**3GPP TSG-RAN WG1 RAN49- BIS** **R1-073083**
**Orlando, Florida, USA**
**June 25th – 29th 2007**

**Agenda item:** **5.10.1**

**Source:** **Broadcom Corporation**

**Title:** **Precoding with Polarized Antennas for MIMO in E-UTRA – System Level Analysis**

**Document for:** **Discussion/Decision**

# 1. Introduction

In this contribution we simulate the codebooks proposed for E-UTRA MIMO from the agreed proposals provided over the reflector [5,6]. In addition, we simulate the differential codebook proposed in [1]. We show that the differential codebook performs well for all antenna configurations. We find no significant difference in performance between the codebooks proposed in [5] and [6]. In [6], two codebooks were proposed: one for single-polarization antenna configuration and one for dual-polarization antenna configuration. We also don't find significant difference in throughput performance between the two codebooks proposed in [6] when both are compared assuming single-polarization and dual-polarization antenna configurations. We also present antenna selection results. Differential codebook precoding feedback technique significantly outperforms the 4-bit proposed codebooks in [5] and [6].

Scenarios simulated were as agreed on the reflector and are:

- ULA – Node-B 4 $\lambda$ spacing; UE 0. $\lambda$ spacing
- Polarized Node-B +/-45$^o$; UE Vertical Horizontal (VH)
- Polarized Node-B VH; UE VH

Simulation assumptions are presented in the next section.

# 2. System Simulation Parameters

The system level simulation results presented in this submission are based on the parameters presented in Tables 1 and 2 (OFDMA downlink, 19 cell (hexagonal, 3-tiered) cellular network with wrap-around model). For the precoding gain analysis SVD precoding was used with the agreed codebooks defined over the reflector prior to the RAN49Bis Meeting. In addition, the differential codebook defined in [1], an antenna selection codebook was also simulated. For the differential codebook, 6-bit feedback was assumed. All simulation results were computed for the 4 Node-B transmit antenna configurations. The UE was assumed to have 2 receive antennas.

Table 1. System Level Simulation Parameters (Macro Cell)

| Parameter | Assumption |
|---|---|
| Cellular Layout | Hexagonal grid, 19 cells, 3 sectors per site, Wrap-Around model. |
| Inter-site distance | 500 Meters |
| Traffic Model | Full Buffer |
| Users | 10 Served, Per Drop |
| Distance-dependent path loss | $L=128.1 + 37.6\log_{10}(R)$, R in kilometers |
| Shadowing standard deviation | 8 dB |
| Penetration Loss | 20 dB. |
| Antenna Gain | 14 dB. |
| Antenna pattern [4] (horizontal)<br><br>(For 3-sector cell sites with fixed antenna patterns) | $A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$<br>$\theta_{3dB}$ = 70 degrees, $A_m$ = 20 dB |
| Carrier Frequency / Bandwidth | 2 GHz. |
| Channel model | Typical Urban (TU) MACRO, Statistical Channel Model. |
| UE speed | 3 km/h. |
| Total BS TX power | 46dBm - 10MHz carrier |
| Minimum distance between UE and cell | 35 meters |
| ULA Configuration TX | 4λ for 2 Tx, 4λ for 4 Tx |
| Polarization Model TX | +/- 45 Degrees, Vertical Horizontal |
| Mobile Antenna Configuration RX | 0.5λ spacing |
| Polarization Model RX | Vertical Horizontal |

The EUTRA downlink parameters are captured in the Table 2 below.

Table 2. 10 MHz OFDMA Downlink Parameters

| SLS Parameter | Details |
|---|---|
| Channel Bandwidth | 10 MHz. |
| Sub-Frame Duration | 0.5E-3 |
| Sub-Carrier-Spacing | 15E3 Hz. |
| Sampling Frequency (time-domain) | 15.36E6 |
| FFT Size | 1024 |
| Useable Carriers | 601 |
| Tx/Rx Antenna Configuration | 2x2 MIMO and 4x2 MIMO Configurations |
| Number of RB/Tones Per User | 5 / 60 |
| Bandwidth Occupied | 0.9 MHz / User |
| CP Length (μs/sample) – Short | 4.69/72 x6, 5.21/80 x1 |
| TTI – Coded Frame | 0.5E-3 |
| DL Modulation | QPSK, 16QAM, 64QAM |
| Coding | TURBO-Release6, R=1/3, Max Block Size = 5114 |
| Code Rates | .10762<br>.18286<br>.25810<br>.33333<br>.40857<br>.48381<br>.55905<br>.33333<br>.40857<br>.48381<br>.55905<br>.40857<br>.48381<br>.55905<br>.63429<br>.70952<br>.78476<br>.86000 |
| INTER-TTI, for HARQ | 6 |
| HARQ Processes, MAX RTX | 6, Max of 4 Retransmissions |
| MCS Feedback Delay | 2-TTI |
| HARQ | Incremental Redundancy Per-Transmission |
| Channel Estimation | Ideal |
| Receiver Structures | PARC-MMSE |
| Beamforming | SVD |
| Rank Feedback | SNR Based reduced rank transmission for low SNR users. Low-Rate Feedback. |

# 3. System Level Simulation Results

Simulation results in this section are provided for precoding matrix index (PMI) feedback with granularity of 2 resource blocks (RBs). Channel quality information (CQI) granularity was simulated for both 1 RB and 5 RBs granularity. Uniform feedback method for both CQI and PMI was assumed [4].

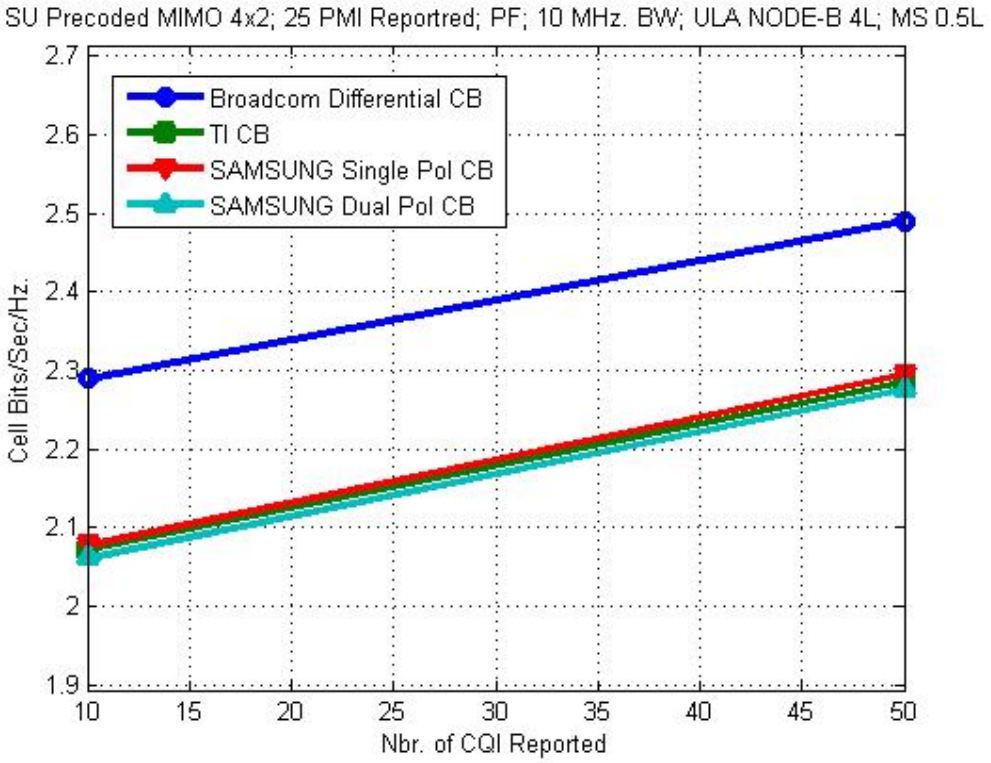


Figure 1. SU-MIMO for 4x2 ULA Throughput Comparisons

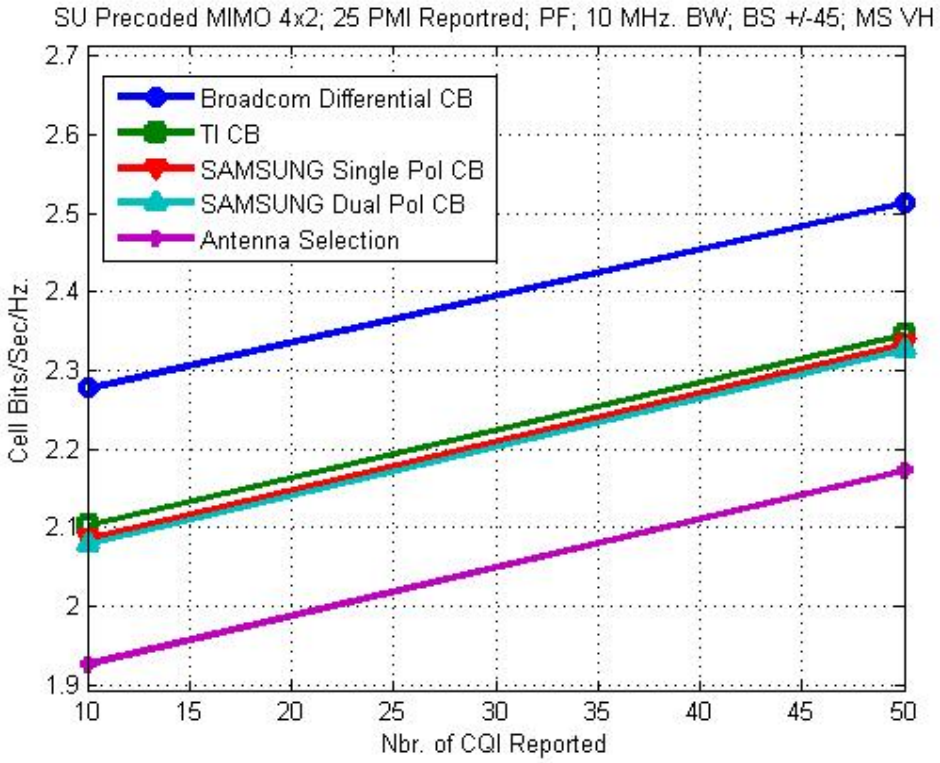


Figure 2. SU-MIMO for 4x2 Polarized Node-B +/-45$^{o}$; UE VH Throughput Comparisons

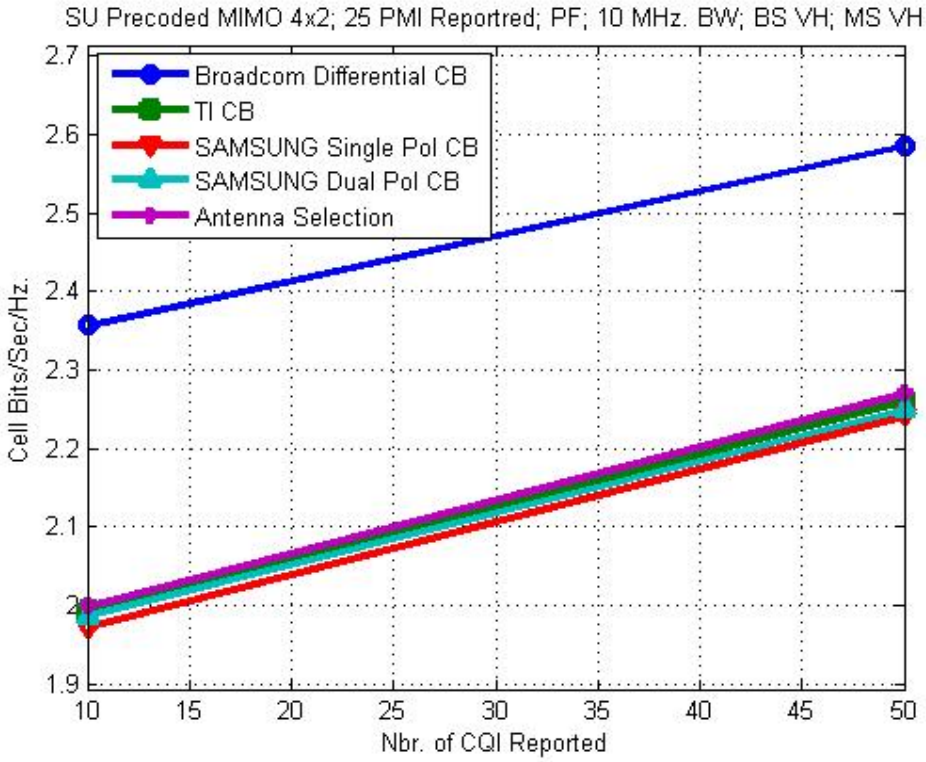


Figure 3. SU-MIMO for 4x2 Polarized Node-B VH; UE VH Throughput Comparisons

From the Figs. 1, 2, and 3 we make the following observations:

- Differential codebook precoding feedback method significantly outperforms 4-bit feedback codebooks proposed in [6].
- There is no significant performance difference between the codebooks proposed in [6].
- There is no significant performance difference between the single-polarization and dual-polarization codebooks proposed in [6].
- For the Node-B VH and UE VH antenna configurations results using the codebooks proposed [6] converge to the antenna selection results. For this antenna configuration case, propagation model favors vertical antennas (less signal attenuation, i.e. path loss) and as a result antenna selection algorithm biases selection towards vertical antennas.
- The Differential codebook further enhances the throughput even for Node-B VH; UE VH scenario where nearly diagonal channels occur, this can not be achieved with the codebooks presented in [6].

In the results presented in this and next sections, differential codebook feedback error propagation was not accounted for since the error propagation can be mitigated using downlink dedicated pilots.

# 4. Cell Edge Performance

Cell edge users suffer when precoding quality (gain) is reduced. This is illustrated in the Figs. 4 and 5 below.

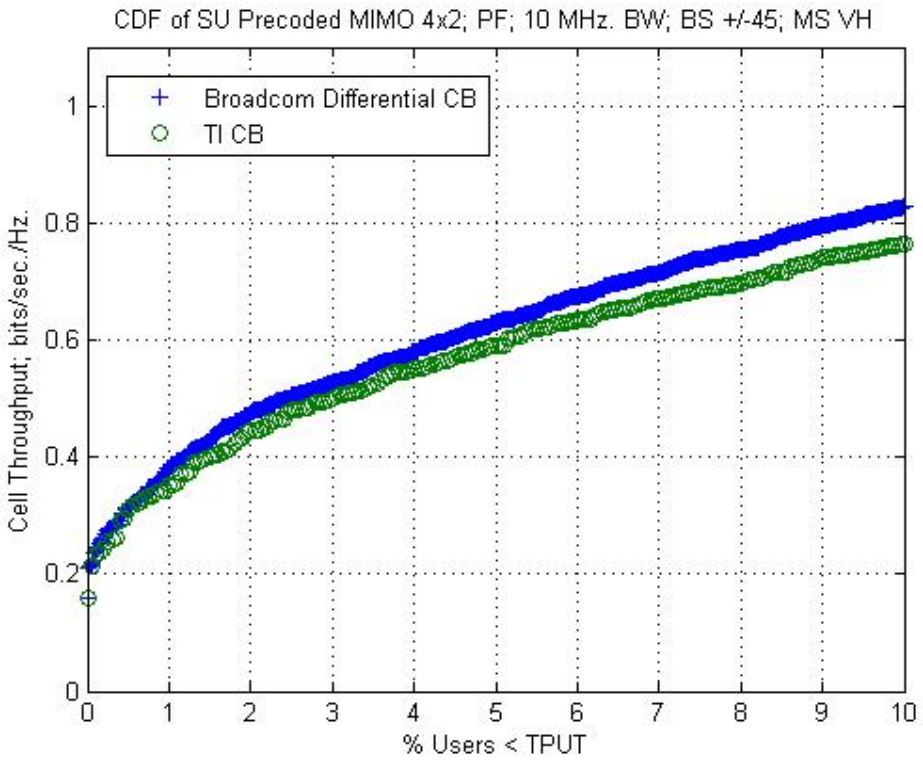


Figure 4. SU-MIMO; 4x2 Polarized Node-B +/-45$^{o}$; UE VH (Cell-Edge Throughput)

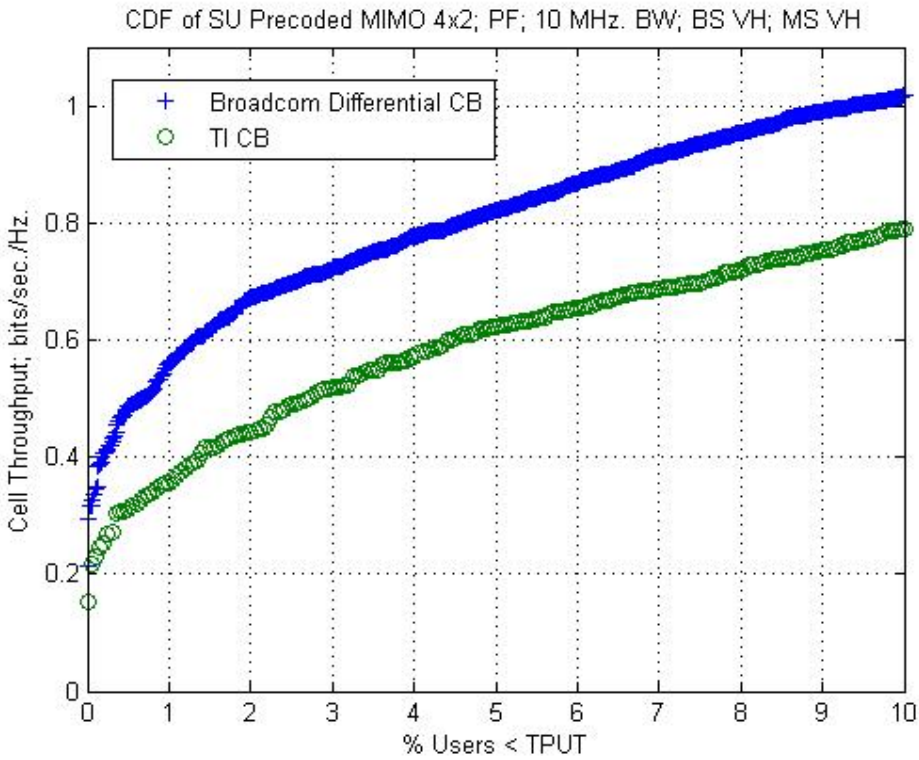


Figure 5. SU-MIMO; 4x2 Polarized Node-B VH; UE VH (Cell-Edge Throughput)

From the Figs. 4 and 5 we make the following observations:

- For the 5% of the cell edge users with the lowest throughput, differential codebook precoding feedback technique can increase throughput by approximately 4% when compared to the codebook presented in [6] (Node-B +/-45 and UE VH antenna configuration).
- For the 5% of the cell edge users with the lowest throughput, differential codebook precoding feedback technique can increase throughput by approximately 30% when compared to the codebook presented in [6] (Node-B VH and UE VH antenna configuration).

# 5. Conclusions

In this presentation we show the following for an SVD based precoding MIMO system with frequency selective scheduling:

- 4-bit feedback codebooks presented in [5] and [6] yield similar system throughput results for ULA and the polarized antenna configurations.
- It may not be necessary to have two different codebooks: one for single-polarization and one for dual-polarization antenna configurations.
- Differential codebook precoding technique adapts to all antenna polarization configurations.
- Cell edge users using differential precoding feedback technique experience up to 30% throughput gain in some polarized conditions when compared to the 4-bit precoding feedback codebooks.

Currently we are investigation a need for the constant modulus differential codebook with respect to the Node-B power amplifier pooling and antenna power imbalance issues discussed recently over the 3GPP-LTE email reflector.

We recommend that 3GPP makes provision for differential codebook method for precoding. The cell throughput enhancement and in particular to cell-edge users further motivates the need to facilitate future use of differential codebooks in EUTRA. The codebook used to generate the results in this contribution is included in the appendix.

# 1. Initialization

At time instant k=0 (or the first channel update), the quantized pre-coding matrix can be initialized as:

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

# 2. Forming Candidate Pre-coding Matrices

Suppose the quantized pre-coding matrix at time instant k-1 (or the (k-1)-th channel update) is $\mathbf{V}_{q,k-1}$, then the candidate pre-coding matrices for the k-th channel update are given by:

$$\mathbf{V}_{q,cand} = \mathbf{V}_{q,k-1} \cdot Q_{q,k}, \qquad Q_{q,k} \in C_q \qquad (2)$$

where the rotation codebook $C_q$ is composed of 4 unitary matrices of size 2x2. The 2-bits scalable rotation codebook $C_q$ can be constructed by the following manner:

$$C_{q=} \left\{ \begin{bmatrix} e^{j\phi} & 0 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix} \;\middle|\; \varphi = \pm\delta \cdot \pi / 2, \quad \phi = \pm\delta \cdot \pi \right\} \qquad (3)$$

where $0 < \delta < 1$ is a small scalar controlling dynamic range of the codebook. A recommended $\delta$ value can be 0.05.

# 3. Finding the Best Pre-coding Matrices

The best coding matrix for time instant k (or the k-th channel update) can be chosen to maximize a certain metric. It can be any reasonable performance metric, i.e. minimizes the MSE, or maximizes the system SINR, etc. In our simulation, $\mathbf{V}_{q,k}$ is chosen based on the following inner-product distance metric, i.e.

$$\mathbf{V}_{q,k} = \arg \max_{\mathbf{V}_{q,cand}} f(\mathbf{V}^H \cdot \mathbf{V}_{q,cand}), \qquad (4)$$

where the metric function $f(\mathbf{A})$ is given by:

$$f(\mathbf{A}) = \left( \frac{1}{N_{RX}} \sum_{j=1}^{N_{RX}} \left| a_{j,j} \right|^2 \right) \qquad (5)$$

where $a_{i,j}$ is the $(i, j)^{th}$ element of matrix $\mathbf{A}$.

# 1. Initialization

At time instant k=0 (or the first channel update), the quantized pre-coding matrix can be initialized as:

$$\mathbf{V}_{q,0} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \qquad (6)$$

# 2. Constructing the Codebooks

For the case of 4x2 MIMO, two codebooks are required to perform the proposed delta quantization scheme. The first codebook $C_q$ is composed of 4 unitary matrices of size 2x2. It is used for rotational corrections and can be constructed by equation (3) in Appendix A. The recommended step size of the dynamic range of $C_q$ used in a 4x2 MIMO system is 0.08. The second codebook $C_p$ is composed of 16 unitary matrices of size 2x2. It is used for orthogonal corrections and its elements are listed in the following table.

Table 3. 10 Elements of the Codebook

| **Element of the codebook** | |
|---|---|
| $P_0$ | [ -0.5041 - 0.8122i, 0.2434 + 0.1644i ;<br>0.0350 + 0.2916i, 0.4920 + 0.8196i ] |
| $P_1$ | [ 0.3763 - 0.1075i, -0.6578 + 0.6436i ;<br>-0.8922 + 0.2256i, -0.2880 + 0.2650i ] |
| $P_2$ | [ 0.0454 + 0.0092i, 0.9954 + 0.0843i ;<br>-0.8490 - 0.5264i, 0.0419 + 0.0197i ] |
| $P_3$ | [ -0.2780 - 0.1329i, -0.6620 - 0.6832i ;<br>-0.2810 - 0.9089i, -0.0171 + 0.3077i ] |
| $P_4$ | [ -0.1195 + 0.6548i, 0.1514 - 0.7308i ;<br>-0.3359 + 0.6664i, -0.3137 + 0.5871i ] |
| $P_5$ | [ 0.5573 + 0.7920i, -0.2152 - 0.1262i ;<br>-0.0429 - 0.2458i, -0.5468 - 0.7993i ] |
| $P_6$ | [ 0.9578 + 0.2015i, -0.0811 - 0.1884i ;<br>0.1587 - 0.1300i, 0.9431 + 0.2617i ] |
| $P_7$ | [ -0.4000 + 0.1014i, 0.5556 - 0.7218i ;<br>0.8800 - 0.2350i, 0.2476 - 0.3302i ] |
| $P_8$ | [ 0.0663 - 0.6760i, -0.0376 + 0.7329i ;<br>0.2996 - 0.6700i, 0.2481 - 0.6323i ] |
| $P_9$ | [ 0.7115 - 0.5784i, 0.2690 - 0.2947i ;<br>0.3719 - 0.1446i, -0.7961 + 0.4550i ] |
| $P_{10}$ | [ 0.0211 - 0.0893i, -0.9910 + 0.0977i ;<br>0.8659 + 0.4918i, -0.0170 + 0.0901i ] |
| $P_{11}$ | [ 0.3354 + 0.1343i, 0.6608 + 0.6579i ; |

| Element of the codebook | |
|---|---|
| | 0.2108 + 0.9083i, 0.0627 - 0.3558i ] |
| $P_{12}$ | [ -0.1481 + 0.7067i, 0.1517 + 0.6750i ;<br>0.4936 - 0.4848i, -0.2590 + 0.6740i ] |
| $P_{13}$ | [ -0.6976 + 0.6295i, -0.2491 + 0.2344i ;<br>-0.3308 + 0.0872i, 0.9034 - 0.2584i ] |
| $P_{14}$ | [ -0.9614 - 0.1990i, 0.0047 + 0.1902i ;<br>-0.1095 + 0.1556i, -0.9100 - 0.3683i ] |
| $P_{15}$ | [ 0.1653 - 0.6998i, -0.1306 - 0.6825i ;<br>-0.4276 + 0.5477i, 0.1722 - 0.6982i ] |

# 3. Forming Candidate Pre-coding Matrices

Suppose the quantized pre-coding matrix at time instant k-1 (or the (k-1)-th channel update) is $\mathbf{V}_{q,k-1}$, then the candidate pre-coding matrices for the k-th channel update are given by:

$$\mathbf{V}_{q,cand} = (1-\alpha^2)^{1/2} \cdot \mathbf{V}_{q,k-1} \cdot Q_{q,k} + \alpha \cdot \mathbf{U}_{q,k-1} \cdot P_{q,k}, \qquad Q_{q,k} \in C_q, \qquad P_{q,k} \in C_p, \qquad (7)$$

where $\alpha$ $(0 \le \alpha \le 1)$ is the step size of the orthogonal correction (a recommended $\alpha$ value is 0.25), and $\mathbf{U}_{q,k-1}$ is the orthornomal complement matrix of $\mathbf{V}_{q,k-1}$. It is constructed by the following manner: 1) The first column 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; 2) The $2nd$ column vector $\mathbf{u}_2$ of $\mathbf{U}_{q,k-1}$ is the first non-zero column vector of matrix $(I - \mathbf{V}_{q,k-1} \cdot \mathbf{V}_{q,k-1}^H - \mathbf{u}_1 \cdot \mathbf{u}_1^H)$, normalized to unit-norm; 3) Matrix $\mathbf{U}_{q,k-1}$ is of size 4x2 and can be represented as $\mathbf{U}_{q,k-1} = [\mathbf{u}_1 \quad \mathbf{u}_2]$. According to equation (7), there are total 64 candidate pre-coding matrices (corresponds to 6 feedback bits), and the best pre-coding matrix is chosen by the following quantization process.

# 6. Finding the Best Pre-coding Matrices

Similar to the case of 2x2 MIMO, The best coding matrix for time instant k (or the k-th channel update) can be chosen to maximize a certain metric. It can be any reasonable performance metric, i.e. minimizes the MSE, or maximizes the system SINR, etc. In our simulation, $\mathbf{V}_{q,k}$ is chosen based on the following inner-product distance metric, i.e.:

$$\mathbf{V}_{q,k} = \arg \max_{\mathbf{V}_{q,cand}} f(\mathbf{V}^H \cdot \mathbf{V}_{q,cand}), \qquad (8)$$

where the metric function $f(\mathbf{A})$ is given by equation (5).

For the proposed pre-coding matrix construction method, $\mathbf{V}_{q,k}$ is guaranteed to be an orthonormal column matrix, i.e. $\mathbf{V}_{q,k}{}^H \mathbf{V}_{q,k} = I_2$. However, due to the quantization effects of fixed-point computation in practical implementations,

$\mathbf{V}_{q,k}$ is recommended to be periodically re-normalized. The re-normalization can be a standard Gram-Schmitz algorithm, i.e. replacing the second column of matrix $\mathbf{V}_{q,k} = [\mathbf{v}_1, \mathbf{v}_2]$ by the following equation:

$$\mathbf{v}_2^{'} = \left(\mathbf{v}_2 - (\mathbf{v}_1^{H}\mathbf{v}_2)\cdot\mathbf{v}_2\right) \Big/ \left\|\mathbf{v}_2 - (\mathbf{v}_1^{H}\mathbf{v}_2)\cdot\mathbf{v}_2\right\| \qquad (9).$$

Hence, the new pre-coding matrix is $\mathbf{V}_{q,k} = [\mathbf{v}_1, \mathbf{v}_2^{'}]$.

# 7. References


[1] R1-070168 Broadcom – Beamforming Compact Codebook Method and Results in E-UTRA

[2] R1-071188 Broadcom – Compact Codebook for Unitary Precoding MIMO with Support for Rank Reduction

[3] R1-072407 Broadcom – CQI and Precoding Granularity Feedback Requirements - System Level Analysis

[4] R1-073082 Broadcom - Uniform Precoding and CQI Best-M: A Hybrid Efficient and Scalable Feedback Method for E-UTRA - System Level Analysis

[5] R1-062650 Texas Instruments - Codebook Design for E-UTRA MIMO Pre-coding

[6] (1) Samsung E-mail dated Mon 6/18/07 8:30 AM (Samsung revised codebooks for Orlando); (2) TI E-mail dated Mon 6/18/07 9:04 AM (R1-07xxx Joint CHHH v2.doc)

[7] R1-070936 Panasonic - MIMO Codebook Design for MU/SU-MIMO

[8] R1-070658 Qualcomm – UE Feedback with Precoding Granularity – System Analysis