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Feedback of Codebook Selection and MIMO Stream Power

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1 Introduction

This contribution proposes a feedback method designed to improve the performance of the receiver performance (e.g., linear MMSE, successive cancellation, or maximum likelihood) when codebook selection over a band of frequencies is used. A codebook weight (e.g., Grassmannian weights [2]) is determined over a group of frequency-domain subcarriers for each MIMO data stream along with a power weighting for each stream. Then a codebook weight and power weighting is fed back for each stream for the group of subcarriers.

2 Summary of Solution

Let there be M_b transmit antennas at the BS and M_m receive antennas at the MSS: Assuming an OFDM downlink with K usable subcarriers, the received $M_m\times1$ signal at the MSS on subcarrier k ($0\le k\le K$-1) and symbol time b is given as (note this is the downlink signal used by the MSS to measure the channel response to each BS antenna):

$$\mathbf{Y}(k,b)=\mathbf{H}(k,b)\mathbf{x}(k,b)+\mathbf{N}(k,b) \quad (1)$$

where $\mathbf{H}(k,b)$ is the $M_m\times M_b$ frequency-domain channel matrix on subcarrier k and symbol time b, $\mathbf{x}(k,b)$ is the $M_b\times1$ training vector, and $\mathbf{N}(k,b)$ is additive noise with covariance matrix $\sigma_n^2\mathbf{I}_{M_m}$ (where $\mathbf{I}_n$ is an $n\times n$ identity matrix). The MSS uses $\mathbf{Y}(k,b)$ to calculate its channel estimates to all BS antennas.

2.1 Codebook selection

It will be assumed that there are N_c codebook weights given in the $M_b\times N_c$ matrix $\mathbf{V}$. This contribution uses Grassmannian weights [2] for $\mathbf{V}$. The $M_m\times N_c$ composite frequency-domain channel for all codebook weights (i.e., the RF channel matrix times all codebook weights) is given as:

$$\mathbf{G}(k,b)=\mathbf{H}(k,b)\mathbf{V} \quad (2)$$

where the MSS uses its estimate of $\mathbf{H}(k,b)$ measured on the downlink.

Now the MSS just needs to determine which of the N_s (where N_s is the number of MIMO streams) columns of $\mathbf{V}$ to use as the codebook weights for each stream. The criteria that will be used to determine the weights is to choose the N_s columns of $\mathbf{G}(k,b)$ (averaged across frequency) that have the highest capacity. Note that the selection criteria is determined by the MSS and other options are possible such as choosing the N_s columns of $\mathbf{G}(k,b)$ (averaged across frequency) with the highest power.

2.2 Stream Power Calculation

Once the composite channel to the N_s selected streams is known, the power weightings are chosen so that the receiver performance is optimized (e.g., the mean squared error after successive cancellation reception is equalized on each stream). Reference [1] gives a description of how the power weighting may be calculated.

2.3 Weight and Power Feedback

The codebook weights are selected from codebooks of 16 constant modulus vectors designed as given in [2]. Thus four bits are needed on each data stream to convey the transmit weight vector. The remaining bits in the CQI feedback channel(s) are used to convey the power weighting.

For the quantization of power weightings for all streams, a more efficient quantization method is described here after recognizing the fact that the range of each stream can be refined after the power weightings of previous streams are quantized. The method sequentially quantizes the power weightings of the data streams in a numerical range that depends on the power weighting of the previously quantized stream powers. Also noted here that the streams are indexed in the order of decreasing power weighting and all power weightings sum up to one. So the number of bits assigned to quantize each stream can be smaller due to the decreasing range.

The quantization scheme is given as:

1. Determine the codebook weight and power weighting for each of the N_s data streams.
2. Quantize the codebook weights for each stream to B bits (B=4 for codebooks of 16 vectors).
3. Quantize the power weighting of the first data stream to one of L_1 levels between $1/N_s$ and P_{ul} (P_{ul} is a predetermined upper limit on the power, e.g., P_{ul}=1). For example, B_1 bits can used to signal the L_1 levels (i.e., $L_1 = 2^{B_1}$). Let P_1 denote the quantized power level for stream one.
4. For the m-th stream where m=2 to N_s-1, quantize the power weighting of the m-th data stream to one of L_m levels between $\frac{1}{N_s+1-m}(1-\sum_{n=1}^{m-1} P_n)$ and the smaller value between the quantized P_{m-1} and $1-\sum_{n=1}^{m-1} P_n$. For example, B_m bits can used to signal the L_m levels (i.e., $L_m = 2^{B_m}$) and $B_m <= B_{m-1}$. For each of the m data streams, let P_m denote the quantized power for stream m.

Thus the total amount of feedback (in number of bits) needed for the power weight is $\sum_{m=1}^{N_s-1} B_m$. Note that the quantization method quantizes the power for streams one through N_s-1 and the power for last stream (N_s-th) is determined from the power of the other streams.

For the 6-bit fast feedback channel and assuming there are four bits to determine the codebook vector on each stream, the proposed number of bits for each stream are: 1) for N_s=2, B_1=4 bits, 2) for N_s=3, B_1=4 and B_2=2, and 3) for N_s=4, B_1=4, B_2=2, and B_3=2.

The above algorithm talks about the range of the power weights but in fact the voltage (i.e., the square root of the power weights) are quantized and fed-back to the BS. Thus the ranges in the above algorithm will be the square root of the ranges given.

Note that for the power weight quantization that the number of streams, N_s, is already determined. Ideally, the MSS should determine N_s and convey this information to the BS along with the power weightings and the codebook weights, since the optimal number of streams is dependent on the channel condition learned at the MSS (e.g., spatial condition and the receive SNR). However, the feedback resource is often pre-allocated by the BS. Although a maximum feedback resource can always be allocated, it can be wasteful. On the other hand, the receiver can feedback the number of data streams first as a request for feedback resource, but it can involve extra latency. Therefore, it may be desirable for the BS to determine N_s and then the BS convey N_s to the MSS. An efficient signaling approach is the implicit determination of N_s by the MSS from the feedback resources assigned by the BS. A simple example of this is that the BS requests the MS to transmit feedback on N_s feedback channels if 6 bit feedback channel is used or on N_s+1 feedback channel if 5-bit feedback is defined. Although the MSS may lose the flexibility to control the number of streams now, the whole system can still benefit from such an efficient mechanism. For example, the default number of streams can be set to 1 initially for all MSS's and then the feedback allocation is increased to allow more streams if the BS finds it necessary and beneficial. Note that single stream is optimal for many cases anyway, such as, but not limited to, the case when the MSS is only equipped with a single antenna, when the receive SNR is low enough to support a single stream, or when the optimality of multiple streams can not be guaranteed because the beamforming weights quickly become obsolete due to rapid channel variation.

A specific example of the power quantization and implicit signaling of N_s is now given for illustrative purposes. The 6-bit fast feedback channel is assumed.

1. The BS requests the MSS to transmit on four six-bit feedback channels (for a total of 24 bits of feedback).
2. The mobile knows N_s=4 because of the amount of feedback requested by the BS (i.e., that there is one stream for each feedback channel requested).
3. The MSS determines which four codebook weights that the BS should transmit with.
4. The MSS quantizes the codebook weights on each stream to B=4 bits (thus N_s*B=16 bits out of the 24 total are used to convey the codebook weight).
5. The MSS quantizes the square-root of the power weighting of each data stream from the above algorithm (where the range of each stream is the square-root of what is shown above to accommodate the quantization of the voltage instead of power) using B_1=4 bits, B_2=2 bits, and B_3=2 bits.
6. The MSS transmits the 24 bits of feedback to the base.
7. The BS transmits using the four codebook weights and their respective power levels specified in the feedback channels.

3 Specific Text Changes

[Apply the following changes to Table 298a in Section 8.4.5.4.15, page 188:]

Table 298 a. CQICH Enhanced allocation IE format

Syntax	Size(bits)	Notes
CQICH_Enhanced_Alloc_IE() {		
Extended DIUC	4	0x09
Length	4	Length (in bytes) of the following fields
CQICH ID	Variable	Index to uniquely identify the CQICH resource assigned to the MSS
Period (=p)	2	A CQI feedback is transmitted on the CQICH every 2p frames
Frame offset	3	The MSS starts reporting at the frame of which the

		number has the same 3 lsb as the specified frame offset. If the current frame is specified, the MSS should start reporting in 8 frames.
Duration (=d)	3	A CQI feedback is transmitted on the CQI channels indexed by the CQICH_ID for 10 x 2d frames. If d == 0, the CQI-CH is de-allocated. If d == 111, the MSS should report until the BS Commend for the MSS to stop.
NT actual BS antennas	3	001 = Reserved 010 = 2 actual antennas 011 = 3 actual antennas 100 = 4 actual antennas 101 = 5 actual antennas 110 = 6 actual antennas 111 = 7 actual antennas 000 = 8 actual antennas
Feedback type	2	00 = Fast DL measurement/Default Feedback 01 = MIMO Antenna Feedback 10 = MIMO mode and permutation zone 11 = ~~Reserved~~ Feedback of codebook index and stream power weightings for the whole allocated band
CQICH_Num	4	Number of CQICHs assigned to this CQICH_ID is (CQICH_Num + 1)
For (i=0; i<CQICH_Num; i++) {		
Allocation index	6	Index to the fast feedback channel region marked by UIUC =0
}		
if (Feedback_type == 10) {		
MIMO permutation feedback cycle	2	00 = No MIMO and permutation mode feedback 01 = the MIMO and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 4 frames. The first indication is sent on the 8th CQICH frame. 10 = the MIMO mode and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 8 frames. The first indication is sent on the 8th CQICH frame. 11 = the MIMO mode and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 16 frames. The first indication is sent on the 16th CQICH frame.
}		
Padding	variable	
}		

4 Simulation Results

Simulation results are now presented showing the performance of the proposed method. The simulations are run on the OIP-B (Pedestrian-B) channel with antenna correlation of 0.5 and the V-A (Vehicular-A) channel (at 30 km/h) with an antenna correlation of 0.5. For all results six bits of feedback per stream are used where the feedback indicates the codebook weight and power weighting of each stream. The narrowband results use the rate ½ convolution code (Figures 1 through 3) and the broadband results use the 3GPP rate ½ turbo code. There is a 96 OFDMA symbol delay (10 MHz bandwidth with 11.2 KHz spacing and a 1024 size FFT) between where the MSS measures the channel and when the BS uses the transmit weights.

Figure 1 and Figure 2 show the results for the OIP-B channel with four BS antennas and one through four MSS receive antennas/data streams. Figure 3 shows the results for the V-A channel at 30 km/h for one and four MSS receive antennas/data streams. Finally, Figure 4 shows results for coding across the entire 10 MHz instead of just the four bins in the previous results (there are four BS antennas and four MSS antennas/data streams). Note that only a single codebook weight and power weighting is used across the entire 10 MHz for each stream and thus the feedback required is extremely low.

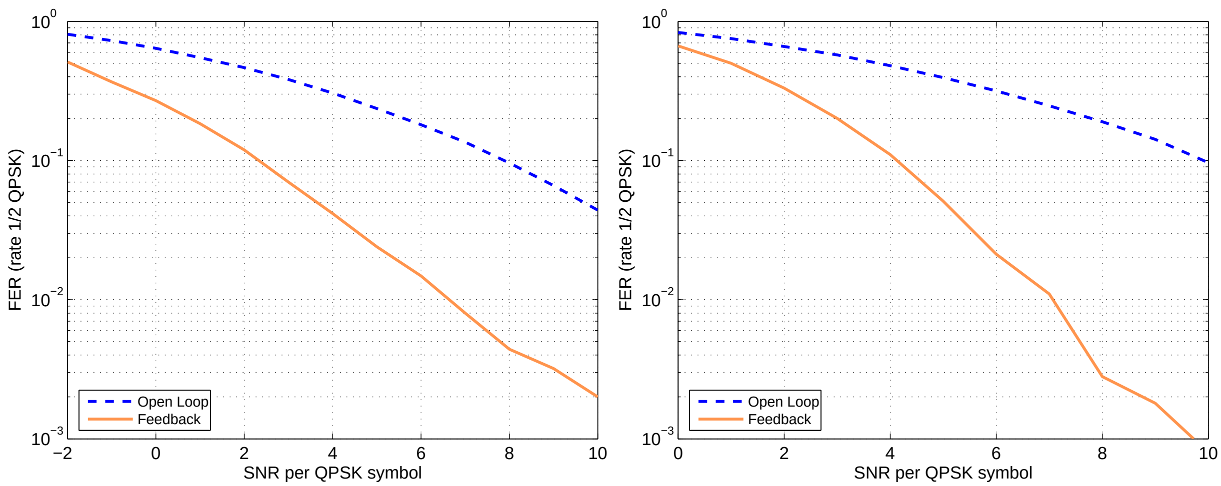

Figure 1. FER results comparing open loop to limited feedback method for four BS antennas and the OIP-B channel (3 km/h). The left plot has one MSS antenna and one data stream and the right plot has two MSS antennas and two data streams.

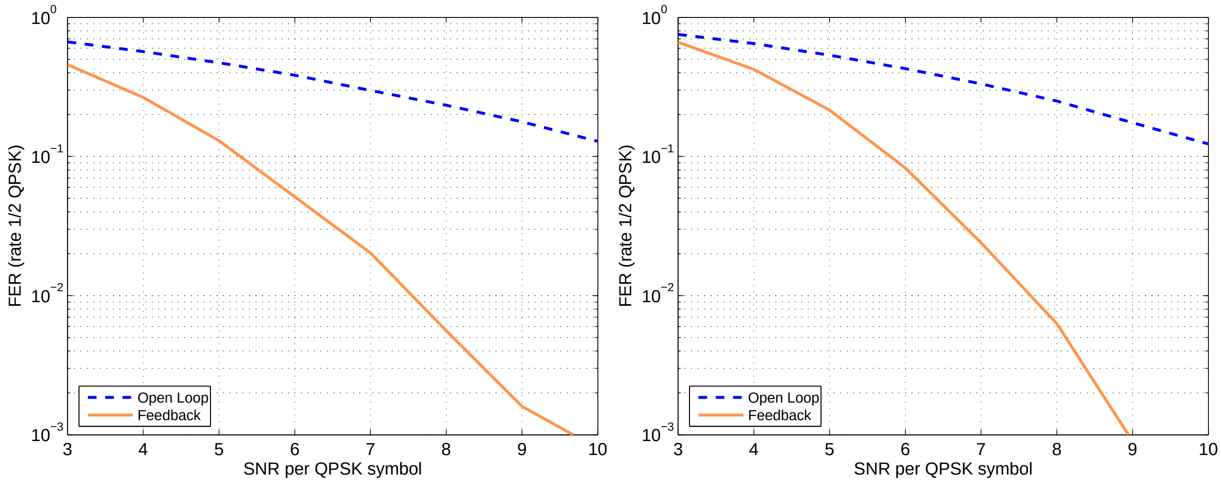

Figure 2. FER results comparing open loop to limited feedback method for four BS antennas and the OIP-B channel (3 km/h). The left plot has three MSS antennas and three data streams and the right plot has four MSS antennas and four data streams.

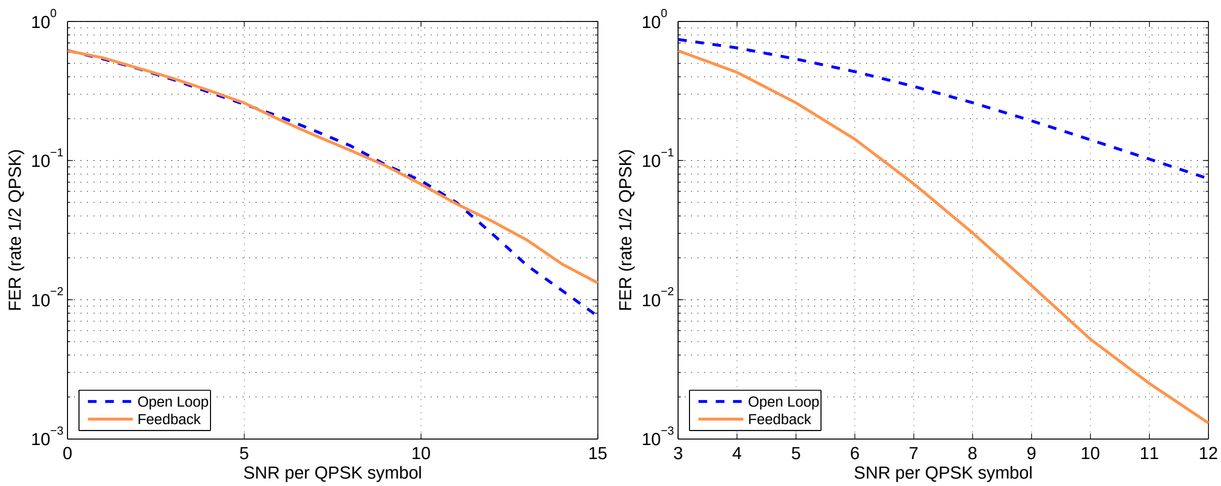

Figure 3. FER results comparing open loop to limited feedback method for four BS antennas and the V-A channel (30 km/h). The left plot has one MSS antenna and one data stream and the right plot has four MSS antennas and four data streams.

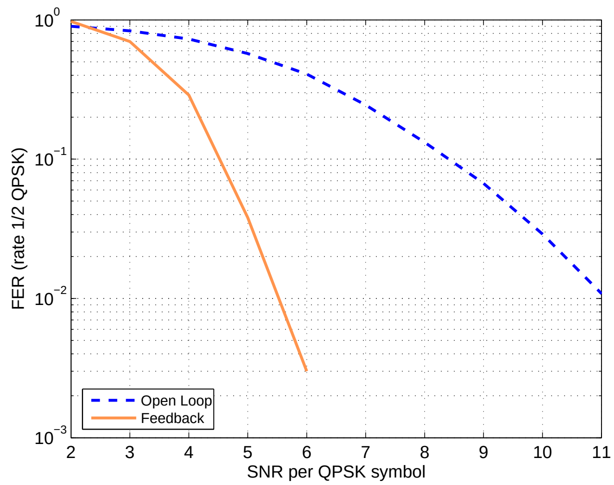

Figure 4. Broadband results comparing open loop to limited feedback method for four BS antennas and the OIP-B channel (3 km/h). There are four data streams and four receive antennas at the mobile.

References

[1] T. A. Thomas and F. W. Vook, "A Method for Improving the Performance of Successive Cancellation in Mobile Spread MIMO OFDM," *Proc. IEEE VTC-2002/Fall*, Vancouver, Canada, September 2002.

[2] D. J. Love, and R. W. Heath Jr., "Grassmannian Beamforming for Multiple-Input Multiple-Output Wireless Systems," *IEEE Transactions on Information Theory*, Vol. 49, No. 10, October 2003.