance matrices) while the inner precoder controls intra-group interference based on short-term effective channel(the channel concatenated with the outer precoder) with a reduced-dimension. The system performance of the aforementioned two-tier precoding schemes are highly degraded by two limiting factors: inter-group and intra-group interference. When the eigen-subspaces spanned by the dominant eigenvectors of groups spatial correlation matrices severely overlap, the outer precoder design may leak power (inter-group interference) to unintended groups. A typical example of overlapping eigen-subspace is that of users in different groups sharing common scatterers.

K users are partitioned into G groups (e.g., via K-mean clustering) and that users in each group share the same spatial correlation matrix, $R_g = U_g \wedge_g U_g^H$ with rank r_g. Let K_g denote the number of users in group $\mathbf{g}$ such that $\sum_{g=1}^{G} K_g = K$. The transmitted signal of conventional two-tier precoded (TTP) broadcasting scheme with two layer precoding is expressed as,

$$\mathbf{x} = \sum_{g=1}^{G} \boldsymbol{B}_g \boldsymbol{W}_g \boldsymbol{P}_g s_g \qquad (14)$$

where $s_g \epsilon \mathbb{C}^{k_g}$ represents the data streams for the g-th group users. And the received signal of the k-th user in g-th group is given by,

$$y_{gk} = \sqrt{P_{gk}}\, h_{gk}^{H}\, \boldsymbol{B}_{gk}\mathbf{w}_{gk}s_{gk} + \underbrace{\sum_{j\neq k}^{K_g}\sqrt{P_{gj}}\; h_{gk}^{H}\mathbf{B}_g\mathbf{w}_{gj}s_{gj}}_{intra-group\ interference} + \underbrace{\sum_{l=g}^{G} h_{gk}^{H}B_l w_l P_l s_l}_{\text{Inter-groupinterference}} \quad (15)$$

where $\mathbf{w}_{gk} = [W_g]_k$. To eliminate the inter-group interference, the outer precoder is designed in the nullspace of the eigen-subspace spanned by the dominant eigenvectors of the other group's spatial correlation matrices. However, the power attached to the weak eigenmodes may leak out to other groups and create inter-group interference. Besides, the intra-group interference cannot be completely be removed due to imperfect CSIT (e.g., limited feedback). To eliminate the interference limited behavior at high SNR, one can optimize the groups, the users in each group, etc, as a function of the total transmit power and CSIT quality. In general, such an optimization problem is quite complex. By treating each group as a single user, an outer RS would tackle the inter-group interference by packing part of one user's message into a common codeword that can be decoded by all users. Likewise, an inner RS would cope with the intragroup interference by packing part of one user's message into a common codeword that can be decoded by multiple users in that group. The common messages are superimposed over the private messages and the transmitted signal of HRS is sent as RS method but in a group level. And after two layer precoder design and proper power allocation for the private messages and common messages intended to the groups and its inner users in a group, the asymptotic sum rate can be obtained from SINRs of private message and common messages of outer and inner group is expressed as,

$$R_{sum}^{HRS,\ o} = R_{oc}^{HRS,\ o} + R_{ic}^{HRS,\ o} + R_{p}^{HRS,o} \quad (16)$$

And by using two layer precoding method with HRS approach, a better sum rate gain and computational complexity of conventional BC schemes are reduced and the results are obtained. The output data obtained after rate splitting method is fed to the OFDM modulation method to enhance the sum rate and for high data transmission at low BER in multiuser MIMO and Massive MIMO.

8. Orthogonal Frequency Division Multiplexing (OFDM)

A digital multicarrier modulation method that encodes the digital data on multiple carrier frequencies which divides into a large number of closely spaced sub-channels and a single user would make use of all orthogonal subcarrier in divided frequency bands to provide more reliable communications at high speeds. OFDM will provide much higher bandwidth efficiency and robustness again multipath fading.

The two layer precoding with rate splitted output is fed to the OFDM modulation method which will increase the sum rate gain and increases the bandwidth, system capacity and speed of the channel at low BER and can attain high data rate transmission in massive MIMO.

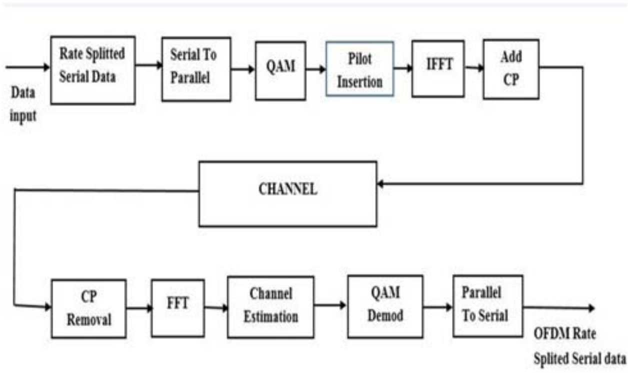

Fig. 1 Block Diagram Of Rate splitted with two layer precoding output fed to OFDM

9. Simulation Results

Experimental results have been analyzed in Matlab 2014a version. The rate splitting approach with two layer precoding method shows significant performances of single layer over two layer precoding. There is a better sum rate gain performance in both RS and HRS method. The rate splitted (RS) output is fed to the OFDM. So the RS and HRS methods together with the OFDM modulation can increase the sum rate than the conventional rate splitting (RS) methods and other linear broadcasting methods like Regularized Zeroforcing (RZF) and TDMA. For RS and HRS method with two layer precoding along with the OFDM have obtained a sum rate gain of 70 bps/Hz at 30dB for RS and 130 bps/Hz at 50dB for HRS. And the results are obtained that validates the significant benefits of Hierarchical Rate Splitting with OFDM over Rate Splitting with OFDM, conventional RS methods and BC-RZF and TDMA. By using OFDM, we can also decrease the Bit Error Rate in massive MIMO.

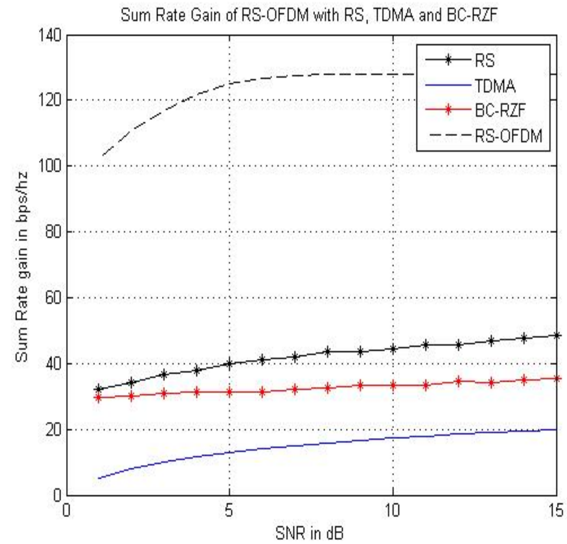

Fig. 3 Comparison of Sum rate gain of OFDM-RS with Conventional RS, BC-RZF, TDMA

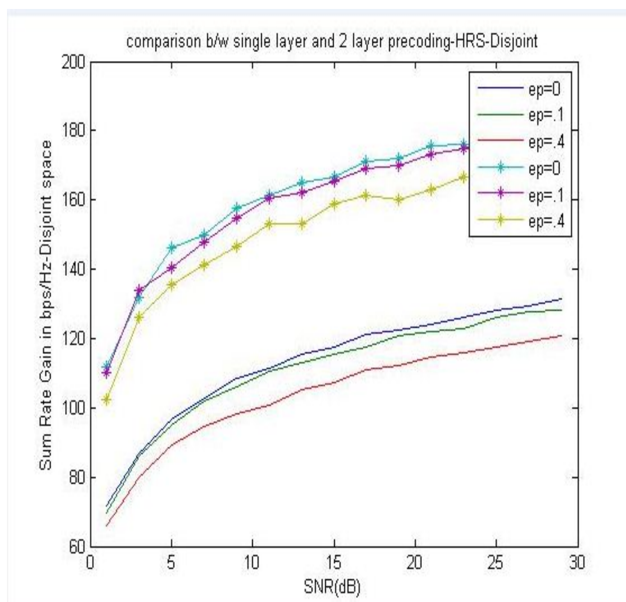

Fig.4 Comparison of single Vs Two layer precoding of HRS-OFDM under various CSIT qualities- Disjoint

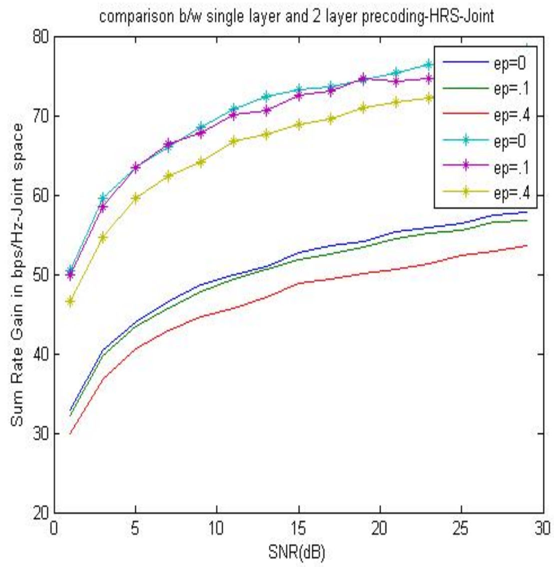

Fig 5. Comparison of single Vs Two layer precoding of HRS-OFDM under various CSIT qualities- Disjoint

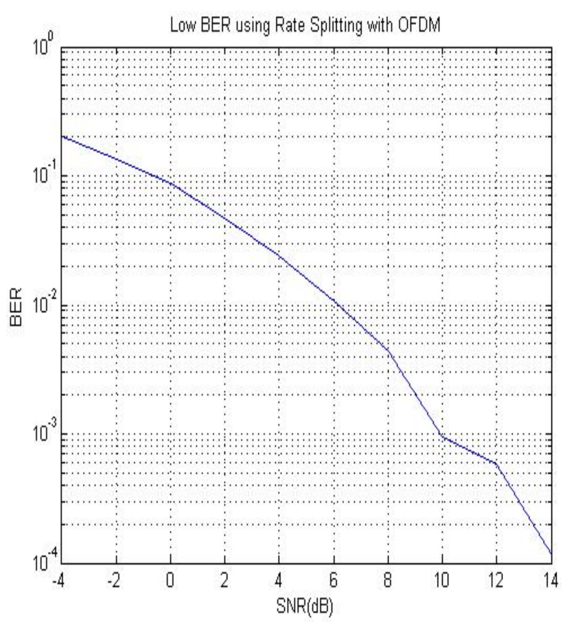

Fig.6 BER performances of two layer precoding in rate splitting with OFDM

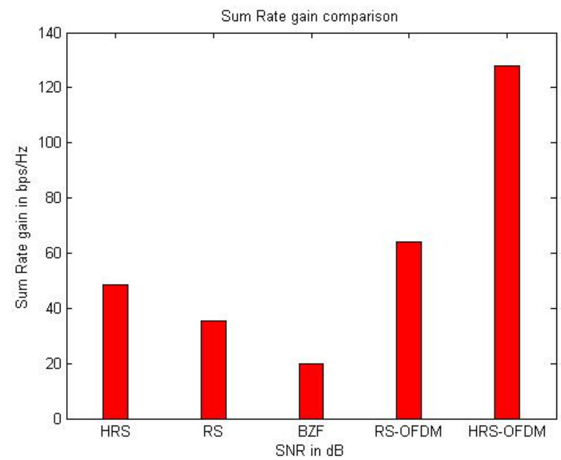

Fig.7.Comparison of OFDM-HRS, OFDM-RS, RS, HRS, BC-RZF, TDMA with two layer precoding

10. Conclusion

A two layer precoding is done along with rate splitting approach to increase the sum rate gain and to reduce the computational complexity in Massive MIMO due to the increase in number of antennas. It provides a better separation with less errors while beamforming. And then the output obtained after two layer precoding with rate splitting method to OFDM modulation. OFDM in Massive MIMO increases the bandwidth, system capacity and high data rate transmission is possible at low BER. OFDM combined with Rate Splitting provides a better sum rate gain and the results obtained validates the significant benefits of it with the conventional rate splitting methods used. And making Massive MIMO a strong candidate for the increasing future generation of wireless communications.

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