Feedback Reduction Schemes For MIMO Broadcast Channels

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Abstract—In this paper schemes for feedback reduction in MIMO broadcast channels are considered for a multi-user system. We consider a case where the number of single antenna users \( K \gg M \) where \( M \) is the size of antenna array at the base station (BS). We consider zero-forcing beamforming system with semi-orthogonal user selection algorithm in which channel state information is split into channel quality information (CQI) and channel direction information (CDI). In such a user-dense multi-user system feedback channel is inundated if all the users are feedbacking even in the case where only a limited feedback is employed. In order to reduce the feedback load we propose threshold based schemes in which threshold is applied on CQI or CDI. We show that by employing proposed feedback reduction schemes feedback load can be significantly reduced without sacrificing much of the sum-capacity of the system.

I. INTRODUCTION

The fact that using multiple antennas for communications link can increase the system capacity is well known [1]. In the context of MIMO broadcast channels, dirty-paper coding (DPC) is the optimal strategy to achieve full capacity region by serving multiple users simultaneously [2]. However DPC requires nonlinear processing making it computationally exorbitant. To work around this computational bottleneck, there are two basic sub-optimal approaches which make use of linear precoding namely: random beamforming (RBF) [3] and Zeroforcing beamforming (ZFBF) [5]. In multiuser systems, multiuser diversity gain is also be achieved if users with Zeroforcing beamforming (ZFBF) [5]. In multiuser systems, multiuser diversity gain is also be achieved if users with favorable channel states are selected from a larger pool of independently fading users [6]. It has been shown in [3] that sum rate of multiuser system increases double logarithmically with number of users \( K \). One key characteristic of multiuser system is that it requires channel state information at transmitter to make spatial beams and in the absence of it, it is equivalent to the single user case in terms of sum-capacity. Now having full CSIT is practically impossible, so an option remains to use partial or finite channel state information. It has been shown that even with partial CSI large portion of a Gaussian MIMO broadcast channel capacity can be extracted [4].

In this work we focus on network with large number of single cell users such that \( K \gg M \) where \( M \) is the number of antennas on BS. Even in the case where finite-rate feedback (by quantizing CSI) is employed at each user, the sum feedback load increases linearly with the number of users. Obviously, the downlink feedback channel in any system architecture is finite and hence gets inundated when there are large number of users feedbacking. This poses a big challenge to design such a network with large feedback load. There has been much focus on this particular issue and various schemes are proposed for feedback reduction for MIMO broadcast channels. In [7], a multiuser-aware feedback scheme is proposed with sum feedback rate constraint using orthogonal beamforming, while, recently, in [8] and [9], threshold based algorithms are developed for RBF scheme where the scheme of [8] is in quintessence of single antenna multi-user case of [10].

In this paper we focus on the framework of ZFBF with semi-orthogonal user selection (SUS) [5]. In this scenario channel state information (CSI) is split into two components namely channel quality information (CQI) and channel direction information (CDI) to enhance the system performance [11]. We develop two threshold based feedback reduction algorithms. In first algorithm threshold is applied on CQI such that users having SINR above a predefined threshold are allowed to feedback. In second algorithm CDI threshold is employed in which users having less quantization error are selected for feedback. We analyze the feedback load reduction for these two schemes and then corresponding achievable sum capacity is studied for large number of users.

II. SYSTEM MODEL

We consider a downlink transmission of a homogeneous network with \( M \) transmit antennas on the base station in a cell with \( K \) single antenna users. We focus on the system with infinite message backlogs hence once a user is scheduled it is guaranteed that it will have enough data to send in the scheduled time slot. In the whole paper we assume \( K \gg M \) i.e. systems with high user density. We also assume Rayleigh block fading model with coherence time \( T \). The channel state information at the transmitter (CSIT) acquired by the feedback channel is assumed to be time independent during this time interval \( T \). Finally, there is an underlying assumption that the perfect CSI at receiver (CSIR) is available.

In any time interval \( T \) up to maximum of \( M \) users can be served given by an active user set \( \mathcal{A} = \{a(1), \ldots, a(|\mathcal{A}|)\} \) where \( 1 \leq |\mathcal{A}| \leq M \) and \( a(.) \) is one of the user being scheduled in the current time slot. If \( s_i \) is the transmitted information symbol for the user \( i \in \mathcal{A} \), and \( s_i \) and \( s_j \) are independent if \( i \neq j \) and \( w_i \in \mathbb{C}^{M \times 1} \) is the linear precoding vector for \( s_i \) then the transmit symbol vector \( x \in \mathbb{C}^{M \times 1} \) is given by

\[
x = \sum_{i \in \mathcal{A}} w_i s_i.
\]
Now assume \( y_k \) be the received symbol of user \( k \), then we have
\[
y_k = h_k x + n_k
\]
\[
= h_k w_k x_{\text{signal}} + \sum_{j \in \mathcal{A}, j \neq k} h_k w_j x_j + n_k, \quad k \in \mathcal{A},
\]
where \( h_k \in \mathbb{C}^{1 \times M} \) denotes the channel gain vector for user \( k \), whose entries are independent and identically distributed (i.i.d.) complex Gaussian variables with zero mean unit variance and \( n_k \) is the additive complex Gaussian noise with zero mean and unit variance.

We assume that the total average transmitted power constraint is \( E \left\{ \| x \|^2 \right\} = P \). The total power is allocated equally to all active users. Therefore, each user’s power in set \( \mathcal{A} \) is \( \rho = P / |\mathcal{A}| \). We also assume that the linear precoder has a power gain of one, i.e., \( \| w_j \|^2 = 1 \). Thus the average power of transmitted information symbol for each user is \( E \{ |x_j|^2 \} = \rho, \forall i \in \mathcal{A} \). The signal-to-interference-plus-noise-ratio (SINR) at receiver \( k \) is expressed as
\[
\text{SINR}_k = \frac{\rho \| h_k w_k \|^2}{1 + \rho \sum_{j \in \mathcal{A}, j \neq k} \| h_k w_j \|^2}.
\]
and the sum-rate for the selected user set is calculated as
\[
R = \sum_{i=0}^{|\mathcal{A}| - 1} E \{ \log (1 + \text{SINR}_i) \}.
\]

A. CDI and CQI quantization models

If the CDI is denoted by \( \hat{\mathbf{h}}_k \), which is the unit-norm vector \( \mathbf{h}_k \), i.e., \( \hat{\mathbf{h}}_k = \mathbf{h}_k / \| \mathbf{h}_k \| \), then \( \hat{\mathbf{h}}_k = \mathbf{Q}_v (\mathbf{\hat{h}}_k) \) is the quantized version of \( \mathbf{\hat{h}}_k \) where \( \mathbf{Q}_v (\cdot) \) is the vector quantization function based on the minimum distance criterion. There are \( N = 2^B \) codes in the codebook which is designed off-line meaning each user feedback \( B \) bits for providing its orientation information to the BS.

The design of an optimal codebook for quantization is still an open problem in general. Although near optimal codebooks can be designed numerically but doing so is out of scope of our work. Hence we use an expedient solution of quantization cell approximation developed in [14] and used in [11], [12]. This approximation holds when we assume that there is an \( M \) dimensional complex super sphere of unit area with each quantization cell being its spherical cap with an area of \( 2^{-B} \). Hence any unit-norm vector \( \mathbf{h} \) will be \( \mathbf{c}_i \) if it falls in to a quantization cell \( \mathcal{R}_i \) where \( \mathbf{c}_i \) belongs to any given codebook \( \mathcal{C} = \{ \mathbf{c}_1, \cdots, \mathbf{c}_N \} \) and \( \mathcal{R}_i \) is
\[
\mathcal{R}_i = \left\{ \mathbf{h} : \left| \langle \mathbf{h}, \mathbf{c}_i \rangle \right|^2 \geq \left| \langle \mathbf{h}, \mathbf{c}_j \rangle \right|^2 \right\}, \quad i = 1, \cdots, N
\]
which is equivalent to
\[
\mathcal{R}_i \approx \left\{ \mathbf{h} : \left| \langle \mathbf{h}, \mathbf{c}_i \rangle \right|^2 \geq 1 - \delta \right\}
\]
where \( \delta = 2^{-B} / \pi. \) If we denote \( \theta_k \) as the angle between the unit-norm \( \mathbf{\hat{h}}_k \) and its quantized version \( \mathbf{h}_k \) then \( \sin^2 \theta_k \) is the quantization error. The CDF of this quantization error is
\[
F_{\sin^2 \theta}(x) = \begin{cases} 2^B x^{M-1}, & 0 \leq x < \delta \\ 1, & x \geq \delta \end{cases}
\]

We use the receiver SINR as CQI in this paper. It is shown in [11] that, opposed to the case where channel norm \( \| h_k \|^2 \) is used as CQI, using user SINR as CQI get benefit from multiuser diversity gain. We also use unquantized SINR as CQI for simplicity because it is already shown in [12] that even 1-bit quantizer is enough to get near sum-rate performance of an unquantized CQI case. Hence it is the CDI quantization bits which are dominant in the total feedback load and not the CQI bits.

B. \( \varepsilon \)-orthogonal user selection

Based on \( B \) bits of CDI information along with real valued SINR feedback from each user, BS performs user selection to support the best \( |\mathcal{A}| \leq M \) users out of \( K \) according to semi-orthogonal user selection (SUS) algorithm in [11]. For doing so, BS initializes the candidate set of users as \( \mathcal{A}_0 = \{ 1, \cdots, K \} \) and selects the first user from set \( \mathcal{A}_0 \) according to the SINRs \( \gamma_k \). After \( i \) users have been selected, BS constructs a new set of users for selecting the \((i+1)\)th user. The users in the new candidate set are mutually semi-orthogonal to the previously selected \( i \) users in terms of their quantized feedback CDI. It is given by
\[
\mathcal{A}_i = \left\{ k | 1 \leq k \leq K : \left| \langle \mathbf{\hat{h}}_k, \mathbf{\hat{h}}_{\mathcal{A}_i(j)} \rangle \right| \leq \varepsilon, 1 \leq j \leq i \right\}, \quad (8)
\]
where \( \varepsilon \) is a semi-orthogonal threshold which determines the maximum absolute inner product allowed between any two quantized channel direction vectors. The approximate cardinality of the \( i \)th user set under semi-orthogonal user selection for large number of users is given by [12]
\[
|\mathcal{A}_0| = K, \quad |\mathcal{A}_i| \approx \frac{K}{i} \left( 1 - (1 - \varepsilon^2)^M \right), \quad i = 1, \cdots, M-1 \quad (9)
\]
where \( \lceil x \rceil \) denotes the largest integer that is equal to or less than \( x \). This process continues until \( M \) active users are selected or the \( i \)th candidate set \( \mathcal{A}_i \) becomes empty. The active user set is formed as
\[
\mathcal{A} = \{ a(1), \cdots, a(|\mathcal{A}|) \}.
\]

C. Zero-forcing precoder

A conventional zero-forcing precoder is used to suppress multiuser interferences generated by semi-orthogonal channels in active user set \( \mathcal{A} \). A unit-norm precoding vector \( \mathbf{w}_i \) where \( i \in \mathcal{A} \) is chosen so as to fulfill the criterion
\[
\mathbf{\hat{h}}_i \mathbf{w}_i = 0, \quad \forall j \neq i, j \in \mathcal{A}.
\]
If the quantized channel matrix is denoted as \( \mathbf{H}(\mathcal{A}) = \left[ \mathbf{\hat{h}}_{\mathcal{A}(1)}^T, \cdots, \mathbf{\hat{h}}_{\mathcal{A}(|\mathcal{A}|)}^T \right]^T \), then the zero forcing precoding matrix \( \mathbf{W}(\mathcal{A}) \) is determined by the pseudo-inverse of \( \mathbf{H}(\mathcal{A}) \), that is,
\[
\mathbf{W}(\mathcal{A}) = \mathbf{H}(\mathcal{A})^\dagger = \mathbf{H}(\mathcal{A})^H (\mathbf{H}(\mathcal{A}) \mathbf{H}(\mathcal{A})^H)^{-1}.
\]
D. Distribution of individual user SINR

Because of the fact that precoding vector \( \mathbf{w}_k \) is not known to the receiver, user SINR given by (3) is not computable at the receiver. Hence an approximate lower bound of user SINR with quantized CDI and perfect CQI case is calculated and given by [11]

\[
\gamma_k = \frac{\rho \| \hat{h}_k \|^2 \cos^2 \theta_k}{1 + \rho \| \hat{h}_k \|^2 \sin^2 \theta_k}
\]  

(13)

where \( \theta_k \) is the angle between \( \hat{h}_k \) and its quantized version \( \tilde{h}_k \). Under the quantization cell approximation model the distribution of \( \gamma_k \) is recently calculated in [12] given by

\[
F_{\gamma}(x) = \begin{cases} 
  F(y_1; M - 1, 1) - e^{-\frac{1}{\delta x + \delta}} \frac{1}{(\delta x + \delta)^{m-1}} x & \text{for } 0 \leq x < \frac{1}{3} - 1 \\
  1 - e^{-\frac{1}{\delta x + \delta}} \frac{1}{(\delta x + \delta)^{m-1}} & \text{for } x \geq \frac{1}{3} - 1
\end{cases}
\]  

(14)

where \( F(x; k, \theta) \) is the CDF of the Gamma distribution with parameters \((k, \theta)\) i.e., \( F(x; k, \theta) = \frac{1}{\Gamma(k)} \int_0^x t^{k-1} e^{-\frac{t}{\theta}} dt \), \( y_1 = (x/\rho) / (\delta x + \delta - 1) \) and \( \delta = 2 - \frac{1}{\sin^2 \theta} \). It has been shown in [11] that all users have similar \( \gamma_k \) hence we have used the notation of \( \gamma_k \) and \( \gamma \) interchangeably in the rest of the paper.

III. User Scheduling Algorithm with CQI Threshold

In this proposed algorithm, each user makes a decision to feed back or not while at the BS user scheduling is performed based on the feedback received from each user. At first a user \( k \) is allowed to feedback only if \( \gamma_k \geq \lambda_{CQI} \). If the user \( k \) pass this threshold test then will be allowed to feedback two quantities i.e. its real valued SINR \( \gamma_k \) and index \( n \), corresponding to the code word chosen according to (6), which consists of \( B \) bits. This algorithm is in essence similar to the algorithm proposed in [8] but we are using it in different setting where user selection is performed as described in II-B at the BS on the pool of surviving users after a threshold is being applied. The beamforming follow the user scheduling stage.

A. Feedback Load Analysis

The probability of having \( r \) users above the given threshold \( \lambda_{CQI} \) i.e. \( \gamma_k \geq \lambda_{CQI} \) in a current time slot can be written as

\[
P_r(\lambda_{CQI}) = \binom{K}{r} (1 - F_\gamma(\lambda_{CQI}))^r (F_\gamma(\lambda_{CQI}))^{K-r}
\]  

(15)

where \( F_\gamma(\lambda_{CQI}) \) can be calculated by using (14). If we want to calculate the measure of reduction in the average feedback load, when CQI threshold is employed as compared to case where no threshold is used, then we can use the same definition of average feedback load ratio (AFLR) as given in [10] which is

\[
\chi(\lambda_{CQI}) = \frac{\mathcal{L}(\lambda_{CQI})}{K}
\]  

(16)

where \( \mathcal{L}(\lambda_{CQI}) \) is given by

\[
\mathcal{L}(\lambda_{CQI}) = \sum_{r=1}^{K} r \cdot P_r(\lambda_{CQI})
\]  

(17)

Now by inserting (15) and (17) in (16) we can obtain

\[
\chi(\lambda_{CQI}) = \sum_{r=1}^{K} \frac{r}{K} (1 - F_\gamma(\lambda_{CQI}))^r (F_\gamma(\lambda_{CQI}))^{K-r}
\]  

(18)

which after some algebra gives

\[
\chi(\lambda_{CQI}) = 1 - F_\gamma(\lambda_{CQI})
\]  

(19)

The above equation is plotted in Fig. 1 for different values of \( \lambda_{CQI} \) and it could be seen that as the threshold is increased the AFLR decreases. Another important observation is that AFLR expression in (19) is independent of the number of users in the system as was also observed in [8]. But it should be pointed out that when there is low number of users in the system, AFLR can still be reduced but then SUS algorithm may not be able to find \( M \) orthogonal users for multiple user transmissions.

B. Sum-rate Analysis

Now naturally we will be interested in evaluating the sum-rate performance of the system when threshold \( \lambda_{CQI} \) is applied. Let \( M_i = \{ \gamma_k, k \in \mathcal{A}_i \} \) be the set of SINRs corresponding to candidate set \( \mathcal{A}_i \). Denote the maximum value in \( M_i \) by \( \gamma_{M_i, \text{max}} \) and its CDF and PDF by \( F_{\gamma_{M_i, \text{max}}}(x) \) and \( f_{\gamma_{M_i, \text{max}}}(x) \), respectively. Applying extreme order statistics, the CDF of \( \gamma_{M_i, \text{max}} \) is

\[
F_{\gamma_{M_i, \text{max}}}(x) = (F_\gamma(x))^{\lvert A_i \rvert}, \quad i = 0, \ldots, M - 1.
\]  

(20)

Its PDF is given by

\[
f_{\gamma_{M_i, \text{max}}}(x) = \frac{\lvert A_i \rvert - 1}{\int_{x}^{\infty} \log (1 + \gamma_{M_i, \text{max}})}
\]  

(21)

where \( F_\gamma(x) \) and \( f_\gamma(x) \) are the CDF and PDF of the SINR \( \gamma_k \), respectively, which can be calculated by (14). \( |A_i| \) in (20) and (21) is determined by (9) which is an approximation for large \( K \). Applying (21), the approximate sum-rate of the SUS scheme with perfect CQI feedback and CQI threshold \( \lambda_{CQI} \) is given by

\[
R_{CQI} \approx \sum_{i=0}^{\lvert A_i \rvert - 1} \log (1 + \gamma_{M_i, \text{max}})
\]  

\[
= \sum_{i=0}^{\lvert A_i \rvert - 1} \int_{x}^{\infty} \log (1 + x) \int_{x}^{\infty} f_{\gamma_{M_i, \text{max}}}(x) \left( F_\gamma(x) \right)^{\lvert A_i \rvert - 1} dx
\]  

(22)

where \( |A| \leq M \) is the cardinality of active user set \( \mathcal{A} \). Table I shows the theoretical and simulation results for large values of \( K \) when \( \lambda_{CQI} = 8 \text{ dB} \), confirming (22) is a lower bound on actual sum-rate of the system. Fig. 2 shows the simulation results for the sum-rate of the system for different values of \( \lambda_{CQI} \). It can be seen that sum-rate decreases when CQI threshold is increased.

<table>
<thead>
<tr>
<th>TABLE I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum-rates when ( \lambda_{CQI} = 8 \text{ dB} ) is applied</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>( K = 200 )</td>
</tr>
<tr>
<td>Theory</td>
</tr>
<tr>
<td>Simulation</td>
</tr>
</tbody>
</table>
IV. USER SCHEDULING ALGORITHM WITH CDI THRESHOLD

In this section we will investigate a user scheduling algorithm in which CDI threshold is being employed at each receiver. As explained in II-A that each user quantizes its unit-norm channel vector $\hat{h}_k$ to a vector $\tilde{h}_k$ according to a criterion [14]

$$\tilde{h}_k = c_k = \arg\max_{c \in C} |\tilde{h}_k, c|^2 = \arg\max_{c \in C} \cos^2(\angle(\tilde{h}_k, c)). \tag{23}$$

Now if $\theta_k = \angle(\tilde{h}_k, \hat{h}_k)$, then the user is allowed to feedback only if $\theta_k \leq \theta$ where $\theta_k$ is a predefined threshold value. Users fulfilling the threshold condition will feedback their respective SINR and $B$ bits based code word index $n$. Using such a threshold scheme not only provides feedback reduction but also indirectly reduces the multiuser interference given by second term in (2) by only allowing users with less quantization errors.

A. Feedback Load Analysis

We calculate the average feedback load ratio for this scheme by following the similar steps in III-A. If we define a channel direction information threshold to be $\lambda_{CDI} = \sin^2 \theta$ then the probability of finding $q$ users having their quantization angle error $\sin^2 \theta \leq \lambda_{CDI}$ is given by the expression

$$P_q(\lambda_{CDI}) = \binom{K}{q} (F_{\sin^2 \theta}(\lambda_{CDI}))^q (1 - F_{\sin^2 \theta}(\lambda_{CDI}))^{K-q} \tag{24}$$

where $F_{\sin^2 \theta}(\lambda_{CDI})$ can be calculated by using (7). Using (24) feedback load ratio can be written as

$$\mathcal{L}(\lambda_{CDI}) = \sum_{q=1}^{K} q \cdot (P_q(\lambda_{CDI})). \tag{25}$$

$$\chi(\lambda_{CDI}) = F_{\sin^2 \theta}(\lambda_{CDI}) \tag{26}$$

Above expression is, interestingly enough, not only independent of number of users $K$ but also do not depend on input SNR. It is plotted in Fig. 3 for different values of $\theta$ ($\lambda_{CDI} = \sin^2 \theta$) and could be seen that as the CDI threshold decreases AFLR also decreases.

B. Sum-rate Analysis

In this section we calculate the sum-rate of the system when threshold $\lambda_{CDI}$ is applied on each receiver. We see that by applying angle error threshold $\lambda_{CDI}$, the number of users feedbacking is reduced (shown by Fig.3). We first calculate the average number of surviving users. If we denote average number of users feedbacking as $K_{ave}$ then

$$K_{ave} = K \times \Pr(\sin^2 \theta \leq \lambda_{CDI}) = K \times F_{\sin^2 \theta}(\lambda_{CDI}) \tag{27}$$

The approximate cardinality of $i$th active user set is now given by

$$|A_{i,ave}| = K_{ave}$$

$$|A_{i,ave}| \approx K_{ave} \prod_{j=1}^{i}(1 - (1 - \epsilon^2)^{M-j}), i = 1, \ldots, M-1 \tag{28}$$

Let $\mathcal{M}_{i,ave} = \{\gamma_k, k \in A_{i,ave}\}$ be the set of feedback SINRs corresponding to candidate set $A_{i,ave}$. Denote the maximum value in $\mathcal{M}_{i,ave}$ by $\gamma_{\mathcal{M}_{i,ave} \max}$, and its CDF and PDF by $F_{\gamma\mathcal{M}_{i,ave} \max}(x)$ and $f_{\gamma\mathcal{M}_{i,ave} \max}(x)$, respectively. Applying extreme order statistics, the CDF of $\gamma_{\mathcal{M}_{i,ave} \max}$ is

$$F_{\gamma\mathcal{M}_{i,ave} \max}(x) = (F_{\gamma}(x))^{|A_{i,ave}|}, i = 0, \ldots, M-1 \tag{29}$$

and its PDF is

$$f_{\gamma\mathcal{M}_{i,ave} \max}(x) = |A_{i}| f_{\gamma}(x) (F_{\gamma}(x))^{|A_{i,ave}|-1} \tag{30}$$

where $F_{\gamma}(x)$ and $f_{\gamma}(x)$ are the CDF and PDF of the feedback SINR $\gamma_k$, respectively, which can be calculated by (14). Now the approximate sum-rate under SUS scheduling scheme with perfect CQI and CDI threshold $\lambda_{CDI}$ can be written as.
The feedback load ratio versus number of users for various values of $\lambda_{CDI}$ with $M=4$, SNR=10dB, $B=12$

$$R_{CDI} \approx \sum_{i=0}^{\lfloor |A|-1 \rfloor} E \left( \log \left( 1 + \gamma_{A_{i,ave}} \right) \right)$$

\begin{equation}
= \sum_{i=0}^{\lfloor |A|-1 \rfloor} \int_{0}^{\infty} \log \left( 1 + x \right) |A_{i,ave}| f_\gamma(x) \left( F_\gamma(x) \right)^{|A_{i,ave}|-1} \, dx
\end{equation}

(31)

Table II shows the theoretical and simulation results for large values of $K$ when $\lambda_{CDI} = 12$ degrees confirming (31) is a lower bound on actual sum-rate of the system. Fig. 4 shows the simulation results for sum-rate of the system when different values of CDI threshold are used. It can be seen that sum-rate is decreased when CDI threshold is decreased because less number of users are allowed to participate in the feedback. Fig. 3 and Fig. 4 together shows the trade-off between feedback reduction and corresponding decrease in sum-rate of the system. Similar trade-off was reported in [8].

<table>
<thead>
<tr>
<th>No. of users ($K$)</th>
<th>$\lambda_{CDI} = 11$ degrees</th>
<th>$\lambda_{CDI} = 12$ degrees</th>
<th>$\lambda_{CDI} = 13$ degrees</th>
<th>No Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory</td>
<td>10.8375</td>
<td>11.1672</td>
<td>11.2255</td>
<td>11.2166</td>
</tr>
<tr>
<td>Simulation</td>
<td>11.3905</td>
<td>11.7012</td>
<td>11.9475</td>
<td>12.0847</td>
</tr>
</tbody>
</table>

V. CONCLUSIONS

In this paper we have focused on multiuser system with limited feedback for MIMO broadcast channels. We have considered a particular case where there are large number of users in the network than the size of antenna array at the BS. In such a scenario users feedback their partial channel state information to the base station for scheduling and then beamforming over the rate-constraint feedback channel. We have investigated two new feedback reduction schemes based on CQI and CDI thresholds for such systems. We have derived closed form expressions for average feedback load ratio while expressions for lower bounded sum-capacity of the system were also derived for large number of users. It is shown that feedback can be significantly reduced when CQI or CDI threshold is applied. It is also shown that the sum-rate is not suffered considerably when proposed threshold based schemes are employed.

REFERENCES