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Dirty Paper Precoding Method For Multi-User MIMO-OFDM With Limited Feedback

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Abstract—This paper Investigates the performance of cellular networks employing multi-user MIMO transmission using dirty paper and block-diagonalization precoding. Considers the downlink of an OFDM-based LTE compliant multi-carrier system in which the users provide channel state information (CSI) to the base station via limited capacity feedback links. With limited feedback, residual interference between the spatially multiplexed users cannot be avoided, causing an interference-limitation of the achievable downlink throughput. Efficient CSI quantization is therefore central in such systems to achieve a performance gain over single-user MIMO. Propose an effective CSI feedback clustering approach in this work to exploit the correlation of the wireless channel in the frequency domain.

Keywords— Limited feedback, multi-user MIMO, blockdiagonalization, DPC, OFDM, distributed antenna systems

I. INTRODUCTION

Cellular networks are currently experiencing a tremendous growth of data traffic. A ten to seventeen fold increase of global mobile data traffic between 2012 and 2017 is predicted by several studies .A few notable statements of Cisco's Visual Networking Index, illustrating these trends, are: Mobile data traffic in 2012 was nearly twelve times the size of the entire Internet in 2000, average smartphone usage grew 81 percent in 2012 and Smartphones represented only 18 percent of total global handsets in use in 2012, but represented 92 percent of total global handset traffic.

The predicted trends in global mobile traffic according to Ericsson are shown in Figure 1. The expected exponential growth in traffic due to data services (video, web-browsing, email, etc.) is illustrated in the figure, while the contribution of voice traffic stays approximately constant. The driving forces behind the expected traffic explosion are hence new applications enabled by modern devices such as smartphones and tablet-computers, while the classical role of the mobile as a phone becomes less and less significant. Similar tendencies are observed globally as shown in Figure 1.2.Such observations substantiate a demand for larger network capacities in future cellular networks, but also for improved per-user data rates to support the requirements of novel applications. Feedback in wireless communications is tied to a long-standing and successful history, facilitating robust and spectrally efficient transmission over the uncertain wireless medium. Since the application of multiple antennas at both ends of the communication link, enabling multiple-input multiple-output (MIMO) transmission, the importance of feedback information to achieve the highest performance is even more pronounced. Especially when multiple antennas are employed by the transmitter to handle the interference between multiple users, channel state information (CSI) is a fundamental prerequisite. The corresponding multi-user MIMO, interference alignment and coordination techniques are considered as a central part of future cellular networks to cope with the growing inter-cell-interference, caused by the unavoidable densification of base stations to support the exponentially increasing demand on network capacities. However, this vision can only be implemented with efficient feedback algorithms that provide accurate CSI at the transmitter without overloading the uplink channel.

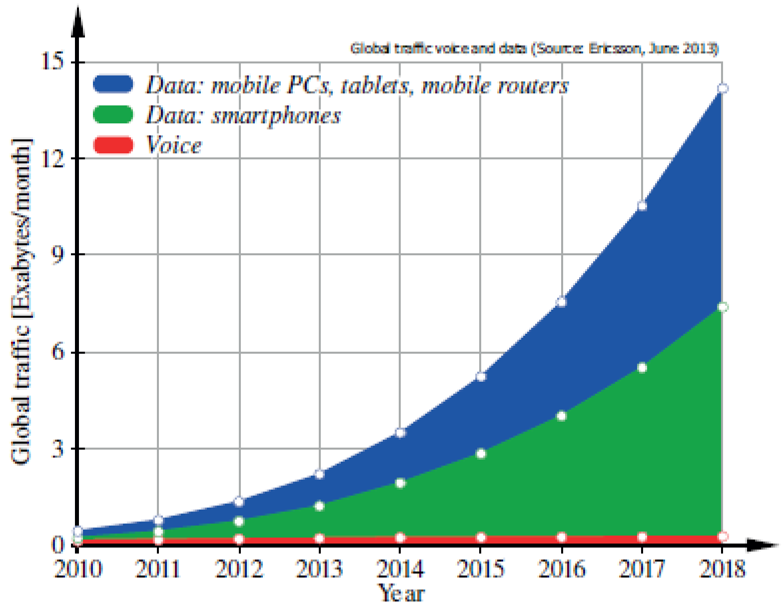

Figure 1: Estimated growth of the global mobile data and voice traffic

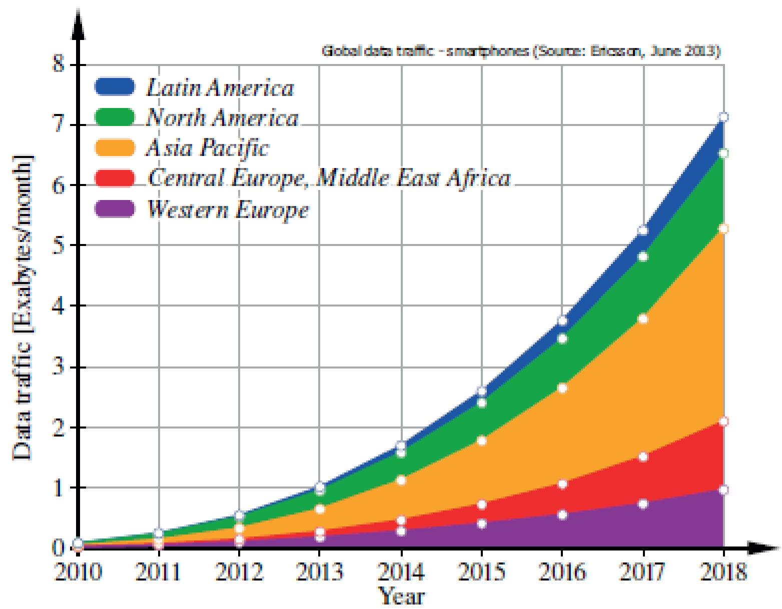

Figure 2: Estimated growth of partitioning of the smartphone data traffic by geographic regions.

Investigates multi-user multiple-input multiple-output (MU-MIMO) transmission based on dirty paper precoding and block diagonalization (BD) precoding with limited feedback in the downlink of orthogonal frequency division multiplexing (OFDM) based cellular networks. .MUMIMO, however, is sensitive to the accuracy of the channel state information (CSI) at the transmitter (CSIT).With imperfect CSIT, e.g., due to limited capacity feedback links, residual multi-user interference causes an interference limitation of the achievable throughput that can only be avoided by scaling the feedback overhead linearly with the logarithmic signal-to noise ratio (SNR). To reduce the feedback burden, the channel correlation over time, frequency and space must be exploited during CSI quantization. Differential and predictive limited feedback algorithms that utilize the temporal correlation of the wireless channel have been proposed in for single stream transmission per user (zero-forcing beamforming) and have been extended in to support multiple streams per user. Additionally, the frequency correlation of the channel can be exploited for feedback overhead reduction. Clustering consecutive OFDM subcarriers and providing the best representation for each cluster for beamforming systems. Feeding back CSI on a subset of OFDM subcarriers and employing interpolation at the transmitter to determine the CSI on the intermediate subcarriers.

II. OFDM SYSTEM MODEL

Consider a MIMO-OFDM system with M transmit antennas, N receive antennas, and K subcarriers. At the transmitter, the transmitted symbol $Xm(i, k)$ is transformed into the time domain signal at the m-th transmit antenna, i-th symbol time and the k-th subcarrier using IFFT .Then, a cyclic prefix (CP) is inserted to avoid inter-symbol interference. At the receiver, the CP is removed before the FFT process. We assume that the CP is greater than the maximum delay spread of channel, and the time and frequency synchronization is perfect, systems. Figure 2-1 shows the general structure of a multicarrier system.

$$Y_n(\mathrm{i,k}) = \sum_{m=1}^{M} H_{m,n}(i,k) X_m(i,k) + Z_n(\mathrm{i,k}) \tag{1}$$

Where $Hn,m(i, k)$ is the frequency response of the channel impulse response (CIR) at the k-th subcarrier and the i-thsymbol time for the (m, n)-th antenna pair. $Zn(i, k)$ is the background noise plus interference term of the n-th receive antenna, which can be approximated as a zero mean additive white Gaussian noise (AWGN) with variance $\sigma 2Z$

III. CHANNEL MODEL

The impulse response of the wireless channel can be represented as

$$h_{n,m}(t, \boldsymbol{\tau}) = \sum_{l=0}^{L} h_{m,n}(t, l) \tag{2}$$

$\delta(\cdot)$ is the Kronecker delta function, $\tau_{n,m}(l)$ and $h_{n,m}(t, l)$ are the delay and complex-value CIR at time t of the l-th path from the (m, n)-antenna pair respectively. Let $H_{m,n}(t, f)$ be the frequency response of the time domain CIR $h_{n,m}(t, \tau)$. The frequency domain CIR with symbol time Tsand subcarrier spacing $f$scan be represented in a discrete manner as

$$h_{n,m}(i, l) = h_{n,m}(iT, l) \tag{3}$$

IV. MIMO BROADCAST CHANNELS WITH FINITE-RATE FEEDBACK

In multiple-antenna broadcast (downlink) channels, capacity can be tremendously increased by adding antennas at only the access point (AP) .In essence, an AP equipped with M antennas can support downlink rates up to a factor of M times larger than a single antenna AP, even when each mobile device has only a single antenna. In order to realize these benefits, however, the AP must do the following.

- Simultaneously transmit to multiple users over the same bandwidth (orthogonal schemes such as time-division multiple access (TDMA) or code-division multiple access (CDMA) are generally highly suboptimal).
- Obtain accurate channel state information (CSI).

Practical transmission structures that allow for simultaneous transmission to multiple mobiles, such as downlink beamforming, do exist. The requirement that the AP have accurate CSI, however, is far more difficult to meet, particularly in frequency-division duplexed (FDD) systems.

Training can be used to obtain channel knowledge at each of the mobile devices, but obtaining CSI at the AP generally requires feedback from each mobile. Such feedback channels do exist in current systems (e.g., for power control), but the required rate of feedback is clearly an important quantity for system designers.

Finite-rate feedback model is one in which each mobile feeds back a finite number of bits regarding its channel instantiation at the beginning of each block. This model was first considered for point-to-point multiple-input multiple-output (MIMO) channels where the transmitter uses such feedback to more accurately direct its transmitted energy towards the receiver, and even a small number of bits per antenna can be quite beneficial. In point-to-point MIMO channels, the level of CSI available at the transmitter only affects the signal-to-noise ratio (SNR) offset; it does not affect the slope of the capacity versus SNR curve, i.e., the multiplexing gain. However, the level of CSI available to the transmitter critically affects the multiplexing gain of the MIMO downlink channel .As a result, channel feedback is considerably more important for MIMO downlink channels than for point-to-point channels.

Consider systems in which the number of mobiles is equal to the number of transmit antennas. This regime is applicable for inherently smaller systems as well as large systems in which stringent delay constraints do not allow user selection to be performed on the basis of channel qualities, e.g., users are selected for transmission based upon queue lengths instead of on channel conditions. Random beamforming is an alternative limited feedback strategy for MIMO downlink channels in which each mobile feeds back a very low rate quantization of the channel as well as an analog SNR value. While this strategy performs well when there are a large number of mobiles relative to the number of transmit antennas, it performs poorly in the small system regime.

Consider a K receiver multiple-antenna broadcast channel in which the transmitter (also referred to as the AP) has M>1 antennas and each receiver has a single antenna. The broadcast channel is mathematically described as

$$y_i = h_i^{+} x + n \tag{4}$$

where $h_1, h_2 \dots h_k$ are the channel vectors of users 1 through K, the vector $x \in C^{MX1}$ is the transmitted signal, and $n_1 \dots n_k$ are independent complex Gaussian noise terms with unit variance.The channel is assumed to be block fading, with independent fading from block to block. The entries of the channel vectors are distributed as i.i.d. unit variance complex Gaussians (Rayleigh fading). Furthermore, each of the receivers is assumed to have perfect and instantaneous knowledge of its own channel vector, i.e., hi. Notice it is not required for mobiles to know the channel of other mobiles. Partial CSI is acquired at the transmitter via a finite rate feedback channel from each of the mobiles.

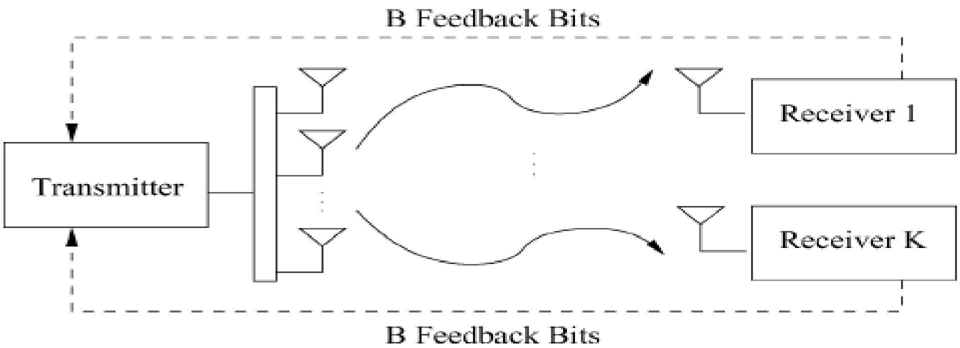

Figure 3: Finite-rate feedback system model.

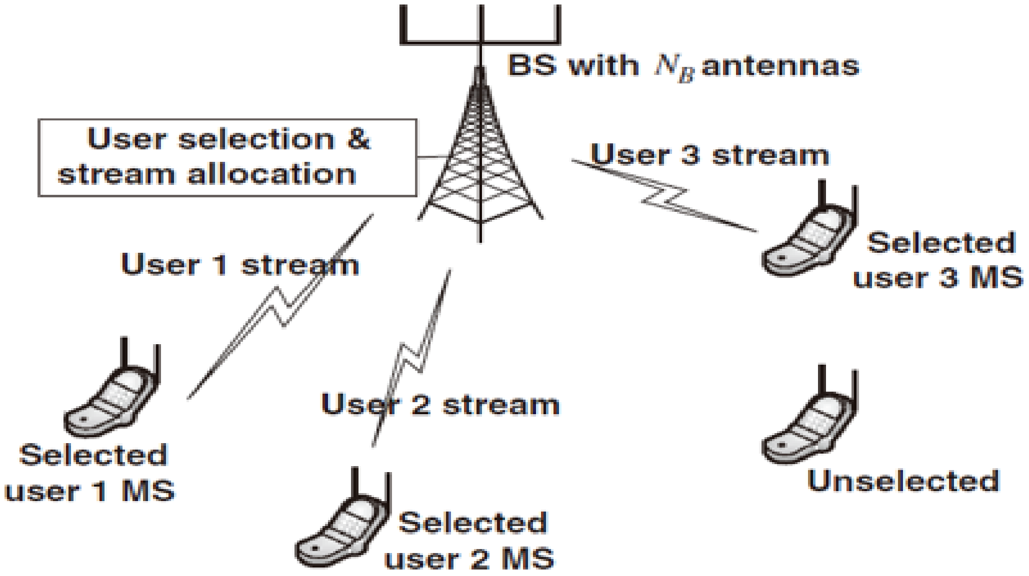

Figure 4: Multi user MIMO communication system :k=4

In the finite-rate feedback model shown in Fig. 3 each receiver quantizes its channel to B bits and feeds back the bits perfectly and instantaneously to the AP, which is assumed to have no other knowledge of the instantaneous state of the channel. The quantization is performed using a vector quantization codebook that is known at the transmitter and the receivers. Typically, each mobile uses a different codebook to prevent multiple mobiles from quantizing their channel to the same quantization vector.

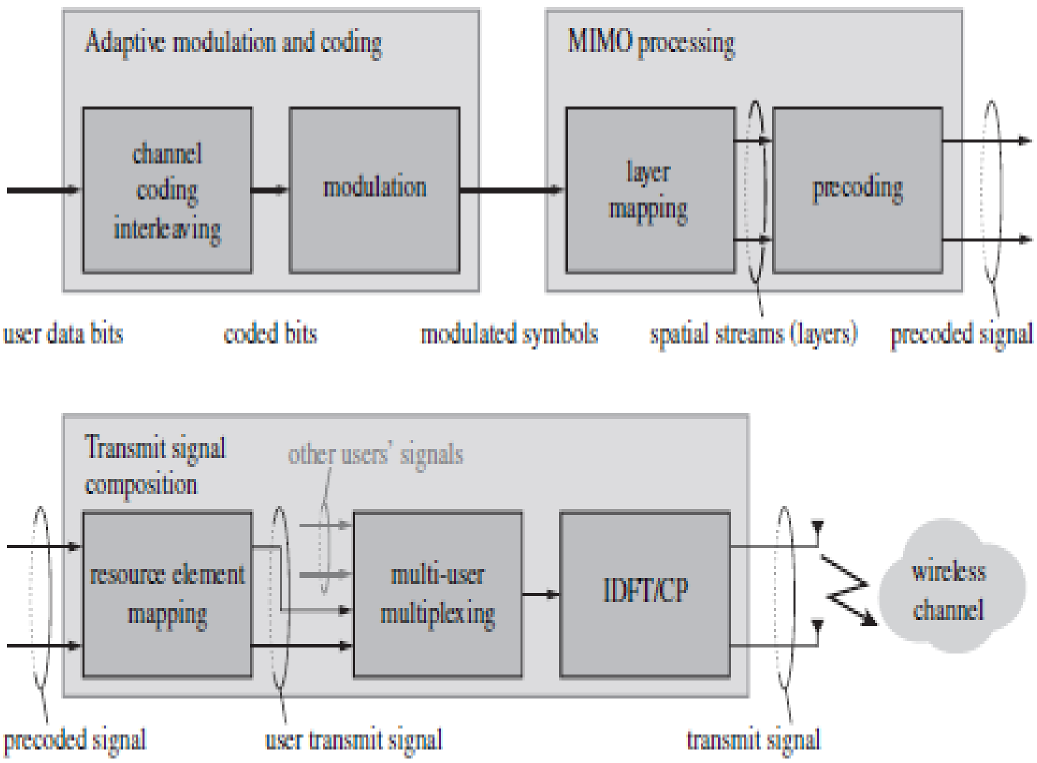

Figure 5: MIMO OFDM transceiver architecture as considered in this dissertation

V. BLOCK DIAGONALIZATION

To optimize the achievable throughput of the system a joint optimization of the multi-user schedule S, the precoders and the antenna combiners is required. Iterative algorithms have been proposed to find locally optimal solutions to this non-convex joint-optimization problem. These approaches, however, involve a significant signaling overhead between the transmitter and the receivers to determine the solution; also, it is not immediately clear how to enable efficient limited feedback operation. Pursue a different practically feasible approach, in which we restrict the precoders to BD and we determine the antenna combiners independently at the users based on purely selfish arguments; thus, we do not consider joint transceiver optimization. With our approach, the users select the antenna combiners to either maximize the gain of the intended signal, ignoring the residual multi-user interference due to limited feedback; or they focus on reducing the residual multi-user interference by minimizing the CSI quantization error.

At the transmitter, block diagonalization (BD) precoding is employed to orthogonalize the transmissions to multiple users. The subspace spanned by the user's channel matrix is identified as the feedback information required at the base station for precoder calculation. In the BD method, unlike in the channel inversion methods, only the interference from other user signals is canceled in the process of precoding. Then, the inter-antenna interference for each user can be canceled by various signal detection methods. For the u th user signal the received signal is given as

$$Y_u = H_u^{DL} \sum_{k=0}^{K} W_K x_k + Z_U \quad (5)$$

Where H_u^{DL} is the channel matrix between BS and the u th userW_U is the precoding matrix for the u th user, and Z_U is the noise vector.

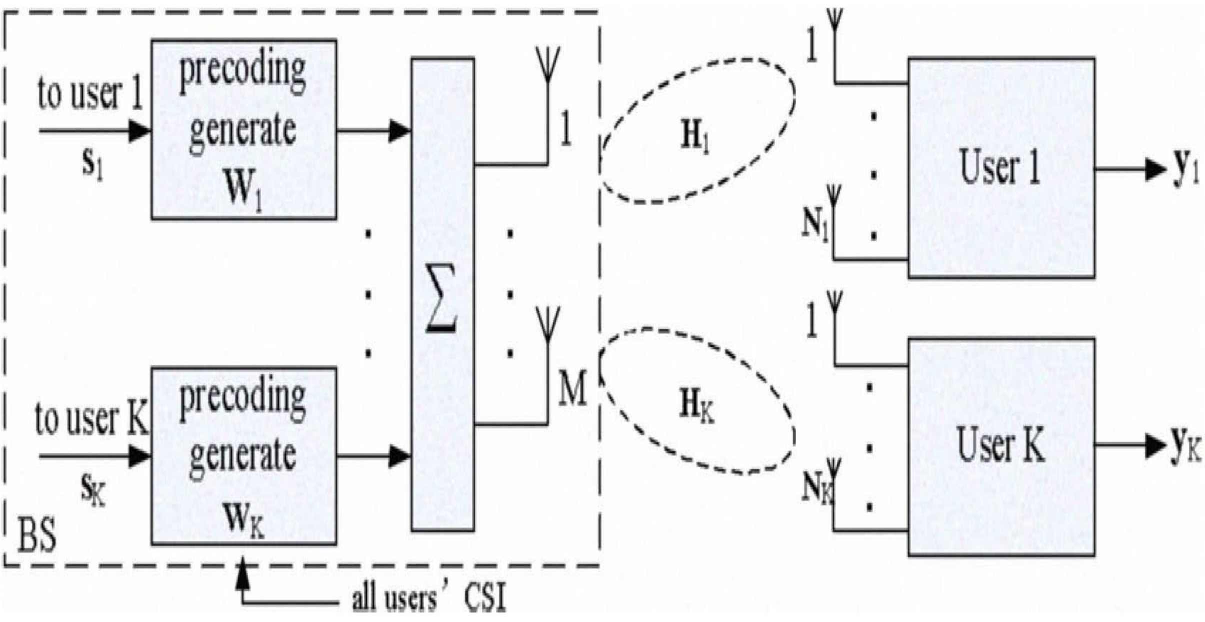

Figure 6: The System Structure of BD

VI. DIRTY PAPER CODING (DPC)

Dirty paper coding (DPC) is a method of precoding the data such that the effect of the interference can be canceled subject to some interference that is known to the transmitter. More specifically, the interferences due to the first up to (k-1) th user signals are canceled in the course of precoding the kth user signal. Consider the case of N_B=3, K= 3, and $N_{M,U}$= 1, u = 1; 2; 3, then the received signal is given as

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \underbrace{\begin{bmatrix} \mathbf{H}_1^{\mathrm{DL}} \\ \mathbf{H}_2^{\mathrm{DL}} \\ \mathbf{H}_3^{\mathrm{DL}} \end{bmatrix}}_{\mathbf{H}^{\mathrm{DL}}} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} \tag{6}$$

The channel matrix can be LQ-decomposed as

$$\mathbf{H}^{\mathrm{DL}} = \underbrace{\begin{bmatrix} l_{11} & 0 & 0 \\ l_{21} & l_{22} & 0 \\ l_{31} & l_{32} & l_{33} \end{bmatrix}}_{\mathbf{L}} \underbrace{\begin{bmatrix} \mathbf{q}_1 \\ \mathbf{q}_2 \\ \mathbf{q}_3 \end{bmatrix}}_{\mathbf{Q}} \tag{7}$$

Leaving the lower-triangular matrix after transmission, the received signal is given as

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \underbrace{\begin{bmatrix} \mathbf{H}_1^{\mathrm{DL}} \\ \mathbf{H}_2^{\mathrm{DL}} \\ \mathbf{H}_3^{\mathrm{DL}} \end{bmatrix}}_{\mathbf{H}^{\mathrm{DL}}} \mathbf{Q}^H \mathbf{x} + \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} l_{11} & 0 & 0 \\ l_{21} & l_{22} & 0 \\ l_{31} & l_{32} & l_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} \tag{8}$$

the received signal of the first user is given as

$$y_1 = l_{11} x_1 + z_1. \tag{9}$$

From the first-user perspective, therefore, the following condition needs to be met for the interference-free data transmission

$$x_1 = \tilde{x}_1 \tag{10}$$

The received signal of the second user is given as

$$y_2 = l_{21} x_1 + l_{22} x_2 + z_2 = l_{21} \tilde{x}_1 + l_{22} x_2 + z_2. \tag{11}$$

it can be seen that the following precoding cancels the interference component, on the transmitter side

$$x_2 = \tilde{x}_2 - \frac{l_{21}}{l_{22}} x_1 = \tilde{x}_2 - \frac{l_{21}}{l_{22}} \tilde{x}_1 \tag{12}$$

Finally, the received signal of the third user is given as

$$y_3 = l_{31} x_1 + l_{32} x_2 + l_{33} x_3 + z_3 \tag{13}$$

The precoded signals in the above equations can be expressed in a matrix as

$$\begin{bmatrix} x_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \end{bmatrix} \tag{14}$$

$$\begin{bmatrix} x_1 \\ x_2 \\ \bar{x}_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ -\frac{l_{21}}{l_{22}} & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ \bar{x}_2 \\ \bar{x}_3 \end{bmatrix} \tag{15}$$

And

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\frac{l_{31}}{l_{33}} & -\frac{l_{32}}{l_{33}} & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \bar{x}_3 \end{bmatrix} \tag{16}$$

Combining the above three precoding matrices, we can express the DPC in the following matrix form

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\frac{l_{31}}{l_{33}} & -\frac{l_{32}}{l_{33}} & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ -\frac{l_{21}}{l_{22}} & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \\ \bar{x}_3 \end{bmatrix}$$
$$= \begin{bmatrix} 1 & 0 & 0 \\ -\frac{l_{21}}{l_{22}} & 1 & 0 \\ -\frac{l_{31}}{l_{33}} + \frac{l_{32}}{l_{33}}\frac{l_{21}}{l_{22}} & -\frac{l_{32}}{l_{33}} & 1 \end{bmatrix} \begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \\ \bar{x}_3 \end{bmatrix}. \tag{17}$$

VII. CHANNEL SUBSAMPLING AND GEODESIC INTERPOLATION

With channel subsampling, the receiver provides CSI feedback only for a subset of the OFDM subcarriers, i.e., the CSI pilots. After receiving the feedback, the transmitter determines the CSI on the remaining subcarriers by drawing equidistant samples of the geodesic between neighboring CSI pilots. Considering a specific CSI pilot $n1$, we assume that user u employs the selfish maximum eigenmode transmission (MET) antenna combiner

$$\Omega_{MET}\left(H_U[n1], Q_j\right) = d_c^2([U_N[n1]]:,1: l_u , Q_j) \tag{18}$$
$$H_U[n1] = U_N[n1]\textstyle\sum_u[n1]V_u[\mathrm{n}1]^H \tag{19}$$

Where (19) denotes an SVD of the channel matrix with singular values in decreasing order. With MET, the user l_u selects the largest eigenmodes as the effective channel, providing a potentially large channel gain and corresponding high SNR.

VIII. SQBC-BASED CLUSTERING

As an alternative to CSI interpolation we propose a novel CSI clustering scheme, which minimizes the average subspace chordal distance per cluster, implying minimal residual interference due to the mismatch between the channel and the clustered and quantized CSI. This approach is suitable for large CSI pilot distances compared to the channel coherence bandwidth, entailing unsatisfactory performance of linear interpolation due to significant channel variations in between CSI pilots.The best unquantized Grassmannian subspace representation of the cluster by minimizing the average chordal distance with respect to the channel matrices

IX. RESULTS

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference,distortion or bit synchronization errors. .In figure 5.3 comparison of BD and DPC precoding methods are done, DPC outperforms the BD. In this comparison, however, transmitted power of DPC is higher than that of BD.

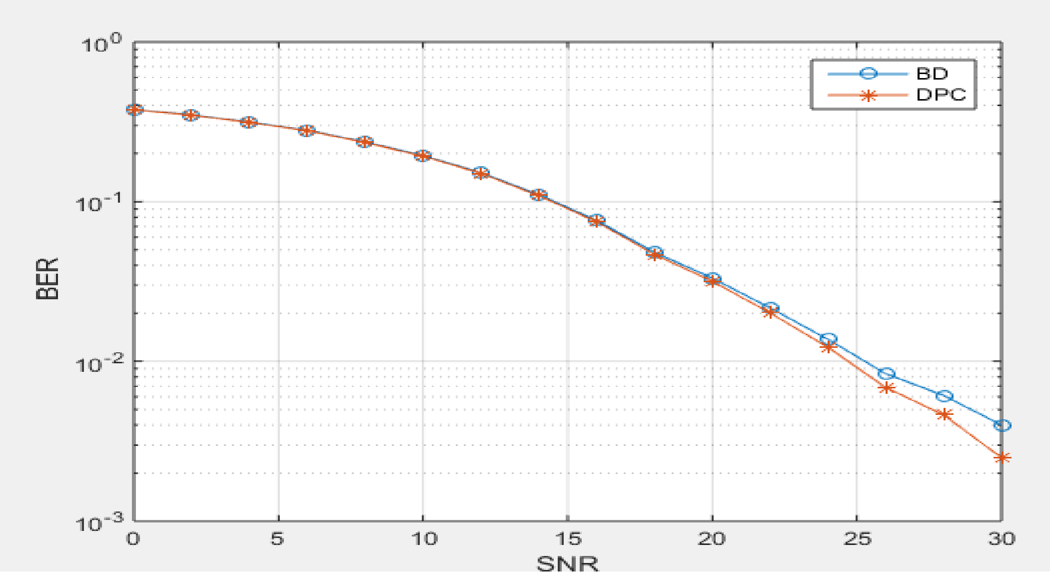

Figure 7: BER performance: DPC vs. BD

the performance of an alternative interference-unaware receive antenna combining algorithm, namely MET,is investigated. With MET the effective channel generated by a user is composed of the L maximum eigenmodes of the channel matrix. Hence, with perfect CSIT the L-dimensional dominant subspace of each users' channel is kept free of interference, providing a potentially large channel gain. On the other hand, the CSI quantization error achieved with MET is significantly larger than with SQBC, and thus the residual multi-user interference has a much stronger impact on the performance of MET

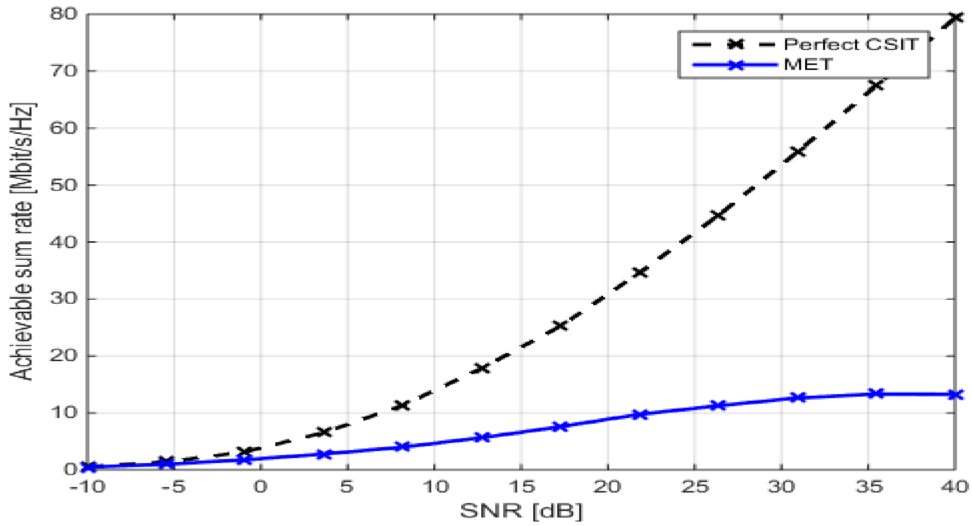

Figure 11: Throughput of MET with interpolation

.As an alternative to CSI interpolation SQBC based clustering is a novel CSI clustering scheme, which minimizes the average subspace chordal distance per cluster, implying minimal residual interference due to the mismatch between the channel and the clustered and quantized CSI. Figure. 11 illustrates the throughput of SQBC based clustering.

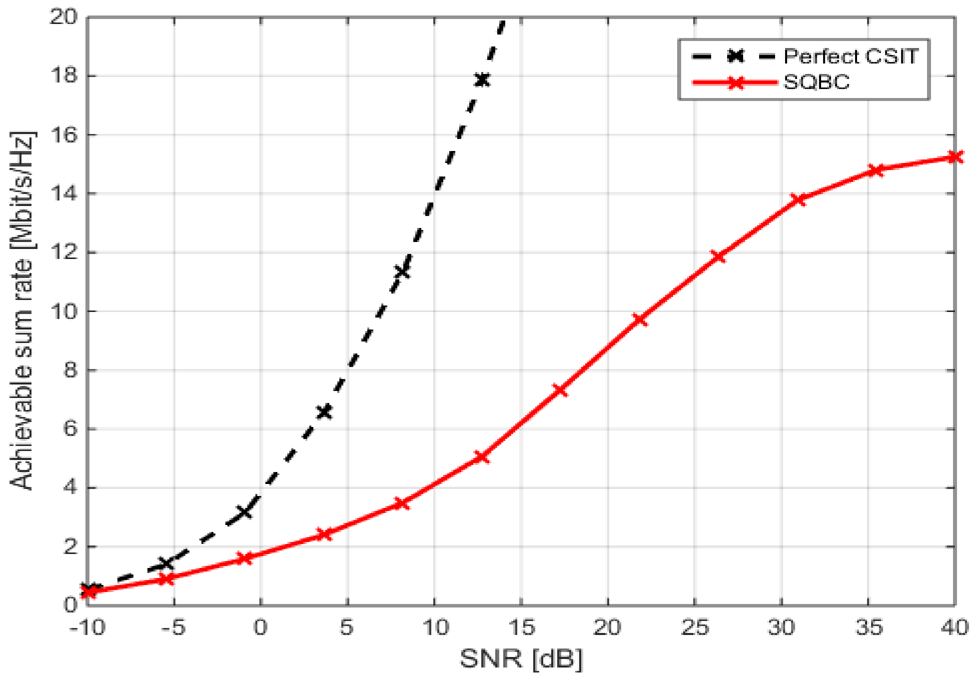

Figure 12: Throughput of SQBC- based clustering

X. CONCLUSION

An efficient CSI feedback clustering method for DPC-based multi-user MIMO-OFDM with limited feedback is considered. In this limited feedback system the block-diagonalization and dirty paper coding is compared. In the case of BD only the interference from other user signals is canceled in the process of precoding. In DPC precoding the data such that the effect of the interference can be canceled subject to some interference that is known to the transmitter. Comparing DPC and BD on the basis of area spectral efficiency both performs similarly. But in the case of sum throughput DPC out performs BD by 2mbps when SNR=20db. And in the case of SINR comparison both have similar results. More detailed investigations are, however, required considering shadow fading, varying node density, etc. With the proposed feedback algorithms a throughput within 1% of the optimal performance of LTE, as obtained from exhaustive search, is achieved .Accurate CSI at the transmitter (CSIT) is critical to minimize the residual multi-user interference observed by the users. When additional degrees of freedom (DoF) are provided by the users via excess receive antennas, the residual multi-user interference (or the feedback overhead) can further be reduced by applying the proposed subspace quantization based combining (SQBC) subspace selection and antenna combining strategy. It is shown that a linear reduction of the slope of the feedback bit scaling law, governing the feedback overhead to obtain a constant loss with respect to perfect CSIT, with the number of excess antennas is achieved by application of SQBC antenna combining. Subspace selection based on SQBC is also an effective approach for extending the feedback methods to OFDM by means of subcarrier clustering. Combining feedback clustering with predictive quantization, close to optimal throughput performance is demonstrated with a reasonable feedback overhead over the practically relevant SNR range from 0 dB to 30 dB.

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