Joint Flock based Quantization and Antenna Combining Approach for MCCDMA Systems with Limited Feedback

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Abstract
The multi-carrier code division multiple access (MCCDMA) is a strong candidate to facilitate multi-user (MU) multi input multi output (MIMO) communication for the current and next generation wireless mobile system. An orthogonal frequency division multiplexing (OFDM) based MCCDMA system with limited feedback channel is considered for reducing channel state information (CSI) feedback load. The residual multi user interference (MUI) inevitably comes with multiuser signals on each subcarrier of OFDM due to limited feedback and increases as large number of users is simultaneously active since it is related to the number of subcarriers and multiple antenna. The efficient quantization of CSI is the vital solution in order to break the interference limitation to increase the user capacity of MCCDMA system. The joint flock based quantization antenna combining approach is proposed to make quantization on flock basis which exploits flock of correlated subcarriers and stick together with combining process of multiple antenna signals for reducing the CSI feedback bits with minimum quantization error. For this, the minimum angular distance criterion is developed based on upper bounded throughput loss to find the reliable representative quantization vector for the flock which is feedback to the transmit with minimum bits and enable the efficient antenna combining jointly to yield the unique effective channel for multiple antennas at the receiver. The simulation result shows that the proposed scheme achieves significant performance improvement in terms of quantization error and compared to conventional schemes with the reduced feedback load and similar order of complexity (O(N)). The result also shows that it can support more number of users due to increased MUI mitigation efficiency.

Keywords: flock, quantization, antenna combining, limited feedback, MU-MIMO, OFDM-MCCDMA

Introduction
The OFDM based MCCDMA system can be efficiently utilized for achieving high spectral efficiencies and diversity gain. It has the potential of high system capacity by exploiting multiple antennas at the transmitter to share the channel with multiple users [1, 2]. In general, complex techniques are required to design higher capacity systems. The capacity of the MIMO system can be achieved with low-complexity linear precoding techniques such as zero forcing beamforming (ZFBF) and block-diagonalization (BD) precoding [3, 4]. These methods facilitate interference-free transmission to multiple users such that perfect CSI should be available at the transmitter [5]. The CSI at the transmitter (CSIT) can be obtained from the users using finite rate feedback links [6]. But, it is very hard to obtain in frequency division duplex systems. The limited feedback scheme has been widely used to give CSI to the transmitter [7]. Due to the limited capacity of the feedback links, the CSI is quantized by the users prior to signaling to the base station. However, the limited feedback scheme degrades the performance of MU-MIMO downlink system due to inherent quantization error. With quantized CSIT, the residual MUI which cannot be avoided significantly impairs the achievable transmission rate of the system [8]. It has been shown that a linear increase in the number of feedback bits with the signal to noise ratio (SNR) in dB is required to maintain a constant rate-gap to perfect CSIT in order to obtain desired multiplexing and multi-user diversity gain for reducing the quantization error in a limited feedback system. Several multi-user precoding techniques require knowledge about the linear vector spaces spanned by the channel matrices to calculate the precoders [9]. These spaces can be represented as points on a Grassmann-manifold. Grassmannian quantization acquires significant interest in CSI feedback [10]. A similar bit-scaling law is determined for BD precoding to multiple users where the number of data streams per user is equal to the number of receive antennas [11]. It has been shown that the CSI requirements become less strict if users are provided with excess receive antennas which are greater than the number of data streams per user [12]. An efficient antenna combining algorithm is proposed, denoted as quantization based combining (QBC), which minimizes the CSI quantization error. This strategy significantly decreases the residual MUI and reduces the slope of the feedback bit-scaling law. This blind approach reduces implementation complexity on transmitter side and allows simple receiver design for number of receive antennas [12]. This is quite different from maximum ratio combining, where the combiner weights and quantization vector are chosen such that received signal power is maximized but quantization error is generally not minimized [13]. It is shown that the quantization-based combining is better in reducing the quantization error and the interference power with small loss of signal power [12].

Receive antenna combining strategies for the MIMO broadcast channel are proposed and investigated for ZFBF and for BD precoding [14]. Moreover, if space division
multiple access (SDMA) schemes are directly used with practical broadband communication techniques such as orthogonal frequency division multiplexing (OFDM), the total feedback load becomes infeasibly large, because it is proportional to the number of subcarriers (SC) [15]. Based on QBC, an algorithm has been proposed which reduces the total feedback load in OFDM based MU-MIMO system by using subcarrier grouping. This algorithm selects one representative quantization vector for each subcarrier group and this vector is feedback to construct a beamforming vector for all the subcarriers in the group [16]. Naturally, it reduces the feedback load but increases the throughput loss as the size of subcarrier group increases due to increased inherent quantization error form mismatch between the representative quantization vector of the group and each subcarrier. In the extension of previous algorithm, an improvement was made in the sum rate of the algorithm by appropriately adjusting each quantization vector of the group and each subcarrier. In the effective channel describing the channel from the transmit antenna array to the effective output of the receiver. Zd[n] is the complex additive white Gaussian noise which has zero mean and a covariance identity matrix.

The effective channel describing the channel from the transmit antenna array to the effective output of the k-th mobile is simply a linear combination of the N users using 

\[ x_k = A_k \pi C_k \theta_k \]  

where \( \pi \) is the precoding matrix, \( A_k \) is the amplitude associated with user, \( k \) and \( C_k \) is spreading codes of \( C_1, C_2 \) for \( K \) users. The spatial multiplexed transmitter communicates parallelly with \( K \) users using \( N_t \) transmit antennas. It is assumed that each users consists of \( N_s \) receive antennas and let \( N_s < N_t \) and data streams, \( L \leq N_s \). It is assumed that \( N_s \) users are randomly selected for transmission.

**System Description**

The multi-user MIMO-OFDM based MCCDMA transceiver is shown in figure 1. It considers data block of \( M \) symbols and represented as \( b_{m}(i) = [b_{m}(i) \ldots b_{m}(j)]^T \) for the \( j \)-th block of user, \( k \) where \( b_{m}(i) \in \{ \pm 1 \} \), \( 1 \leq m \leq M \) and \( 1 \leq k \leq K \). The source information of one data block for user, \( k \) is written as

\[ x_k = A_k \pi C_k \theta_k \]  

where \( \pi \) is the precoding matrix, \( A_k \) is the amplitude associated with user, \( k \) and \( C_k \) is spreading codes of \( C_1, C_2 \) for \( K \) users. The spatial multiplexed transmitter communicates parallelly with \( K \) users using \( N_t \) transmit antennas. It is assumed that each users consists of \( N_s \) receive antennas and let \( N_s < N_t \) and data streams, \( L \leq N_s \). It is assumed that \( N_s \) users are randomly selected for transmission.

**Figure 1: MCCDMA system for the proposed technique.**

The transmit signal is represented as per ZFBF and written as,

\[ x_k[n] = b_k[n] s_k[n] \]  

where \( x_k[n] \) is ZFBF vector and \( s_k[n] \) is the normalized scalar symbol for \( 1 \leq n \leq N_s \), where \( N_s \) is the number of subcarriers. The received signal of user, \( k \) for n-th subcarrier of OFDM is written as,

\[ y_k[n] = \frac{1}{\sqrt{N_t}} H_k[n]^H x_k[n] + Z_k[n] \]  

where \( P \) is the total transmit power; power \( P/N \) is equally split into all transmit antennas among the \( K \) users for the fully loaded system, \( N_s = K \); \( H_k[n] \) is the channel matrix of user, \( k \) for n-th subcarrier and \( \cdot H \) denotes conjugate transpose. \( Z_k[n] \) is the complex additive white Gaussian noise which has zero mean and a covariance identity matrix.

The effective channel describing the channel from the transmit antenna array to the effective output of the \( k \)-th mobile is simply a linear combination of the \( N_s \) vectors describing the \( N_s \) receive antennas [12]. Each mobile linearly combines its \( N_s \) outputs using appropriately chosen combiner weights, \( G_k \) to produce a scalar output [12]. Assuming single data stream and receive antenna combining [12], the received signal at each mobile station (MS) after receive combining is given as,

\[ r_k[n] = G_k[n]^H y_k[n] \]  

\[ r_k[n] = h_k^{eff}[n]^H x_k[n] + z_k[n] \]  

The product of channel matrix and antenna combiner as the effective user channel,

\[ h_k^{eff}[n] = H_k[n] G_k[n] \]  

where \( G_k \) is antenna combiner of unit norm, which is applied in the receiver for separating the intended signal from multi-user interference.

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Then, the signal- to-interference-plus noise ratio (SINR) is

\[ B[n] = \left( \hat{H}[n]^H \hat{H}[n] \right)^{-1} \hat{H}[n]^H \]

where \( h_{\text{eff}}[n] \) is the quantized effective channel of user, \( k \) and \( b[n] \) is the \( k\)-th column of \( B[n] \).

Then, the signal-to-interference-plus noise ratio (SINR) is given by,

\[ \text{SINR}_k[n] = \frac{\| h_{\text{eff}}[n] b_k[n] \|^2}{1 + \sum_{i \neq k} \| h_{\text{eff}}[n] b_i[n] \|^2} \]

**Preliminaries**

For analytical tractability, the random vector quantization (RVQ) is considered in which each of the \( 2^B \) quantization vectors is independently chosen from the isotropic independently distributed generated codebook [5-7]. The \( N \)-dimensional unit norm, \( 2^B \) quantization vectors are denoted as \( \{w_1, w_2, \ldots, w_{2^B}\} \). Each mobile has channel matrix and let \( Q_k[n] = [h_k[n]^1, \ldots, h_k[n]^{N_r}] \) be an orthonormal basis for channel span \( (H_k[n]) \). In order to perform quantization, each mobile quantizes its channel to the quantization vector that forms the minimum angle between each quantization vector and channel span \( (H_k[n]) \). For each quantization vector, \( w_i \), without loss of optimality, the minimization can be performed to find the effective channel vector in span \( (H_k[n]) \) that makes the minimum angle with

\[ w_l. \min_{l=1,2^B} \sin^2 \left( \angle(h_{\text{eff}}[n],w_l[n]) \right) \]

That is, the mobile, \( k \) finds the optimal quantization vector, \( w_l \) closest to span \( (H_k[n]) \) from the codebook, \( C \). This effective channel vector can be represented in maximization form as,

\[ h_{\text{eff}}[n] = \arg \max_{w \in C} \| Q_k[n]^H w \| \]

The \( h_{\text{eff}}[n] \) can be in any direction in the \( N \)-dimensional subspace spanned by \( \{h_k[n]^1, \ldots, h_k[n]^{N_r}\} \) i.e. in span \( (H_k[n]) \) for mobile \( k \). After the quantization step, each user feedback the quantized channel, \( h_{\text{eff}}[n] \) for all the subcarriers individually to the transmitter. The feedback load is proportional to the number of subcarriers.

The receive antenna combining is the technique to find optimum effective channel that reduces channel quantization error by appropriately combining receive antenna outputs with chosen combiner weights, \( G_k \) [12]. The linear combiner is considered at each mobile which effectively converts each multiple antenna mobile into a single antenna receiver.

**Proposed Scheme: Joint Flock Based Quantization and Antenna Combining**

**Problem Formulation**

The residual multi user interference (MUI) inevitably comes with multiuser signals on each subcarrier of OFDM based MC-CDMA due to limited feedback and increases as large number of users is simultaneously active since it is related to the number of subcarriers and multiple antenna. If QBC can be used for each subcarrier individually, the quantization error decreases but the feedback load of the system increases significantly when the number of subcarriers is large because feedback load is proportional to the number of subcarriers. Also, the QBC leads to a small loss in the gain of the effective channel and results in small signal power compared to the maximum-ratio combining based technique.

The above problem extends the QBC scheme, called as QBC based SC grouping (QBC-SC) algorithm that performs subcarrier grouping for reducing the feedback load [16]. Although subcarrier grouping can reduce the total feedback overhead, sum rate degradation is unavoidable because quantization vectors are replaced by one representative quantization vector \( h_{\text{eff}}^g \) for each group which is not optimal for other subcarriers in the group. Moreover, unnecessary mismatches exist between the representative quantization vector and the effective channels. This is because effective channels computed before grouping are aligned with their own quantization vectors, \( h_{\text{eff}}[n] \), not \( h_{\text{eff}}^g \) whereas their quantized channel information is made to be represented by \( h_{\text{eff}}^g \). Another view to solve this problem is that if effective channels are recomputed as per \( h_{\text{eff}}^g \), it is not guaranteed to be the optimal codeword in the aspect of group. This is because none of the subcarriers except the representative one can achieve any benefits from the codebook in channel quantization procedure. This result in large quantization error for each subcarrier than if quantization performed individually for all subcarriers. By Lemma 1, the quantization error for the quantization of individual subcarrier case is the minimum of \( 2^B \) independent beta \( (N_r-N/N_r) \) random variables when considering entire codebook [8].

In order to solve these problems, the joint flock based quantization and antenna combining approach is proposed which jointly computes the effective channels and representative quantization vector with respect to the search of considering entire codebook.

**Flock Based Quantization**

In this proposed scheme, at first, the number of subcarriers are aggregated based on the frequency correlation between adjacent subcarriers which is denoted as flock of subcarriers (F) and then quantized. For this, the entire subcarriers are separated into \( F \) flocks of size \( N_s \) and the quantization is performed on flock basis. Among the \( N_s \) quantized effective channel vectors, \( h_{\text{eff}}[n] \), one representative quantization
vector, $\hat{h}^{\text{flk}}_k$ is chosen for each flock where $n$ is subcarriers index from 1 to $N_s$. Because the representative quantization vector, $h^{\text{flk}}_k$ for the flock will be used as the beamforming vector at transmitter for all the subcarriers in flock, $f$, it is chosen by considering all the channel subspaces,

$$
\{Q_\ell[i]: (f − 1)N_s ≤ i ≤ fN_s \}
$$

(12)

It is convenient to map the selection vector to its associated quantization error from the quantization procedure. The figure 2 describes the flock based quantization procedure for the case of $N_s = 2$, $N_t = 3$ and $N_r = 2$. If quantization is done for each subcarrier, for example, $w_2$ and $w_3$…may be chosen as $h^{\text{flk}}_k[1]$ and $h^{\text{flk}}_k[2]$ for span($H[1]$) and span($H[2]$) respectively. The angular distance, $\alpha$ is computed for the angle between the selected RVQ code word, $w_l$ and the channel directions or span which is related to quantization error between the quantization vector and the channel subspaces.

Figure 2: Description of flock based Quantization procedure

Considering quantization error between the quantization vector and the channel subspaces, a minimum angular distance criterion is developed from upper bounded per-user throughput loss gap relative to the MISO downlink channel with perfect CSIT to choose flock representative quantization vector, $h^{\text{flk}}_k$. The upper bounded per-user throughput loss is given as,

$$
\Delta R(P) ≤ \log_2 \left(1 + P \frac{N_t - N_r + 1}{N_t} \right) \ast (1 - \|Q_\ell[i]H w_l\|^2) \ast \left(1 - \|Q_\ell[i]H w_l\|^2\right)
$$

(13)

The gap of throughput loss of 3 dB with vector downlink channel with perfect CSIT is equivalent to per user throughput gap of log2 $b = 1$ bps/Hz if the proposed scheme is used with $N_t$ antennas/mobile. The second (more considerable) term for loss, which is an increasing function of $P$, is due to quantization error.

The maximum angular distance threshold ($\delta$) is derived from this upper bounded throughput loss gap for minimum angular distance criterion. This sets an upper limit for quantization error in the choice of flock representative quantization vector, $\hat{h}^{\text{flk}}_k$.

$$
\delta ≤ \sin(\angle(h^{\text{flk}}_k, h^{\text{eff}}_k)).
$$

(14)

This decides number of feedback bits required and size of the codebook for the optimum quantization. As a result, the best flock representative quantization vector that forms the channel subspace, $\angle(h^{\text{flk}}_k, h^{\text{eff}}_k)$ is chosen in such a way that angular distance, $\alpha$ is always less than maximum angular distance threshold, $\delta$ by considering the entire codebook and all the channel subspaces. Therefore, the best flock representative quantization vector is denoted as,

$$
h^{\text{flk}}_k = \arg \min_{\omega \in \mathbb{C}} \| Q_\ell[i]H \omega \|^2
$$

(15)

Thus, the impact of the proposed minimum angular distance quantization criterion increases as codebook size increases.

Then, each user sends the quantized channel, $h^{\text{flk}}_k[i]$ for each flock to the transmitter that will be used as the beamforming vectors for all the subcarriers in flock, $F$. In this way, flock based quantization reduces the feedback load from $B \times N_s$ bits which is required for quantization of $N_s$ number of subcarriers individually to only $B$ bits for flock based quantization.

**Joint Flock Based Quantization and Antenna Combining**

Next, objective is to find the combiner weights, $G_k[i]$ based on flock representative quantization vector to calculate the effective channel at the receiver in order to calculate received output, $y_k^{\text{eff}}$. For this, the joint flock based quantization and antenna combining is proposed to simultaneously perform the flock based quantization and antenna combining. For minimum quantization error amongst all directions in span ($H_k[i]$), optimal direction of unit norm vector, $S_k^{\text{proj}}[i]$ can be determined by projecting $h^{\text{flk}}_k$ onto channel span ($H_k[i]$).

$$
S_k^{\text{proj}}[i] = \frac{Q_k[i]Q_\ell[i]^H h^{\text{flk}}_k[i]}{\|Q_k[i]Q_\ell[i]^H h^{\text{flk}}_k[i]\|}
$$

(16)

Next step is to choose combiner weights that yield an effective channel in the channel space which has the minimum quantization error amongst all directions in span ($H_k[i]$) and the corresponding combining vector is,

$$
G_k[i] = \frac{(H_k[i]H_k[i]^H)^{-1}H_k[i]^H S_k^{\text{proj}}[i]}{\|H_k[i]H_k[i]^H)^{-1}H_k[i]^H S_k^{\text{proj}}[i]\|}
$$

(17)

This combining vector is used to calculate received output as in (4).

**Results and Discussion**

Based on the discussion given in the earlier sections, the performance of MCCDMA systems with the proposed joint flock based quantization and antenna combining approach (prop. Tech) is evaluated using MATLAB for downlink frequency selective Rayleigh fading channel with AWGN.
The simulations are conducted to evaluate the performance in terms of throughput, quantization error and bit error rate (BER) with respect to signal to noise ratio (SNR), number of feedback bits (B) and number of users (K) respectively. The system uses four transmit antennas at the BS, four users, and two receive antennas per user. It is assumed that each MS uses randomly generated codebooks for channel quantization, with size of $2^8$ and the same codebook is used for all subcarriers. These codebooks are offline i.e. evaluated and stored before the simulations. The MCCDMA system uses orthogonal complementary code (OCC) codes as spreading code. It considers two-ray multipath channel with its delay profile being $[1/2, 0, 1/2]$ and one chip inter path delay. The data packet of 3000 blocks per frame, transmission block of 10 symbols, the symbol length of 64, the modulation of 16-QAM, the number of subcarriers of 128 and minimum mean square error (MMSE) type detector are considered. i.e. $N_s=4$, $N_t=2$, $K=4$ and B is fixed to 10 bits or varies with P according to the equation, $B=P(N_t-N_s)/3$.

First, the throughput of proposed joint flock based quantization and antenna combining scheme (prop. tech) is compared in Figure 3 with QBC-based subcarrier grouping algorithm (SCg-QBC), MRC-based combining algorithm (MRC based) and combining scheme without grouping (Ref-Ns=1) with respect to SNR. In this case, let $N_s=4$, $N_t=2$, $K=4$, $N_c=8$ and B is increased proportionally as P increases according to $P(N_t-N_s)/3$.

The graph shows that the throughput increases as SNR increases. It is observed that the combining scheme without grouping (Ref-Ns=1) achieves the maximum capacity but it demands large number of feedback bits when SNR increases (for ex. 1024 bits for 25dB). The throughput curves for the SCg-QBC and MRC-based schemes deteriorate obviously because quantized representative vector is not optimal for the remaining $N_s-1$ subcarriers in the group due to large size of the group in these schemes whereas the proposed scheme achieves nearly the same performance as that in the scenario of combining scheme without grouping (Ref-Ns=1) due to the optimal selection of quantized channel vector but with reduced feedback load. It is clear that the proposed scheme outperforms SCg-QBC and MRC-based schemes in all means and it is the optimal approach compared to scheme (Ref-Ns=1) while considering the quantization error is the major performance factor.

Considering the performance of the combining scheme without grouping (Ref-Ns=1) based on scaling bit law, it demands large feedback bits though it achieves the maximum capacity. This violates the objective of the design purpose but viewed as the reference of the extreme case in opposite side. For SNR=15dB, 640bits are required for the case of without grouping of subcarriers (i.e Ns=1). The feedback load is reduced by 85% with throughput loss of 5% using the proposed scheme. This indicates significant reduction in the feedback load with small loss in performance. Next, considering the gap between proposed scheme and SCg-QBC and MRC based schemes, the difference is more the reflected at high SNR side which means that the feedback bits is not enough for quantization process in the SCg-QBC and MRC based schemes to retain the good performance. This degradation in performance is due to mismatches between the effective channel and representative quantization vector for the group of subcarriers and due to large group size. It is necessary to provide more feedback bits for such schemes to improve throughput performance. The proposed scheme achieves 30% more throughput than SCg-QBC scheme for $N_s=8$ and SNR=25dB. In the MRC-based combining algorithm, maximum signal power is utilized from directly quantized singular value of $H_k$ and achieves good performance at low SNR regions as compared with QBC-based subcarrier grouping scheme. However, at high SNR regions, the interference power increases since majority of the subcarriers in the group are not aligned with representative quantization vector and only few subcarriers are having sufficient channel gain. This indicates the wastage of feedback on weakest eigenmode vectors. Hence, it cannot be improved further. So, MRC based scheme is good compared to SCg-QBC scheme but needs more feedback bits for reducing the quantization error. The proposed scheme shows improvement due to the good utilization of the power with reduced feedback. Also, the proposed scheme computes the reliable representative quantization vector while considering all combination of the channel subspaces for the flock and entire quantization code-words. Hence, it is adaptive to propagation conditions and robust against interference. It is clear that the proposed scheme achieves much throughput than the existing schemes with reduced feedback load.

In the second experiment, the quantization error of proposed joint flock based quantization and antenna combining scheme is compared in figure 4 with QBC-based subcarrier grouping algorithm (SCg-QBC) and MRC-based combining algorithm (MRC based) with respect to number of feedback bits. In this case, let $N_s=4$, $N_t=2$, $K=4$, $N_c=8$ and $SNR=16dB$. The throughput performance comparison wrt SNR

Figure 3: Throughput performance comparison wrt SNR
These schemes convert multiuser OFDM based MIMO downlink into unique effective channel. Practically, the quantization error is evaluated to estimate the accuracy of the quantization process and to verify the performance of the proposed scheme with existing schemes. The graph shows that the quantization error decreases as number of feedback bits increases. The quantization error goes to minimum in proposed scheme and decrease linearly with the number of feedback bits due to perfect alignment between with effective channel whereas in QBC-based subcarrier grouping algorithm (SCg-QBC) and MRC-based combining algorithm (MRC based), it decreases exponentially due to inherent problem to represent optimal quantization vector for the remaining Ns − 1 subcarriers in a group as Ns increases. The error is more pronounced in the SCg-QBC scheme due to mismatch between the representative quantization vector for the group and effective channel. It is clear that the proposed scheme outperforms QBC-based subcarrier grouping algorithm and MRC-based combining algorithm. When B is small, SCg-QBC and MRC based schemes dominates because the proposed scheme has to search the entire codebook. It indicates that the remarkable impact on performance when size of the codebook increases. At B=14 bits, the proposed scheme achieves 25% less quantization error compared to MRC based scheme.

The quantization error factor decides the throughput performance of the system along with feedback and SNR. The computational complexity of proposed scheme is same as MRC based combining scheme as arrived from the equations $\|Q[k][n]\|^2$ and $\|H[k][n]\|^2$. It is appropriate to adjust the size of the flock (Ns) and the feedback load to reduce the quantization error to counteract the loss of the SNR of the effective user channel.

In the next scenario, the BER performance of proposed joint flock based quantization and antenna combining approach (prop. tech) is compared in figure 5 with QBC-based subcarrier grouping algorithm (SCg-QBC) and MRC-based combining algorithm (MRC based) for the variability of total number of users. In this case, let Ns=4, Ns=2, Ns=8 and SNR=10dB.

The BER curves for the SGg-QBC deteriorate obviously due to increased quantization error because the representative quantization vector is not the optimal for the remaining Ns − 1 subcarriers in a group when Ns increases as number of users increases whereas the proposed technique performs nearly the same as that in the single user scenario with reduced feedback bits and minimum quantization error because of proposed method selects best quantization vector for representing the flock by considering the entire codebook and all channel subspaces. In MRC scheme, it is not too surprising because it chooses only the strongest eigenmode of a few users, and feedback for remaining weak users is really wasted. Thus, the performance of MRC scheme is outperformed by the proposed scheme. It should be designed in such a way that all the feedback bits should be effectively utilized for the strongest eigenmode.

Thus, residual MUI due to large quantization error makes the other schemes as interference limited systems. But, the robustness of the proposed method against residual MUIs is retained under heavy load conditions. Hence, the user capacity of the MCCDMA system increases due to this increased interference mitigation efficiency.

**Conclusion**

The joint flock based quantization and antenna combining approach has been proposed for multiuser MIMO-OFDM based MC-CDMA systems to mitigate the residual multi user interference. The algorithm has been developed to make efficient quantization on flock basis for reducing CSI feedback load with minimum quantization error. The minimum angular distance criterion has been developed based on upper bounded throughput loss to find the reliable representative quantization vector among the all subcarriers in the flock. For this, maximum angular distance threshold has been computed to set the upper limit for quantization error. The flock representative quantization vector is feedback to the transmitter for beamforming for all subcarriers at BS and enables the efficient antenna combining jointly to yield the unique effective channel for multiple antennas for reducing the quantization error and complexity at the receiver. This figure of merit allows the excess number of subcarriers and excess number of receiving antennas with minimum quantization error. This makes less residual multi user interference among the additional number of users and hence,
the user capacity of MCCDMA systems is increased. The simulation results shows that the proposed scheme achieves significant performance improvement in terms of quantization error and throughout compared to other existing channel quantization and receive combining schemes with the reduced feedback load and similar order of complexity (O (N)). The results show that the developed system is adaptive to multipath frequency-selective fading channel conditions with higher loads and hence, more number of users can be supported due to increased MUI mitigation efficiency.

References


