

St. Louis**Meeting Date: February 12th – February 16th 2007****Agenda item: 6.7.1****Source: Broadcom Corporation****Title: Compact Codebook for Unitary Precoding MIMO w/Support for Rank Reduction****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 precoding 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. Simulation results are presented for 2x2, 4x2, and 4x4 systems. Codebook for each system is rank independent, i.e. reduced rank operation is supported by a subset of columns of the full-rank precoding matrix V .

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 (μ s/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.
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. $N_{TX} \leq N_{RX}$, 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 precoding matrix can be constructed by the following manner:

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

The Matrices \mathbf{Q}_q and \mathbf{P}_q are complex unitary rotation matrices chosen from rotation codebooks C_Q and C_P respectively (i.e. $\mathbf{Q}_{q,k} \in C_Q$, $\mathbf{P}_{q,k} \in C_P$). 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 $\mathbf{Q}_{q,k} = C_Q(indx_q_k)$, $\mathbf{P}_{q,k} \in C_P(indx_p_k)$ to construct precoding matrix $\mathbf{V}_{q,k}$ where $indx_q_k$ and $indx_p_k$ 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 $(\mathbf{I} - \mathbf{V}_{q,k-1} \cdot \mathbf{V}_{q,k-1}^H)$, normalized to have unit-norm. The next is constructed as the first non-zero column of $(\mathbf{I} - \mathbf{V}_{q,k-1} \cdot \mathbf{V}_{q,k-1}^H - \mathbf{u}_1 \cdot \mathbf{u}_1^H)$, 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 \mathbf{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:

$$\mathbf{V}_{q,k} = \mathbf{V}_{q,k-1} \cdot \mathbf{Q}_{q,k}, \text{ where } \mathbf{Q}_{q,k} = C_Q(\text{indx}_{-}q_k)$$

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 $\text{indx}_{-}q_k$, thus requiring 2 bit feedback. We assume feedback at the rate of the HARQ process, and compare the results of the 2-Bit Codebook (CB) to the ideal case (Floating Point Feedback (FLT)). The results are shown in Fig. 1.

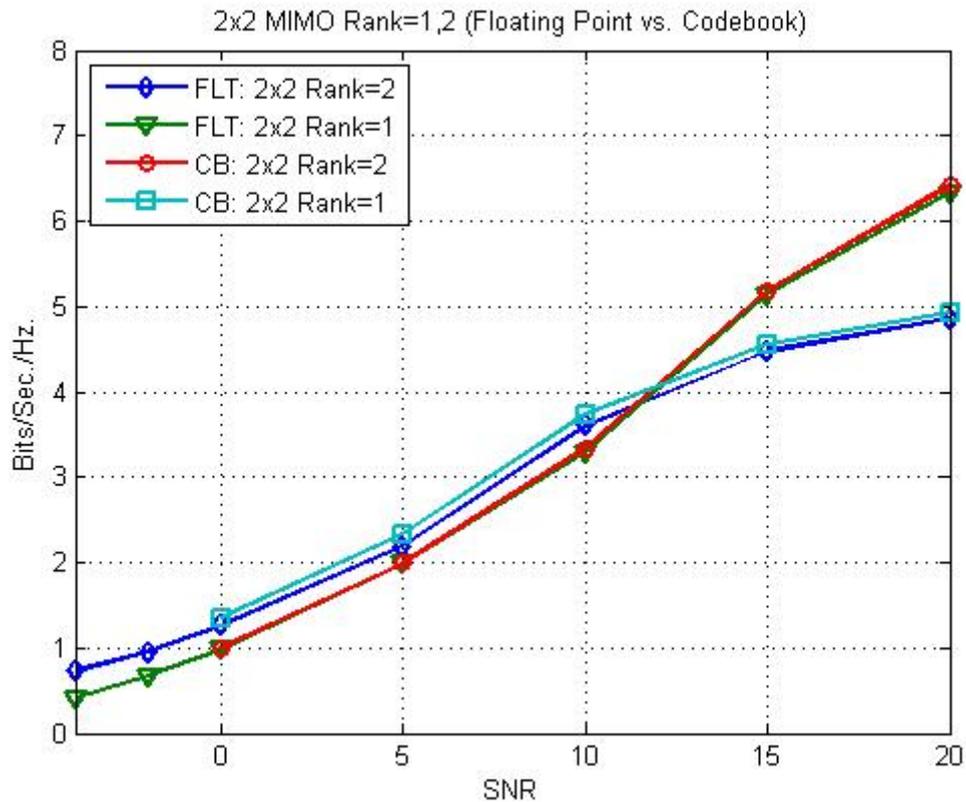


Figure 1: 2x2 Compact Codebook for 2x2 MIMO

For Rank=1 system the precoding vector is defined as the 1st column of matrix $\mathbf{V}_{q,k}$.

5. Simulation Results: Compact Codebook 4x2 MIMO

For the 4x2 MIMO systems, the following operations are performed to define the compact codebook:

$$\mathbf{V}_{q,k} = (1 - \alpha^2)^{1/2} \cdot \mathbf{V}_{q,k-1} \cdot \mathbf{Q}_{q,k} + \alpha \cdot \mathbf{U}_{q,k-1} \cdot \mathbf{P}_{q,k}, \text{ where } \mathbf{Q}_{q,k} = C_Q(\text{indx}_{-q_k}), \mathbf{P}_{q,k} \in C_P(\text{indx}_{-p_k})$$

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 4 Bit indices. Again, we assume feedback at the rate of the HARQ process, and compare the results to the floating point feedback. Together with the codebook C_Q of size 2, the overall feedback requirement is 6 bits and the simulation results are shown in Fig. 2.

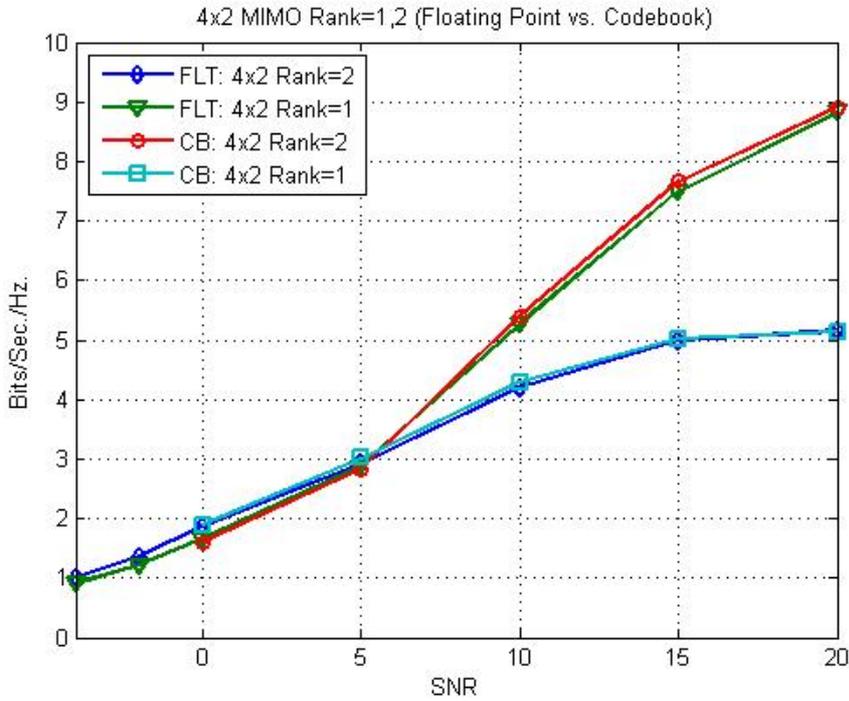


Figure 2: 4x2 Compact Codebook for 4x2 MIMO System

6. Simulation Results: Compact Codebook 4x4 MIMO

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

$$\mathbf{V}_{q,k} = \mathbf{V}_{q,k-1} \cdot \mathbf{Q}_{q,k}, \text{ where } \mathbf{Q}_{q,k} = C_Q(\text{indx}_{-}q_k)$$

We initialize as follows:

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

For a 4x4 MIMO system we fix the codebook C_Q to a size of 256 elements indexed by $\text{indx}_{q,k}$, thus requiring 8 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. 3 for floating point feedback and Fig. 4 for 8-Bit Codebook feedback with rank=1,2,3, and 4.

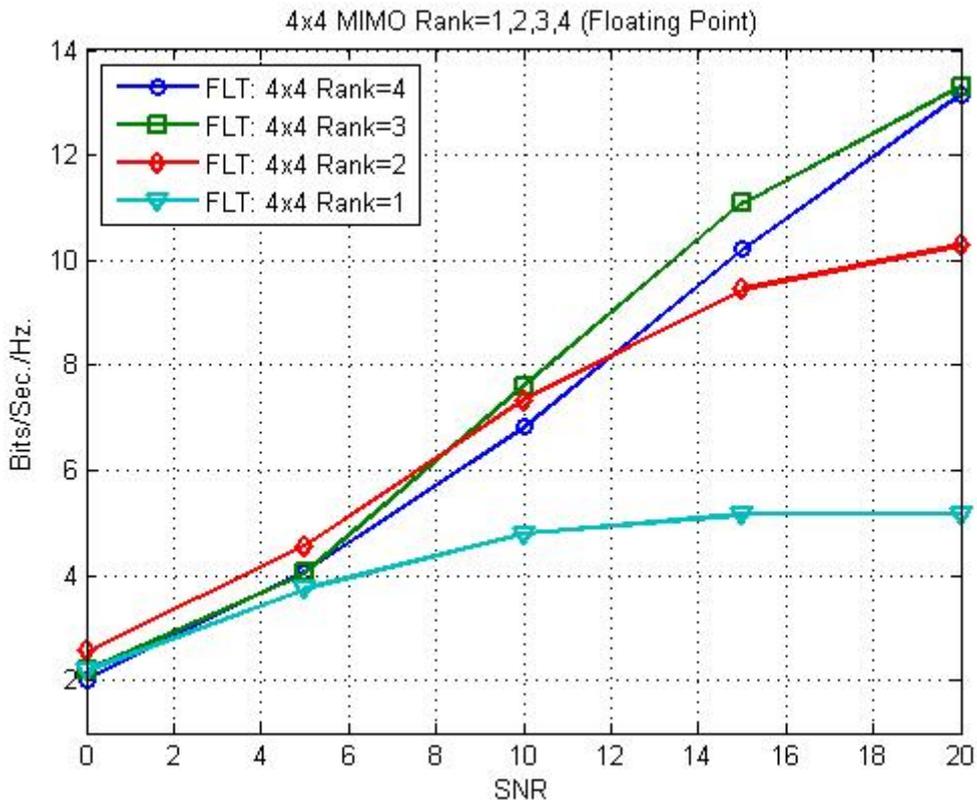


Figure 3: 4x4 Floating Point Feedback for 4x4 MIMO

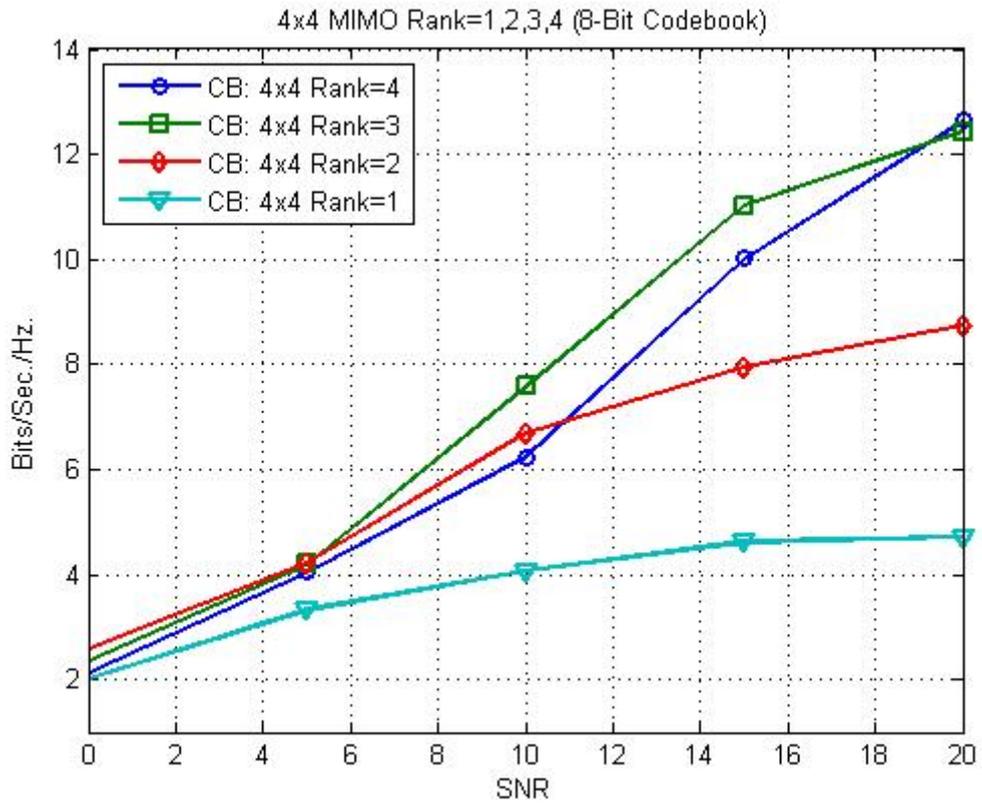


Figure 4: 4x4 Compact Codebook for 4x4 MIMO

7. Appendix (Rank Reduction Capacity Formulation)

As a theoretical justification of the throughput results provided in previous sections, we provide in this section the ideal throughput curves for 2x2, 4x2, and 4x4 MIMO systems with different ranks.

With equal power allocations on the active spatial streams, the system throughput is given by the following equation (with perfect CSI at the transmitter):

$$\bar{C} = E_H \left[\sum_{i=1}^{\text{rank}} \log_2 (1 + \text{SNR} \cdot \lambda_i / \text{rank}) \right]$$

where λ_i is the i^{th} largest eigen-value of matrix product $(H^H \cdot H)$, and \bar{C} is the capacity in Bits/Sec/Hz and E_H denotes average over different channel realizations.

The simulations provided below are performed by using an i.i.d. Rayleigh fading channel model, where each element of the H matrix has i.i.d. complex Gaussian distribution with zero mean and unit variance. Figure 5 represents the ideal throughput for 2x2 MIMO system with rank=1 and 2; Fig. 6 demonstrates the ideal throughput curves for 4x2 MIMO system with rank=1 and 2; and Fig. 7 is for 4x4 MIMO system with rank=1,2,3 and 4.

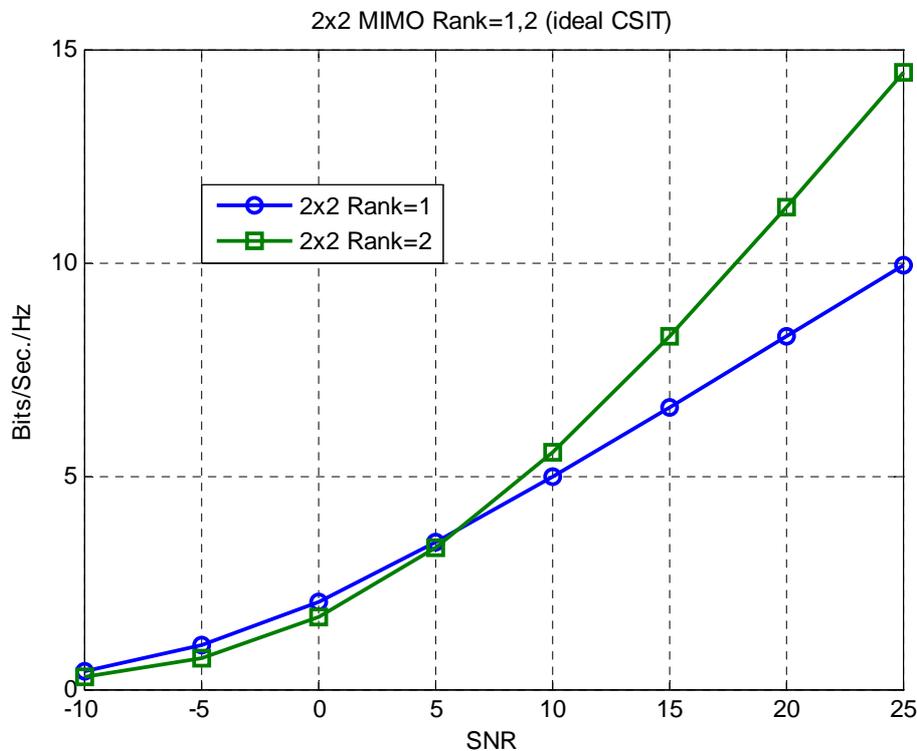


Figure 5: Ideal Throughput Performance for 2x2 MIMO System

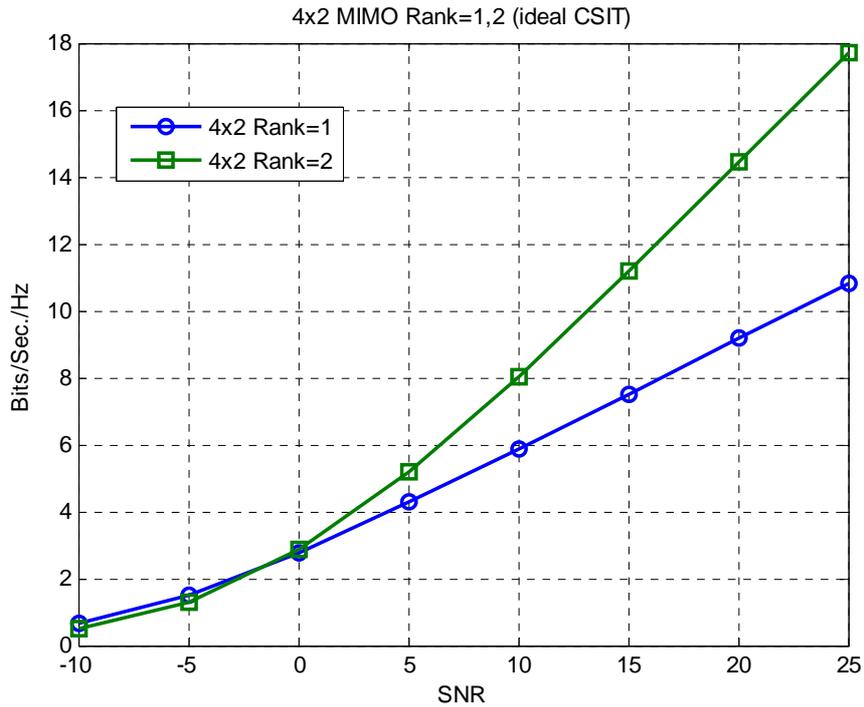


Figure 6: Ideal Throughput Performance for 4x2 MIMO System

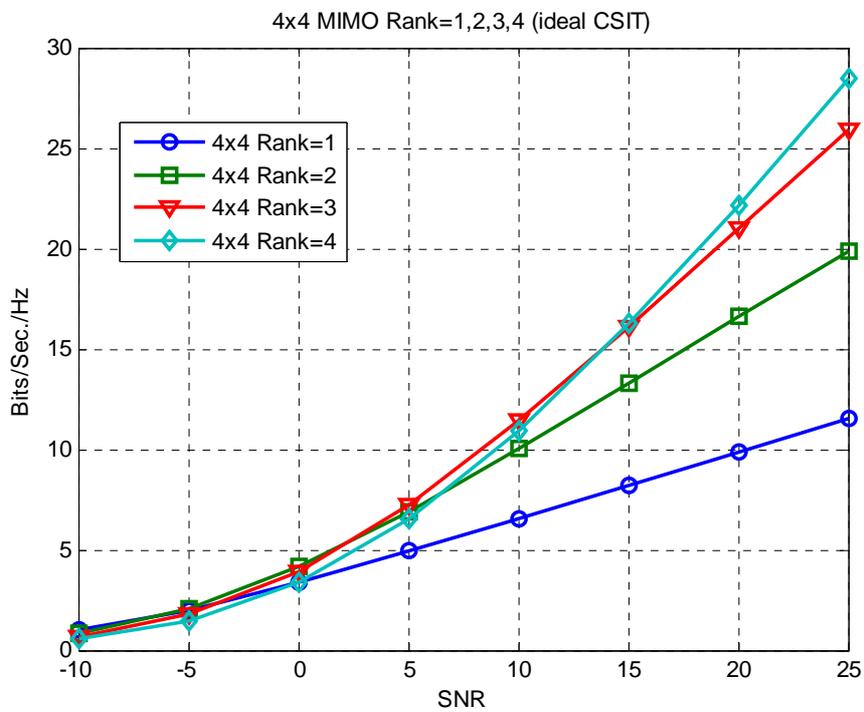


Figure 7: Ideal Throughput Performance for 4x4 MIMO System

8. Conclusions and Further Discussion

In this submission we present rank independent codebooks that yield good performance with low feedback requirement. In all cases results show that nearly ideal performance can be achieved with low overhead.

For 4x4 MIMO system, simulation results indicate that operation other than Rank=2 and 3 may not be required. For 2x2 MIMO system throughput results show that both Rank=1 and Rank=2 operation may be required. Precoding gain beyond 20 dB SNR is diminished (levels off). Precoding gain for Rank=4 systems beyond 20 dB may demand an increased feedback requirement, i.e. finer resolution Codebook, that may not be warranted.

9. References

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- [3] R1-063241 Broadcom – Feedback Reduction with Incremental MCS Set for LTE
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- [7] R1-063203 NEC Group – On the Precoding codebook design for EUTRA MIMO NEC Group
- [8] R1-063311 NTT DoCoMo – Investigations on Precoding Schemes for MIMO in E-UTRA Downlink
- [9] R1-060458 Intel - Link Analysis of Single and Multi Codeword Schemes - Precoding
- [10] R1-061127 Qualcomm - Comparison between Single and Multiple Codewords for Precoded MIMO
- [11] R1-063372 NOKIA – Linear Precoding for 2TX Antennas