A Differential Codebook with Adaptive Scaling for Limited Feedback MU MISO Systems

Jawad Mirza, *Student Member, IEEE,* Pawel A. Dmochowski, *Senior Member, IEEE,* Peter J. Smith, *Senior Member, IEEE,* and Mansoor Shafi, *Fellow, IEEE*

***Abstract*—In this letter, we propose an adaptive scaling based differential codebook (DCB) for multiuser (MU) multiple-input single-output (MISO) systems operating under spatially and temporally correlated channels. The proposed adaptive scaling technique depends upon the spatial and temporal correlation present in the channel and the mean quantization error associated with the previous feedback, hence avoiding the need to periodically reset the codebook. The performance of the proposed DCB is evaluated for both zero-forcing beamforming (ZFBF) and signal-to-leakage-and-noise ratio beamforming (SLNR BF) schemes. Simulation results show the effectiveness of the proposed DCB and also the superiority of the SLNR BF scheme over the ZFBF scheme.**

***Index Terms*—Zero-forcing beamforming, signal-to-leakage-and-noise ratio beamforming, differential codebook, multiple-user (MU), multiple-input single-output (MISO) systems.**

I. INTRODUCTION

THE feedback of channel state information (CSI) to the transmitter is an important component of multiple-input multiple-output MIMO systems as it is critical for transmit beamforming and interference mitigation [1]. However, it is difficult to provide perfect CSI to the transmitter and a low-rate feedback link is commonly used by the receiver to send the quantized CSI to the transmitter. For this purpose, both transmitter and receiver maintain a codebook containing quantized entries representing the channel information. Such systems are also known as limited feedback MIMO systems.

The performance of limited feedback MIMO systems depends heavily upon the codebook design. If the codebook is well designed and matches the propagation environment then quantization errors are reduced, resulting in a smaller capacity loss. In temporally correlated channels, the use of a differential codebook (DCB) that exploits the temporal correlation has been shown to improve the capacity of a MIMO system [2]. A polar-cap DCB design for a temporally and spatially correlated MU MISO channel is discussed in [3]. The polar-cap DCB has one codeword at the center and the rest of the codewords are on the radius of the polar-cap. This codebook is rotated to be centered on the previously selected codeword after each feedback and outperforms the rotation-based codebook [2]. The disadvantage of [3] is that it requires the process to be reset after a few feedback intervals, especially when using the adaptive scaling method. The adaptive scaling in [3], [4] continually shrinks the radius of the codebook as the channel evolves. After a while, the polar-cap DCB becomes too narrow to successfully track the channel and this issue is handled by resetting the codebook to the original version. This letter provides new results as compared to [4] as we propose a different and improved adaptive scaling technique. In this paper we make the following contributions:

- Motivated by [3], we propose a new adaptive scaling method for the DCB operating under spatially and temporally correlated MISO channels. It does not require the process to be reset periodically. The adaptive scaling takes the effect of spatial/temporal correlation and quantization errors into consideration as a result it does not shrink beyond a certain limit. Therefore, in our proposed method the codebook is not set to a base codebook after every few feedback intervals. Hence, the gains offered by the DCB are conserved as a complete reset is not necessary.
- We use SLNR BF for the MU transmission. By comparing with the DCB using ZFBF, we show the superiority of SLNR BF. To the best of the authors' knowledge, there is no study that evaluates the performance of the SLNR BF system with DCBs. On the other hand, there are many studies that consider the ZFBF scheme with DCBs.

Notation: In this letter, we use $\mathbf{A}^H$, $\mathbf{A}^T$, $\mathbf{A}^{-1}$, and $\mathbf{A}^{\perp}$ to denote the conjugate transpose, the transpose, the inverse and the null space of the matrix $\mathbf{A}$, respectively. $\|.\|$ stands for the norm and $\mathbb{E}[.]$ denotes the statistical expectation.

II. SYSTEM MODEL

Consider a MU MISO system with a single base-station (BS) equipped with n_T transmit antennas, serving K users simultaneously. Each user has only a single antenna ($n_R = 1$). The received signal at the i^{th} user is given by

$$y_i = \mathbf{h}_i\mathbf{x} + n_i, \tag{1}$$

where, $\mathbf{h}_i$ is a channel of size $1 \times n_T$ between the BS and the i^{th} user. $\mathbf{x}$ is the transmitted signal from the BS such that $\mathbf{x} = \sum_{i=1}^{K} \mathbf{w}_i s_i$, where $\mathbf{w}_i$ and s_i are the normalised beamforming vector and data symbol of the i^{th} user, respectively. The noise term of user i is denoted by n_i and is assumed to be a complex Gaussian variable with variance, σ_i^2. We assume that all the users have same noise variance i.e. $\sigma_i^2 = \sigma^2$. The data symbol is assumed to be normalized such that $\mathbb{E}[|s_i|^2] = 1$. The received signal-to-noise ratio (SNR) of the user i is defined by $\text{SNR}_i = \mathbb{E}[|h_i(j)|^2]/\mathbb{E}[|n_i|^2]$, where $h_i(j)$ is the jth element of $\mathbf{h}_i$. The signal-to-interference-plus-noise ratio (SINR) for the i^{th} user is given by

$$\text{SINR}_i = \frac{|\mathbf{h}_i\mathbf{w}_i|^2}{\sigma_i^2 + \sum_{k=1,k\neq i}^{K} |\mathbf{h}_i\mathbf{w}_k|^2}. \tag{2}$$

If the interference is assumed Gaussian, a sum-capacity of the MU MISO system can be written as

$$\mathrm{C_{sum}} = \sum_{i=1}^{K} \log_2(1 + \mathrm{SINR}_i). \tag{3}$$

We assume that the receiver has estimated the channel via reference signals transmitted from the BS. Each user has its own codebook denoted by $\mathbf{F}_i = [\mathbf{f}_{1_i}, \mathbf{f}_{2_i}, \ldots, \mathbf{f}_{\mathrm{N}_i}]$ where N is the number of codebook entries or codewords. Each codeword in a codebook is a column vector of size $n_T \times 1$. Thus, for each feedback, a user sends $B = \log_2 N$ bits to the transmitter via a feedback link. These bits correspond to the selected codeword, $\bar{\mathbf{f}}_i$, given by $\bar{\mathbf{f}}_i = \mathrm{argmax}_{1 \le j \le 2^B} |\bar{\mathbf{h}}_i^H \mathbf{f}_{\mathrm{j}}|$, where $\bar{\mathbf{h}}_i = \mathbf{h}_i^T / \|\mathbf{h}_i\|$. At the BS, the selected codeword is multiplied by the channel quality indicator (CQI), CQI$= \|\mathbf{h}_i\|$. We assume that perfect[1] CQI is available at the transmitter for all the users. Therefore, the reconstructed quantized version of the i^{th} user channel, $\mathbf{h}_i$, is given by $\hat{\mathbf{f}}_i = \|\mathbf{h}_i\| \bar{\mathbf{f}}_i^T$. The BS uses quantized channel versions to find beamforming vectors for each user. In LTE Rel. 9, the demodulation reference signal (DM-RS) is introduced that is user specific and delivers the beamforming vector information to the user [5].

III. Multiuser Transmission Strategies

In this section we briefly explain the two well-known beamforming techniques namely, ZFBF [6] and SLNR BF [7].

A. ZFBF

ZFBF eliminates multiuser interference completely when perfect CSI is available at the transmitter [6] and the beamforming vectors are formed such that the product $\mathbf{h}_i \mathbf{w}_k$ is zero, for all values of k where $k \neq i$. In the case of a limited feedback system, where only quantized CSI is available at the transmitter, ZFBF cannot cancel the multiuser interference completely but is still able to reduce it significantly [8]. At the BS, the quantized channel matrix, $\mathbf{H}$, of size $K \times n_T$ is constructed from the quantized channel versions such that $\mathbf{H} = [\hat{\mathbf{f}}_1^T \ \cdots \ \hat{\mathbf{f}}_K^T]^T$. As discussed in [6], a beamforming weight matrix is obtained by taking the pseudo-inverse of $\mathbf{H}$ given by $\mathbf{W} = \mathbf{H}^H (\mathbf{H}\mathbf{H}^H)^{-1}$. The ZFBF vector for the i^{th} user is given by $\mathbf{w}_i$, where $\mathbf{w}_i$ is the normalized i^{th} column of the beamforming weight matrix, $\mathbf{W}$.

B. SLNR BF

The main idea of SLNR BF is to minimize the total power leaked from the i^{th} user to all other users, while maintaining a strong desired signal to noise ratio. In limited feedback systems, the leakage is approximated by $\sum_{k=1,k\neq i}^{K} |\hat{\mathbf{f}}_k \mathbf{w}_i|^2$. The SLNR BF solution is provided in [7] for the perfect CSI case. We use the same approach here for limited feedback systems by replacing the perfect channel with imperfect or quantized channel. The SLNR BF vector, $\mathbf{w}_i$, for the i^{th} user is the normalized version of the maximum eigenvector of

$$(\sigma_i^2 \mathbf{I} + \tilde{\mathbf{H}}_i^H \tilde{\mathbf{H}}_i)^{-1} \hat{\mathbf{f}}_i^H \hat{\mathbf{f}}_i, \tag{4}$$

[1]The modeling of CQI uncertainties is out of the scope of this letter.

where $\tilde{\mathbf{H}}_i$ is a quantized channel matrix of size $(K-1) \times n_T$ for the i^{th} user constructed from the codebook entries fed back by the other users such that, $\tilde{\mathbf{H}}_i = [\hat{\mathbf{f}}_1^T \cdots \hat{\mathbf{f}}_{i-1}^T \ \hat{\mathbf{f}}_{i+1}^T \cdots \hat{\mathbf{f}}_K^T]^T$.

IV. Differential Codebook (DCB)

In this section, we explain the DCB design where each user generates its codebook by modifying the rank-1 GCB. In order to generate the DCB, we alter the GCB denoted by $\mathcal{C}$ such that its center is at $[1, 0, \ldots, 0]^T$. This alteration involves selecting the Grassmannian codeword, $\mathbf{c}_j$ where $1 \le j \le 2^B$, that is closest to the vector $[1, 0, \ldots 0]^T$ in terms of chordal distance and then obtaining the rotation matrix, $\mathbf{\Theta}$, between them to rotate all the GCB entries. We denote this adjusted GCB by $\tilde{\mathcal{C}} = [\tilde{\mathbf{c}}_1, \tilde{\mathbf{c}}_2, \ldots, \tilde{\mathbf{c}}_{2^{\mathrm{B}}}]$. After this adjustment we scale the rotated codewords by a scaling factor α that defines the radius[2] of the DCB in order to bring the codewords closer for tracking the temporally correlated channel. This rotation and scaling is similar to rules described in [9]. This step completes the generation of the DCB at both BS and user i. The feedback steps are as follows:

- For the first transmission, the user i selects an appropriate codeword $\bar{\mathbf{f}}_i$ from a base codebook (e.g RVQ) and feeds back the index of this selected codeword to the BS. The base codebook is only used for the first feedback, since it is more likely to find a codeword that is nearest to the channel rather than the scaled and rotated DCB.
- For the next transmission, Both BS and user i rotate their DCBs such that the index of the selected codeword for the first feedback (from the base codebook) becomes a new center of the DCB.
- The process continues with the DCB with adaptive scaling, to be discussed later, where the main idea is to vary the value of the scaling parameter, α, depending upon time correlation and mean quantization error.

A. Codebook Rotation and Scaling

The codebook rotation and scaling follow the principles explained in [9]. We drop the user index i from the expressions and introduce the time index t from this point onwards for clarity. In order to rotate the previously selected codeword $\bar{\mathbf{f}}_{t-1}$ to the current selected codeword $\bar{\mathbf{f}}_t$, the rotation matrix is given by $\mathbf{\Theta}_t = \begin{bmatrix}\bar{\mathbf{f}}_t & \bar{\mathbf{f}}_t^{\perp}\end{bmatrix} \begin{bmatrix}\bar{\mathbf{f}}_{t-1} & \bar{\mathbf{f}}_{t-1}^{\perp}\end{bmatrix}^H$. Once, the rotation matrix, $\mathbf{\Theta}_t$, is calculated, all the codewords in the codebook are rotated using this rotation matrix. Each codeword of the adjusted GCB, $\tilde{\mathcal{C}}$, is scaled individually, so that the j^{th} codeword, $\tilde{\mathbf{c}}_j$ is scaled to

$$\mathbf{s}(\tilde{\mathbf{c}}_j) = \left[\sqrt{1 - \alpha^2(1 - r_1^2)} e^{j\theta_1}, \alpha r_2 e^{j\theta_2}, \ldots, \alpha r_{n_T} e^{j\theta_{n_T}}\right]^T, \tag{5}$$

where $r_m e^{j\theta_m}$ is the polar form of the m^{th} entry of the original codeword and α is a scaling parameter satisfying $0 < \alpha < 1$. We divide the scaled codeword by its norm, in order to maintain a unit norm codeword.

[2]Note that after scaling, all the codewords lie inside the radius, α. Hence, the chordal distance between center of the DCB and outermost codeword is always less than α.

B. Adaptive Scaling

In this paper, we assume the channel is spatially and temporally correlated with time correlation coefficient ϵ. If the time between the two time instants is T and we assume the Jakes' model, then $\epsilon = J_0(2\pi f_D T)$, where f_D is the Doppler frequency. If long term channel statistic ϵ is shared with the BS, then the use of adaptive scaling has been shown to improve the performance of DCBs in temporally correlated channels [2], [3], particularly in low speed scenarios. Now we will discuss the proposed adaptive scaling method that depends upon mean quantization error and spatial and temporal correlation. The average chordal distance between the previous and current channel directions is given by

$$\mathrm{d}_{\text{mean}} = \mathbb{E}\left[\sqrt{1 - \left|\bar{\mathbf{h}}_{t-1}^H \bar{\mathbf{h}}_t\right|^2}\right]. \tag{6}$$

using Jensens' inequality in (6) we get

$$\mathrm{d}_{\text{mean}} \leq \sqrt{1 - \mathbb{E}\left[\left|\bar{\mathbf{h}}_{t-1}^H \bar{\mathbf{h}}_t\right|^2\right]}. \tag{7}$$

If we assume that channel is modeled as a first order Gauss-Markov process with both spatial and temporal correlation [3], then

$$\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{h}_t\right|^2\right] = \mathbb{E}\left[\left|\mathbf{h}_{t-1}^H(\epsilon \mathbf{h}_{t-1} + \sqrt{1-\epsilon^2}\mathbf{R}^{1/2}\mathbf{g}_t)\right|^2\right], \tag{8}$$

where $\mathbf{g}_t$ is a $\mathbb{C}^{n_t \times 1}$ vector having i.i.d. entries with $\mathcal{CN}(0,1)$ distribution. $\mathbf{R}$ is a spatial correlation matrix given by an exponential model [3].

$$\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{h}_t\right|^2\right] = \mathbb{E}\left[\left|\epsilon\|\mathbf{h}_{t-1}\|^2 + \sqrt{1-\epsilon^2}\mathbf{h}_{t-1}\mathbf{R}^{1/2}\mathbf{g}_t\right|^2\right], \tag{9}$$

simplifying (9) and putting expectation of cross terms to zero, we get

$$\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{h}_t\right|^2\right] \leq \epsilon^2 \mathbb{E}\left[(\|\mathbf{h}_{t-1}\|^2)^2\right] + (1-\epsilon^2)\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{R}^{1/2}\mathbf{g}_t\right|^2\right] \tag{10}$$

Using independence between amplitude and direction of $\mathbf{h}_t$ and $\mathbf{h}_{t-1}$ [10], we can approximate $\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{h}_t\right|^2\right]$ for spatially and temporally correlated channels, such that

$$\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{h}_t\right|^2\right] \approx \mathbb{E}\left[(\|\mathbf{h}_{t-1}\|^2)^2\right] \mathbb{E}\left[\left|\bar{\mathbf{h}}_{t-1}^H \bar{\mathbf{h}}_t\right|^2\right]. \tag{11}$$

Substituting (12) in (10) and simplifying we get

$$\mathbb{E}\left[\left|\bar{\mathbf{h}}_{t-1}^H \bar{\mathbf{h}}_t\right|^2\right] \approx \epsilon^2 + (1-\epsilon^2)\Psi \tag{12}$$

where,

$$\Psi = \frac{\mathbb{E}\left[\left|\mathbf{h}_{t-1}^H \mathbf{R}^{1/2}\mathbf{g}_t\right|^2\right]}{\mathbb{E}\left[(\|\mathbf{h}_{t-1}\|^2)^2\right]}. \tag{13}$$

The quantity Ψ can be measured by using the fact that $\mathbf{h}_{t-1}^H$ can be written as $\mathbf{h}_{t-1}^H = (\mathbf{R}^{1/2}\mathbf{u})^H$, where $\mathbf{u}$ is distributed according to $\mathcal{CN}(0,1)$, such that

$$\Psi = \frac{\mathbb{E}\left[\left|\mathbf{u}^H \mathbf{R}\mathbf{g}_t\right|^2\right]}{\mathbb{E}\left[(\|\mathbf{R}^{1/2}\mathbf{u}\|^2)^2\right]}. \tag{14}$$

Performing the Eigen decomposition on $\mathbf{R}$, (14) can be written as

$$\Psi = \frac{\mathbb{E}\left[\left|\tilde{\mathbf{u}}^H \mathbf{D}\tilde{\mathbf{g}}_t\right|^2\right]}{\mathbb{E}\left[(\tilde{\mathbf{u}}^H \mathbf{D}\tilde{\mathbf{u}})^2\right]}. \tag{15}$$

where $\mathbf{D}$ is a diagonal matrix containing eigenvalues $(\mathrm{d}_1, \mathrm{d}_2, \ldots, \mathrm{d}_{n_T})$ of $\mathbf{R}$. $\tilde{\mathbf{u}}$ and $\tilde{\mathbf{g}}_t$ are also $\mathcal{CN}(0,1)$ distributed. Solving expectations in (15), we get

$$\Psi = \frac{\sum_{i=1}^{n_T} \mathrm{d}_i^2}{2\sum_{i=1}^{n_T} \mathrm{d}_i^2 + \sum_{\substack{p=1 \\ p\neq q}}^{l} \sum_{\substack{q=1 \\ q\neq p}}^{l} \mathrm{d}_p \mathrm{d}_q} \tag{16}$$

where $l = \frac{n_T!}{2!(n_T-2)!}$. Substituting (16) in (12) gives

$$\mathbb{E}\left[\left|\bar{\mathbf{h}}_{t-1}^H \bar{\mathbf{h}}_t\right|^2\right] \approx \epsilon^2 + (1-\epsilon^2)\frac{\sum_{i=1}^{n_T} \mathrm{d}_i^2}{2\sum_{i=1}^{n_T} \mathrm{d}_i^2 + \sum_{\substack{p=1 \\ p\neq q}}^{l} \sum_{\substack{q=1 \\ q\neq p}}^{l} \mathrm{d}_p \mathrm{d}_q}. \tag{17}$$

Finally, we can approximate d_{mean} by using (17) in (7)

$$\mathrm{d}_{\text{mean}} \approx \sqrt{1 - \epsilon^2 - (1-\epsilon^2)\frac{\sum_{i=1}^{n_T} \mathrm{d}_i^2}{2\sum_{i=1}^{n_T} \mathrm{d}_i^2 + \sum_{\substack{p=1 \\ p\neq q}}^{l} \sum_{\substack{q=1 \\ q\neq p}}^{l} \mathrm{d}_p \mathrm{d}_q}}. \tag{18}$$

When the channel is spatially and temporally correlated the average chordal distance in (18) is small, implying that the codewords in the codebook should be close to the previously selected codeword. However, another factor that must also be taken into account before selecting the scaling parameter is the DCB quantization error associated with the previous feedback. If α_{t-1} was the scaling parameter at time $t-1$, then the upper bound on the mean quantization error at time $t-1$ is given by [3]

$$\mathbb{E}\left[1 - |\bar{\mathbf{f}}_{t-1}^H \bar{\mathbf{h}}_{t-1}|^2\right] \leq \left[\alpha_{t-1} 2^{\frac{-B}{2(n_T-1)}}\right]^2. \tag{19}$$

The quantization error in (19) is given in term of squared chordal distance. As it is an upper bound, we can get a loose upper bound on the quantization error in term of the chordal distance by taking the square root of (19) and denoting it by $\mathrm{d}_{\text{error}_{t-1}}$ we get

$$\mathrm{d}_{\text{error}_{t-1}} \leq \alpha_{t-1} 2^{\frac{-B}{2(n_T-1)}}. \tag{20}$$

Now we have two chordal distances d_{mean} and $\mathrm{d}_{\text{error}_{t-1}}$ that are upper bounds on mean channel distance between two successive channel directions and mean quantization error for the previous DCB radius. Using these upper bounds, we propose the scaling parameter for time t to be

$$\alpha_t = \mathrm{d}_{\text{mean}} + \mathrm{d}_{\text{error}_{t-1}}. \quad \text{for} \quad t > 1 \tag{21}$$

Therefore, starting the process with base codebook, we initially have the scaling parameter $\alpha_0 = 1$ and corresponding upper bounded mean quantization error is $2^{\frac{-B}{2(n_T-1)}}$. For the

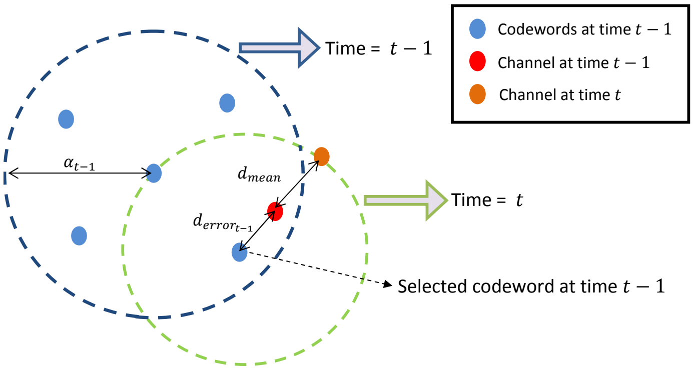

Fig. 1. Illustration of the DCB with adaptive scaling.

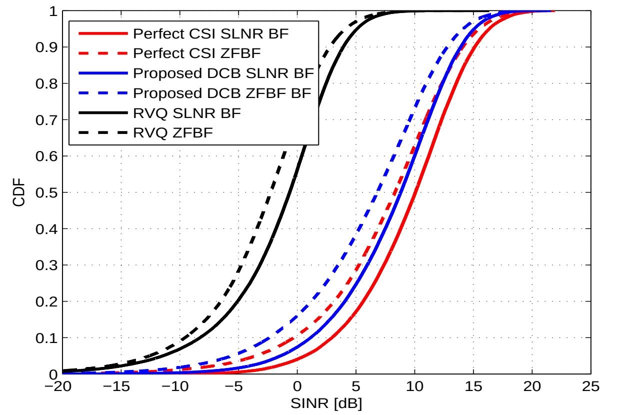

Fig. 2. SINR CDF for the 1st user at SNR = 10 dB with v = 1 km/h ($\epsilon = 0.9987$).

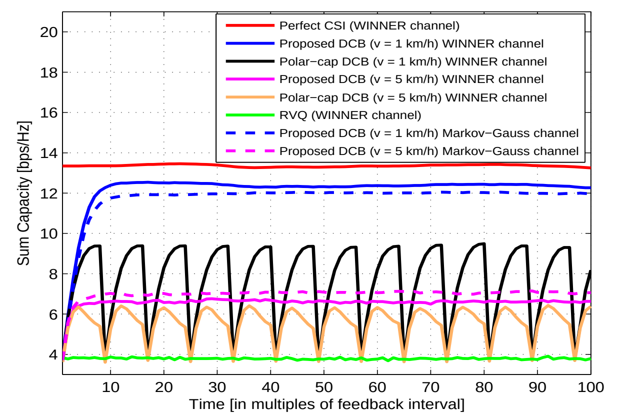

Fig. 3. Sum-capacity vs time for SLNR BF at SNR = 10 dB with v = 1 km/h and v = 5 km/h.

second feedback, we measure the scaling parameter using (20) such that $\alpha_1 = 2^{\frac{-B}{2(n_T-1)}}$. The scaling parameter for the succeeding feedback intervals is calculated using (21). This time varying or adaptive scaling reduces with time till it reaches an asymptotic value given by

$$\alpha_c = \mathrm{d}_{\mathrm{mean}} \left[1 - 2^{\frac{-B}{2(n_T-1)}}\right]^{-1} \tag{22}$$

The adaptive scaling technique for time $t-1$ and t is depicted in Fig. 1. The advantage of this adaptive scaling technique is that the DCB follows the channel and tries to keep the next channel within the reach of the DCB. Periodic reset of the DCB to the base codebook is not required in this method.

V. Performance Evaluation

We perform Monte-Carlo simulations to evaluate the performance of a MU MISO system with the DCB using the proposed adaptive scaling method. The BS is equipped with 4 antennas in a uniform linear array (ULA) setting with 0.5λ spacing among neighboring antennas. The spatially/temporally correlated MU MISO channel is modeled using the WINNER II channel model. The scenario considered is urban macro (Uma) with non-line-of-sight (NLOS) propagation and the carrier frequency is 2.5 GHz. We assume that the feedback link is lossless with zero delay. The feedback interval is 5 ms. The base codebook is a 4 bit rank-1 RVQ codebook [11] and the DCB design is based on a 4 bit rank-1 GCB. The total number of users are 4. We also evaluate the performance in a spatially/temporally correlated channel modeled by first order Gauss-Markov process [3] with spatial correlation coefficient equal to 0.9.

A. Comparison of ZFBF and SLNR BF

In Fig. 2, the cumulative distribution function (CDF) of the SINR is plotted for one of four users when the user speed is 1 km/h. We compare three cases: perfect CSI, the proposed DCB, and the RVQ codebook for both ZFBF and SLNR BF methods. The SLNR BF outperforms the ZFBF scheme and the SINR performance of the SLNR BF scheme with the proposed DCB is even better than the perfect CSI ZFBF case.

B. Temporal Stability of Sum Capacity

Figure 3 shows the sum-capacity vs. time with v = 1 km/h and v = 5 km/h at SNR=10dB. The time axis is in multiples of 5 ms feedback intervals. The sum-capacity with the proposed DCB with adaptive scaling is higher than a 4 bit RVQ codebook. It is seen that the sum-rate performance does not degrade over time with proposed adaptive scaling technique and remains stable. On the other hand, the polar-cap DCB with adaptive scaling as discussed in [3] requires reset to a base codebook after every $T_{max} = 9$ feedback intervals as the radius of the polar-cap becomes too small to follow the channel. When the speed increases, the capacity loss also increases, as in the case of v = 5 km/h, implying that the quantization errors are large and the DCB uses large scaling parameter in order to keep tracking the varying channel. The performance gain of the proposed scheme also holds for the channels modeled by first order Gauss-Markov channels. In Fig. 4 sum-capacity results are shown against the range of SNR values. The performance of the proposed DCB is superior than the polar-cap DCB due to two main reasons; first, as seen in Fig. 3, the temporal stability of sum-capacity due to the adaptive scaling and secondly, the proposed DCB design has better codewords arrangement that leads to higher sum-capacity as seen in Fig. 4.

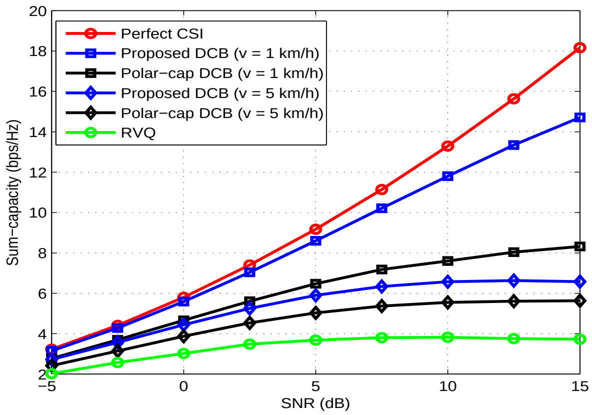

Fig. 4. Sum-capacity performance vs. SNR for different user speeds with SLNR BF in a WINNER II channel.

VI. Conclusion

In this letter, we propose an adaptive scaling method for MU MISO systems using DCB under spatially and temporally correlated channels. It does not require periodic resets and performs well for long transmission periods. We also show the superiority of SLNR BF over ZFBF method.

References

[1] D. J. Love, R. W. Heath Jr., V. K. N. Lau, D. Gesbert, B. D. Rao, and M. Andrews, "An overview of limited feedback in wireless communication systems," *IEEE J. Sel. Areas Commun.*, vol. 26, no. 8, pp. 1341 – 1365, 2008.

[2] T. Kim, D. Love, and B. Clerckx, "MIMO systems with limited rate differential feedback in slowly varying channels," *IEEE Trans. Commun.*, vol. 59, no. 4, pp. 1175 – 1189, 2011.

[3] J. Choi, B. Clerckx, N. Lee, and G. Kim, "A new design of polar-cap differential codebook for temporally/spatially correlated MISO channels," *IEEE Trans. Wireless Commun.*, vol. 11, no. 2, pp. 703 – 711, 2012.

[4] J. Mirza, P. Dmochowski, P. Smith, and M. Shafi, "Limited feedback multiuser MISO systems with differential codebooks in correlated channels," in *Proc. IEEE Int. Conf. on Commun.*, 2013.

[5] C. Lim, T. Yoo, B. Clerckx, B. Lee, and B. Shim, "Recent trend of multiuser MIMO in LTE-advanced," *IEEE Commun. Mag.*, vol. 51, no. 3, pp. 127–135, 2013.

[6] T. Yoo and A. Goldsmith, "On the optimality of multiantenna broadcast scheduling using zero-forcing beamforming," *IEEE J. on Sel. Areas Commun.*, vol. 24, no. 3, pp. 528 – 541, 2006.

[7] M. Sadek, A. Tarighat, and A. Sayed, "A leakage-based precoding scheme for downlink multi-user MIMO channels," *IEEE Trans. Wireless Commun.*, vol. 6, no. 5, pp. 1711 – 1721, 2007.

[8] N. Jindal, "MIMO broadcast channels with finite-rate feedback," *IEEE Trans. Inf. Theory*, vol. 52, no. 11, pp. 5045 – 5060, 2006.

[9] V. Raghavan, R. W. Heath Jr., M. Sayeed, *et al.*, "Systematic codebook designs for quantized beamforming in correlated MIMO channels," *IEEE J. Sel. Areas Commun.*, vol. 25, no. 7, pp. 1298 – 1310, 2007.

[10] T. Kim, D. J. Love, and B. Clerckx, "Leveraging temporal correlation for limited feedback multiple antennas systems," in *Proc. IEEE Int. Conf. on Acoustics Speech and Signal Process*, pp. 3422 – 3425, 2010.

[11] C. Au-Yeung and D. Love, "On the performance of random vector quantization limited feedback beamforming in a MISO system," *IEEE Trans. Wireless Commun.*, vol. 6, no. 2, pp. 458 – 462, 2007.