3GPP TSG-RAN WG1 RAN47-BIS **R1-070168**
Sorrento Italy
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Agenda item: **6.7.2**

Source: **Broadcom Corporation**

Title: **Beamforming Compact Codebook Method and Results in E-UTRA**

Document for: **Discussion**

1. Introduction

E-UTRA based MIMO operations have specified codebook as the method for Beamforming in E-UTRA. Beamforming is performed at the NODE-B via lookup pre-defined codebooks. The Beamforming matrix V is constrained to be unitary.

In this contribution we examine codebook requirements for Beamforming operations in E-UTRA. A compact codebook with good performance is presented.

2. Numerology, Simulation, and Channel Model Assumptions

The simulation assumptions are as follows:

Table 1. Throughput Simulation Parameters for OFDM Downlink

LLS Parameter	Details
Channel Bandwidth	5 MHz.
Sub-Frame Duration	0.5E-3
Sub-Carrier-Spacing	15E3 Hz.
Sampling Frequency (time-domain)	7.68E6
FFT Size	512
Useable Carriers	301
TX/RX Antenna Configuration	2x2 MIMO, 4x2 MIMO
PRB Used (12-Tones / PRB)	6 / 72 Tones (Localized)
Bandwidth Occupied	1.125 MHz.
CP Length (μs/sample) - Short	4.69/36 x6, 5.21/40 x1
Test Geometry (SNR) Throughput Simulations	0,5,10,15,20
TTI – Coded Frame	0.5E-3
DL Modulation	QPSK, 16QAM, 64QAM
Coding	TURBO, R=1/3, Max Block Size = 5114
Code Rates	See Reference [1], Table 3.
INTER-TTI, for HARQ	6
HARQ Processes	6
MCS Feedback Delay	2-TTI
Maximum Retransmissions	4
HARQ	Incremental Redundancy Per-Transmission
Channel Estimation	Ideal
Receiver Structures	PARC-MMSE
Beamforming	SVD-Based
Carrier Frequency	2GHz.

LLS Parameter	Details
Channel Model	ITU-PED 6-Ray Channel
Doppler Frequency	5 Hz.
TX Antenna Correlation Coefficient	0
RX Antenna Correlation Coefficient	0

3. Compact Codebook Design / Operation

To be specific, suppose $\hat{\mathbf{H}}$ is the channel estimation at current time instant, the receiver can form a singular-value-decomposition (SVD) on the channel matrix, i.e.:

$$\hat{\mathbf{H}} = \hat{\mathbf{U}}\hat{\mathbf{\Sigma}}\hat{\mathbf{V}}^H$$

Where $\hat{\mathbf{V}}$ is the right singular vector matrix of the SVD. If the number of transmit antennas is smaller than that of the receive antennas, i.e. $N_{TX} \le N_{RX}$, then $\hat{\mathbf{V}}$ is a square matrix of size N_{TX}-by-$N_{TX.}$

Based on previous channel quantization $\mathbf{V}_{q,0}$ and the current channel information $\hat{\mathbf{V}}$, the new quantized pre-coding matrix can be constructed by the following manner:

$$\mathbf{V}_{q,k} = (1-\alpha^2)^{1/2} \cdot \mathbf{V}_{q,k-1} \cdot Q_{q,k} + \alpha \cdot \mathbf{U}_{q,k-1} \cdot P_{q,k}$$

The Matrices Q_q and P_q are complex unitary rotation matrices chosen from rotation codebooks C_Q and C_P respectively (i.e. $Q_{q,k} \in C_Q$, $P_{q,k} \in C_P$). Parameter α is a scalar value that determines the step size of the orthogonal correction between two consecutive channel updates. For square MIMO systems (i.e. 2x2, 4x4) α is set to zero.

The codebooks C_Q and C_P are indexed with $indx_q_k$ and $indx_p_k$ to indicate the entry in the codebook that is to be used by the NODE-B for Beamforming. The indices $indx_q_k$ and $indx_p_k$ are fed back by the UE for MIMO Beamforming.

The NODE-B uses $Q_{q,k} = C_Q(indx_q_k)$, $P_{q,k} \in C_P(indx_p_k)$ to construct Beamforming Matrix $\mathbf{V}_{q,k}$ where $indxq_k$ and $indxp_k$ are fed back to the NODE-B for Beamforming operations.

The iteration may be started with the following:

$$\mathbf{V}_{q,0} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \mathbf{U}_{q,0} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

The matrix $\mathbf{U}_{q,k-1}$ may constructed vector by vector, the first vector $\mathbf{u}_1$ of $\mathbf{U}_{q,k-1}$ is the first non-zero column vector of matrix $(I - \mathbf{V}_{q,k-1} \cdot \mathbf{V}_{q,k-1}^H)$, normalized to have unit-norm. The next is constructed as the first non-zero column of $(I - \mathbf{V}_{q,k-1} \cdot \mathbf{V}_{q,k-1}^H - \mathbf{u}_1 \cdot \mathbf{u}_1^H)$, again normalized to unit-norm. Mobile and base station perform the same operation.

We examine codebook requirements for 4x2 MIMO systems for the codebook C_P. The matrix P_q is chosen from the codebook C_P. Both C_Q and C_P contain complex unitary rotation matrices.

The proposed channel quantization scheme can be easily extended to other antenna configurations as well.

4. Simulation Results: Compact Codebook 2x2 MIMO

For the 2x2 MIMO Systems, the following operations are performed:

$$\mathbf{V}_{q,k} = \mathbf{V}_{q,k-1} \cdot Q_{q,k} \text{ , where } Q_{q,k} = C_Q\left(indx_q_k\right)$$

We initialize as follows:

$$\mathbf{V}_{q,0} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

For a 2x2 MIMO System we fix the codebook C_Q to a size of 4 elements indexed by $indx_q_k$, thus requiring 2 bit feedback. We assume Feedback at the rate of the HARQ process, and compare the results to the Floating Point Feedback (FLT). The results are shown in Fig. 1.

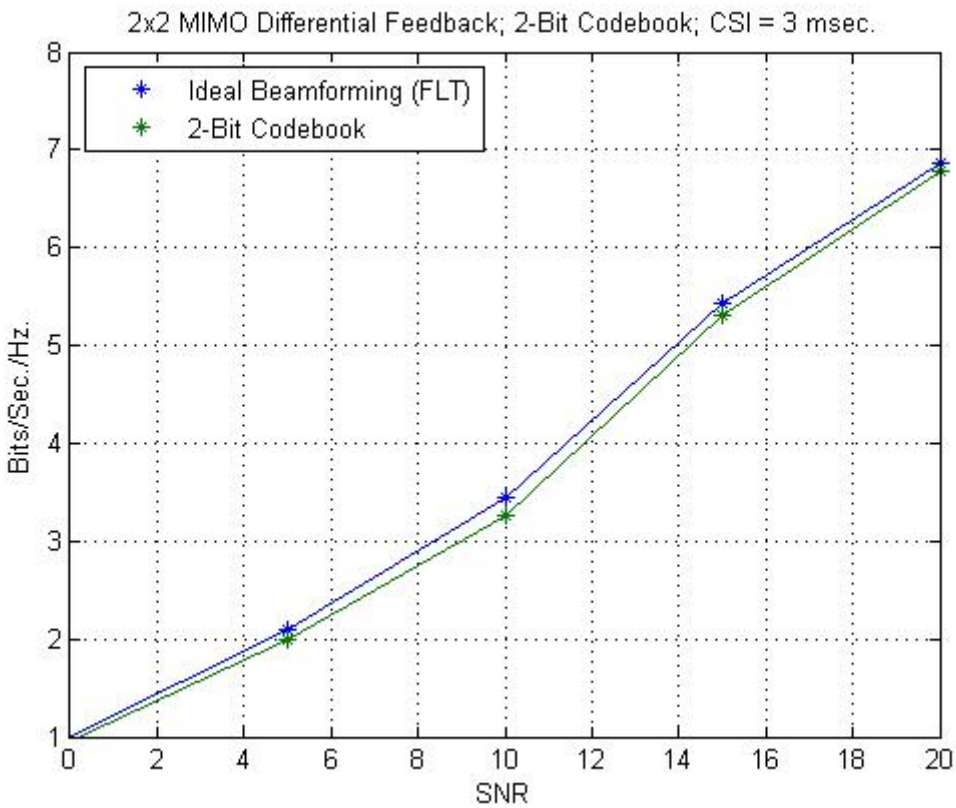

Figure 1: 2x2 Compact Codebook for 2x2 MIMO

5. Simulation Results: Compact Codebook 4x2 MIMO

For the 4x2 MIMO systems, the following operations are performed:

$$\mathbf{V}_{q,k} = (1-\alpha^2)^{1/2} \cdot \mathbf{V}_{q,k-1} \cdot Q_{q,k} + \alpha \cdot \mathbf{U}_{q,k-1} \cdot P_{q,k} \text{ , where } Q_{q,k} = C_Q(indx_q_k),\ P_{q,k} \in C_P(indx_p_k)$$

We initialize as follows:

$$\mathbf{V}_{q,0} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \mathbf{U}_{q,0} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

For a 4x2 MIMO system we fix the codebook C_Q to a size of 4 elements ($indx_q_k$ requires 2-bits for representation). For a 4x2 MIMO system we require the additional codebook C_P indexed by $indx_p_k$ and we simulate performance with 3, 4 and 5 Bit indices. Again, we assume feedback at the rate of the HARQ process, and compare the results to the floating point feedback. The results are shown for C_P codebook sizes of 3, 4, and 5 bits. Together with the codebook C_Q of size 2, we show overall feedback requirement of 5, 6, and 7 bits in Fig. 2.

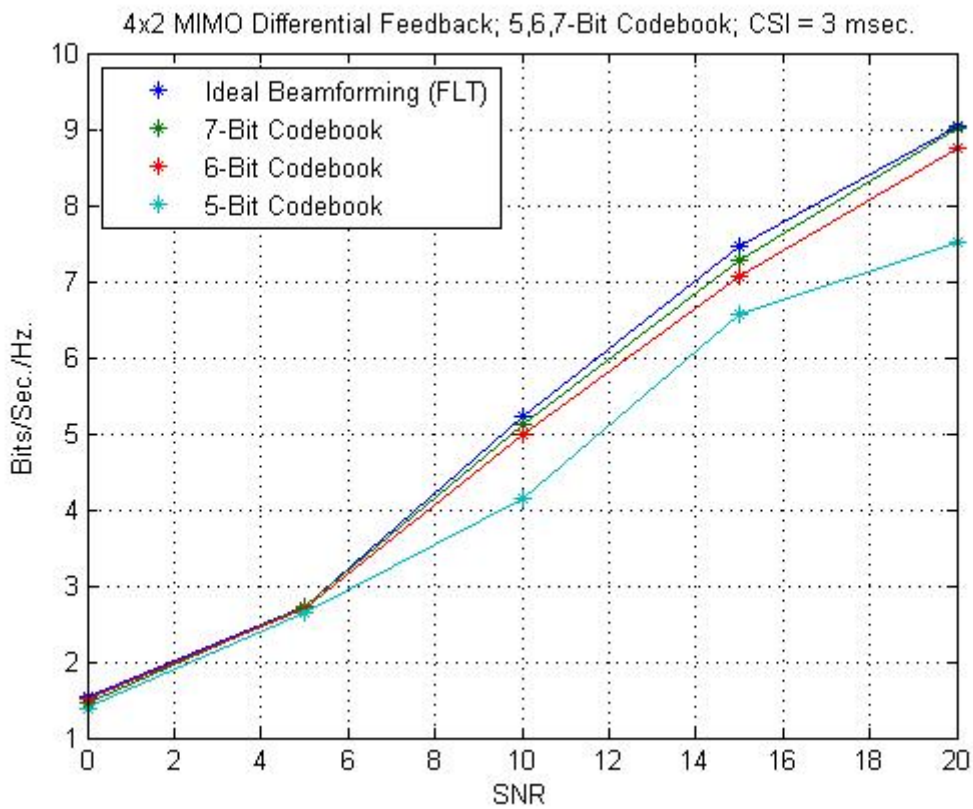

Figure 2: 4x2 Compact Codebook for 4x2 MIMO System

6. Conclusions and Further Discussion

Results for the Compact codebook show that for **2x2 MIMO a codebook of 2-Bits** is sufficient. For **4x2 MIMO a codebook of 6-bits** offers near optimal performance.

In [2] we examine the rate of feedback and granularity in frequency. A codebook for 4x4 MIMO will be presented at the RAN-48 Meeting in February 2007.

7. References

[1] R1-063241 Broadcom – Feedback Reduction with Incremental MCS Set for LTE

[2] R1-070169 Broadcom – Beamforming Frequency and Time Update Requirements in E-UTRA

[3] R1-063058 Motorola – Frequency Domain Adaptive Precoding for E-UTRA

[4] R1-063238 Texas Instruments – Aspects of Codebook-based Pre-coding for E-UTRA MIMO

[5] R1-063154 Freescale Semiconductor – Cluster size for codebook based Precoding in downlink MIMO for EUTRA

[6] R1-063203 NEC Group – On the Precoding codebook design for EUTRA MIMO NEC Group

[7] R1-063311 NTT DoCoMO – Investigations on Pre-coding Schemes for MIMO in E-UTRA Downlink

[8] R1-060458 Intel - Link Analysis of Single and Multi Codeword Schemes - Precoding

[9] R1-061127 Qualcomm - Comparison between Single and Multiple Codewords for Precoded MIMO

[10] R1-063372 NOKIA – Linear Precoding for 2TX Antennas