Capacity Enhancement of Multi-User Massive MIMO Systems through MAI cancellation using Limited feedback system

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Abstract- Massive multiple-input multiple-output (MIMO) system is very important for achieving the requirement of higher spectral efficiency (SE) in the present and next generation cellular mobile systems. The limited feedback systems are applied to acquire the channel state information (CSI) and tackle CSI-reference signal (CSI-RS) the overhead problem for frequency division duplexing (FDD) in massive MIMO systems. However, the limited feedback suffers multi-user interference (MUI) due to selection of irrelevant beam-forming vector for the users at dispersive locations when the user channels are heavily correlated. This degrades the system performance. Also, it has been noticed that the performance is not improved but complexity increases as the size of codebook in the limited feedback system is increased to counteract the poor scattering of channel characteristics. So, innovative CSI acquisition scheme is developed to mitigate MUI and reduce complexity using advanced codebook based limited feedback algorithm for FDD based multi-user (MU) - massive MIMO systems. This algorithm finds the unique beamforming vector to mitigate MUI against adverse channel characteristics and reduces feedback requirement using efficient combining coefficients calculations. The simulation shows that the proposed CSI acquisition scheme achieves higher SE without extra CSI feedback bits and additional complexity compared to existing methods.

***Keywords**: limited feedback, spectral efficiency, MU-massive MIMO, channel state information, beamforming, frequency division duplexing*

I. INTRODUCTION

The MIMO system has been proved for enhancing the system capacity and reliability in wireless technologies. Massive MIMO systems are developed at higher scaling for next-generation wireless networks to enhance SE [1]. Recently, the base stations (BS) are installed with a large number of antennas whereas the minimum complexity is retained in the user equipment. Especially, the BSs of massive MIMO systems uses hundreds or a large number of small dipole antennas which permit MU-MIMO communication using spatial multiplexing for uplink and downlink channels [2].

The details of CSI at the transmitter and its accuracy are important to acquire the multiplexing gain and the array gain for increasing the capacity of the massive MIMO systems [3]. The acquisition of CSI has been tried in time division duplexing for massive MIMO systems using channel reciprocity by up-linking the training sequences. However, it suffers from pilot contamination with enormous training sequences as the number of users grows. This degrades the performance with additional feedback and results in MUI [4]. Alternatively, the FDD is promising for CSI estimation to circumvent this difficulty for the present and next-generation cellular systems. Hence, it is the best choice for massive MIMO of FDD systems [5 & 6].

On the other hand, the conventional CSI estimation techniques are affected with the number of sequences of pilot symbols which grows with the number of transmit antennas *M* at the BS. This becomes the serious problem for the case of a massive MIMO system because the number of CSI feedback bits and the pilot training sequences approaches very large values with a higher value of *M* [7 & 8]. The CSI estimation techniques select beamforming vectors for the users at the dispersive locations using limited feedback algorithms for the channels with sparse characteristics. However, it suffers MUI due to selection of irrelevant beam-forming vector for those users when the user channels are heavily correlated [9 & 10]. Furthermore, it has been noticed that the performance worsens and complexity increases as the size of codebook in the limited feedback system is increased to tackle the problem of selecting unique beamforming vector against the scattering of channel characteristic [11 &12].

Hence, efficient CSI estimation and effective feedback design are required for FDD based massive MIMO systems to mitigate MUI and reduce CSI feedback overhead against the poor scattering of the channel characteristics in order to improve SE. So, innovative CSI acquisition scheme is proposed to mitigate MUI and reduce complexity using advanced codebook based limited feedback algorithm for FDD based MU-massive MIMO systems. Advanced codebook design provides good framework for the selection of the beamforming vectors without an extra CSI feedback bits and additional complexity. This proposed algorithm called as a flock based quantization and antenna combining approach finds the unique beamforming vector to handle MUI against adverse channel characteristics and reduces feedback requirement using efficient coefficients calculation.

The paper is arranged as follows. The methodology including system model, innovative CSI acquisition scheme and advanced codebook based limited feedback algorithm for FDD based MU-massive MIMO systems is described in Section II. The results and discussion and conclusion are given in the last two sections III and IV.

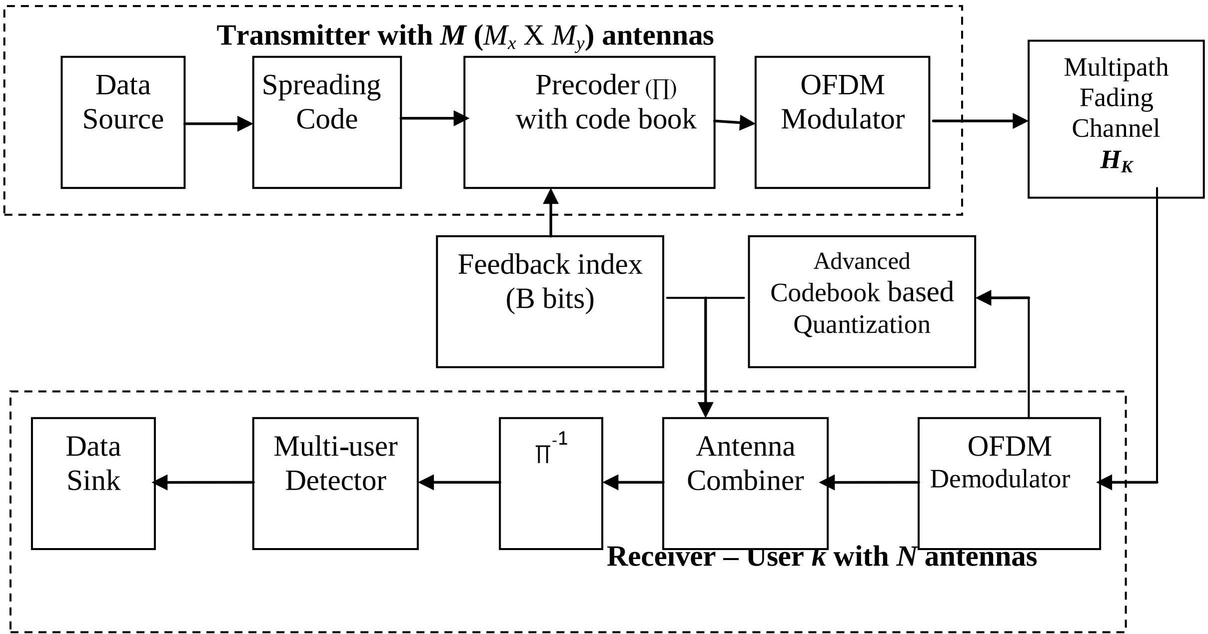

Figure 1. MU-Massive MIMO system for the proposed technique.

II. METHODLOGY

A. System Description

The MU-massive MIMO system is shown in figure 1. The system uses the data block of M symbols and specified as $b_k(i) = [b_1^{(k)}(j)\ldots b_M^{(k)}(j)]^T$ for the j-th block of user, k where $b_m^{(k)}(j) \in \{\pm 1\}$, $1 \le m \le M$ and $1 \le k \le K$. The source information of one data block for the user, k is given as $x_k = A_k\, \pi\, C_k\, b_k$ where A_k is the amplitude associated with user, k, π is the precoding matrix and C_k is spreading codes of C_1 .. C_K for K users. The spatial multiplexed transmitter communicates parallelly with K users using M transmit antennas of dual-polarized type and arranged in horizontal and vertical directions of M_X and M_Y antennas respectively. Each user uses N receive antennas and M is higher than N.

The signal to be transmitted is represented as ,

$$x_k[n] = b_k[n]\, s_k[n] \tag{1}$$

where $x_k[n]$ is transmitted signal vector and $s_k[n]$ is the symbol for the range of subcarriers, $1 \le n \le N_s$. The received signal of the user, k for n-th subcarrier of OFDM is written as,

$$y_k[n] = \sqrt{\frac{P}{N_t}} H_k[n]\, V[n]\, x[n] + Z_k[n] \tag{2}$$

where P is the signal transmit power and power, (P / N_t) is equally shared among transmit antennas for K users under the fully loaded system, $H_k[n]$ is the channel matrix and $V[n] = \{v_1[n], v_2[n], \ldots, v_K[n]\}^T$ is the beamforming vector matrix of size, M x K for K users. $Z_k[n]$ is the complex additive white Gaussian noise which has zero mean and a covariance identity matrix.

In order to achieve maximum SE, the beamforming vector should be designed such that each mobile unit quantizes its channel to the beamforming vector that obtains the maximum received signal to interference plus noise ratio (SINR). The optimality condition for this goal to design the beamforming vector is formulated as,

$$V[n] = \sum_{n=1}^{N_s} \sum_{k=1}^{K} \log_2 (1 + \delta_k\, [n] \tag{3}$$

where $\delta_k[n]$ is received SINR at the user, k for the n^{th} subcarrier and it can be written as,

$$\delta_k[n] = \frac{\frac{P}{M}\left|h_k[n]^H\, v_k[n]\right|^2}{1 + \sum_{i \ne k}^{K} \frac{P}{M}\left|h_k[n]^H\, v_k[n]\right|^2} \tag{4}$$

However, it demands more CSI-RS overhead and computations for estimating the channel coefficients and it grows with the number of antennas. And, it is difficult to find the coefficients due to the MUI for highly correlated channels as antennas are packed in the small region. This degrades the performance.

In order to reduce the computation complexity, advanced codebook based limited feedback is proposed for FDD based MU-massive MIMO systems to increase the accuracy of the CSI and reduce the CSI feedback overhead. The proposed flock based quantization and antenna combining algorithm finds the unique beamforming vector using advanced codebook based limited feedback to handle MUI against adverse channel characteristics and reduces feedback requirement using efficient combining coefficient calculations.

B. Technique

As shown in figure 1, the selected beamforming vectors in the pre-constructed codebook, C with size of N_Y are combined with groups of CSI-RSs in the precoder. This beamforming groups of CSI-RSs are delivered from BS to receiver for the downlink channel estimation. Thus, columns of antennas are pre-coded with same beamforming vector whereas each column forms the port of CSI-RS beamforming group. The channel matrix of size, N x M_y described between M_X antennas at the BS and the user k for n^{th} subcarrier for n^{th} CSI-RS beamforming group can be represented as,

$$\hat{\mathrm{H}}[\mathrm{n}] = \left[\hat{h}_1^1[n], \ldots \ldots, \hat{\mathrm{h}}_K^{\mathrm{Mx}}[n]\right]^H = \mathrm{H}_k[n]\, [I_{Mx}.\, v_n] \quad (5)$$

$\hat{\mathrm{V}}[\mathrm{n}]$ is k-th column of $\hat{\mathrm{V}}_k[n]$. Where v_n is n^{th} beamforming vector in the preconstructed codebook, C,

$$\hat{\mathrm{V}}[n] = \left(\hat{\mathrm{H}}[n]^{\mathrm{H}}\, \hat{\mathrm{H}}[n]\right)^{-1} \hat{\mathrm{H}}[n]^{\mathrm{H}} \quad (6)$$

$$\mathrm{v}_k[n] = \hat{\mathrm{v}}_k[n] / \left\|\hat{\mathrm{v}}_k[n]\right\| \quad (7)$$

C. Algorithm:

Although subcarrier combining group can reduce the overall feedback overhead, the data rate cannot be increased because quantization beamforming vectors are represented by unique representative quantization beamforming vector $\hat{h}_k^g$ for the entire group. This is not the best fit for remaining subcarriers in the same group. In order to solve the issue of mismatch between quantization beamforming vectors and effective channels, the joint flock based quantization and antenna combining approach is proposed. It finds the effective channels and the quantized beamforming vectors jointly by searching all entries of the codebook. This jointly finds and representative quantization beamforming vector with respect to the search of considering the entire codebook. The best beamforming vector is selected based on the estimation of channel matrices for every user. Then, it is quantized with an index of N_Q bits for each entry of the codebook $c_k[j]$ where $c_k[j]$ represents the quantized beamforming vector for the user, k and block, j. Thus, it does not require any beamforming groups of CSI-RSs for the precoder. This avoids the CSI feedback overhead.

In the receiver side, codebook, C is scanned according to all channel subspaces and finds optimal beamforming vector for maximum SINR as per (4). The index bits of the selected beamforming vector and associated coefficients are transmitted as quantized CSI through the reverse link as feedback to the BS. The beamforming vectors are computed for each user using these quantized CSI in the BS. Then, beamforming is performed after precoding and combining algorithm like zero forcing or MRC to mitigate MUI.

III. RESULTS AND DISCUSSION

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The performance of MU-massive MIMO systems using the proposed technique is evaluated to prove the discussion presented in the previous sections. The results are compared with conventional CSI estimation technique and conventional limited feedback based CSI estimation technique. The operating frequency is set to 2GHz of carrier frequency with a bandwidth of 10MHz, It is assumed that each user uses dual-polarized antenna array of N=2 antennas and the BS is equipped with M=64 antennas where M is composed of M_X= 4 and M_Y=8 antennas in different dimensions. The minimum distance between the two antennas is 0.5 lambda in the horizontal direction and 0.8 lambda in the vertical direction. The 3GPP channel model is used to simulate the scattering effect of the spatial correlated channel [13]. The QPSK constellations are used to quantize the amplitude and phase and uses uniform sampling. The quantization bits, N_Q is set to 3. Here, the codebooks are randomly generated with respect to channel quantization for each user equipment and all subcarriers. The size of the codebook is 2^B and generated offline.

First, the SE performance of the proposed technique is compared with conventional CSI estimation technique and conventional limited feedback based CSI estimation technique against the variability of SNR for known codebook size and a fixed number of users as shown in figure 2. The simulation curves display that SE increases with SNR values. The SE for conventional CSI estimation technique increases to the maximum value but it demands more CSI feedback bits for its performance. The SE curve for conventional limited feedback based CSI estimation technique deteriorates at higher SNR values since the quantized beamforming vector is not optimal for the other (Ns – 1) subcarriers in the selected group due to the unmatched and large size of the group in the technique. Fortunately, the proposed technique achieves the better SE performance with unique beamforming vector selection and minimum CSI feedback overhead. It is noted that the SE of the proposed technique gains 60 % more than the conventional scheme at SNR of 15 dB. It is clear that the MUI is mitigated and outperforms the other existing techniques where the quantization error is one of the major performance criteria.

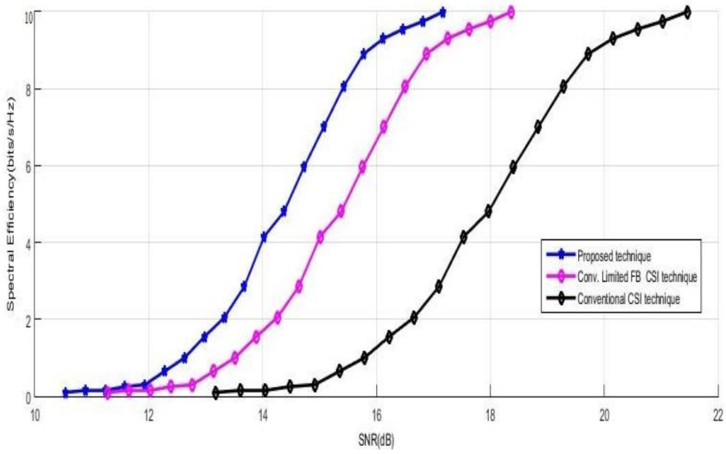

Figure 2. SE performance wrt SNR for different techniques

In the next scenario, the SE performance of the proposed technique is compared with respect to the number of active users as shown in figure 3 against conventional CSI estimation technique and conventional limited feedback CSI estimation technique for known codebook size and fixed SNR value. The SE curve for the conventional CSI estimation technique is deteriorated with increased quantization error and hence MUI as number of users increases because the representative beamforming vector is not the optimal because it identifies strong eigenmode for a few users and wasting the feedback for remaining weak users. The SE performance of the conventional limited feedback based CSI estimation technique is slightly better than the conventional CSI estimation technique. However, it demands more CSI feedback bits to reduce the quantisation error. The curve shows that the proposed technique outperforms the existing techniques because the proposed techniques identifies unique beamforming vector by reviewing all channel subspaces over the entire codebook with minimum quantization error and feedback overhead. Thus, MUI determines the existing techniques as poor performance due to large quantization error whereas the proposed technique is robust against MUI under a large number of users. Hence, the MU-massive MIMO system enhances the capacity with increased MUI mitigation efficiency against scattering propagation characteristic of the channel.

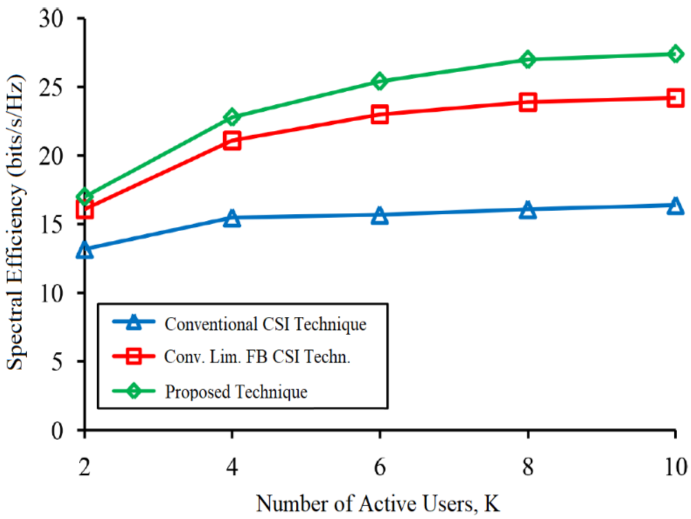

Figure 3. SE performance against number of users (*K*) for different techniques

The proposed techniques consider the number of CSI feedback bits and use the quantized bits as an index of the codebook for calculating the combining coefficients as per the proposed algorithm. The proposed technique does not increase the CSI feedback bits and occupies the small bandwidth of the uplink channel and achieves the best performance without extra CSI feedback bits compared to existing techniques.

IV. CONCLUSION

An innovative CSI acquisition scheme is proposed to mitigate MUI and reduce complexity using advanced codebook based limited feedback algorithm for FDD based MU-massive MIMO systems. Advanced codebook design provides a good framework for the selection of the best beamforming vectors by reviewing all channel subspaces over entire codebook with minimum quantization error. The combining coefficients are calculated efficiently using the proposed algorithm that finds the unique beamforming vector to mitigate MUI against adverse channel characteristics and reduces the number of computations. Thus, the quantized feedback bits are sent to BS without the need of extra CSI feedback bits and additional complexity. The simulation results show the capability of the proposed technique to achieves the higher SE compared to existing techniques against scattering propagation characteristic of the channel. Hence, the MU-massive MIMO system enhances the capacity with increased MUI mitigation efficiency.

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