

**Agenda item:** 5.10.1  
**Source:** Broadcom Corporation  
**Title:** Uniform Precoding and CQI Best-M – A Hybrid Efficient and Scalable Feedback Method for E-URTRA – System Level Analysis  
**Document for:** Discussion/Decision

## 1 Introduction

In this contribution we introduce a UE – Node-B closed-loop FB (feedback) method that combines the reporting of both CQI and the PMI (precoding matrix index) into a scalable, “hybrid”, feedback system. While Uplink penalty versus the added throughput gain to E-UTRA has been extensively discussed, less emphasis has been put on the scalability of the FB method used. Nevertheless, it is clear to all that the scalability of the method is a vital element in providing a diversified range of applications and, consequently, a rich scope of services.

With these three elements in mind (Uplink penalty, throughput-gain and scalability), we show that indeed the network may control the UE throughput by controlling the granularity of the PMI x CQI grid, a depiction of such is shown in figure 1:

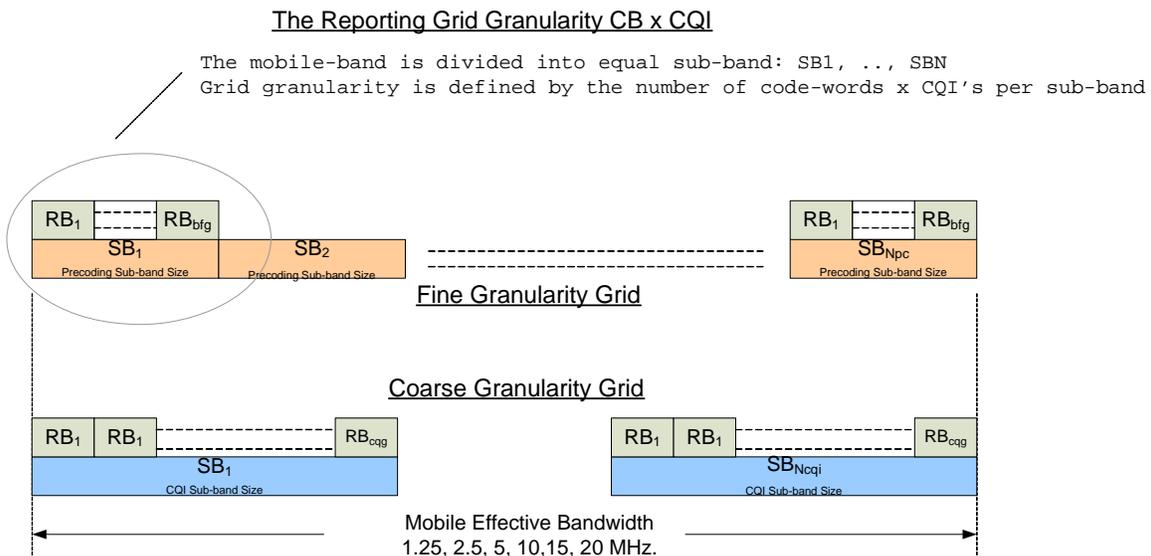


Figure 1 Scalable “Hybrid” Feedback Grid for Precoding and CQI Feedback

In particular, we have found that a FB method that combines a uniform PMI with best-M CQI has certain advantages. A typical scenario is shown the figure 2. The network is informed of the best M for each UE. It therefore may (but does not have to) assign a UE its best RB's. Having a grid of Uniform PMI feedback over the entire BW facilitates high spectral efficiency for that particular UE. This degree of freedom (choosing who has priority to its best-M CQI) enables the network to differentiate between users in a variety of scenarios, such as service requirements, total user load or outage. As stated before, more than one FB grid of (PMI x CQI) may further enhance the network throughput.

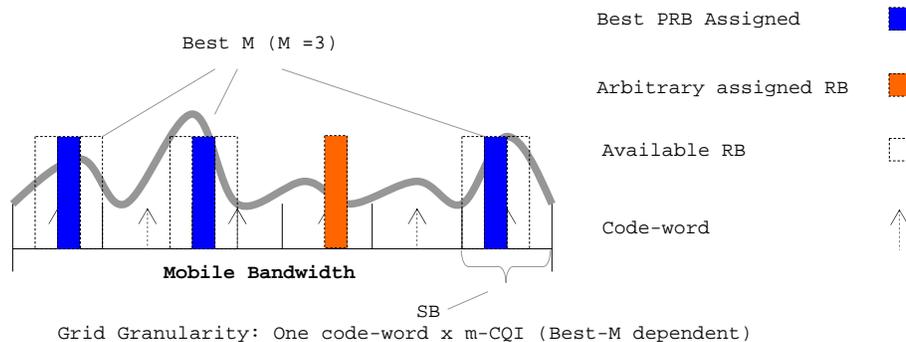


Figure 2 Uniform PMI with Best-M Feedback

Note that the Best-M CQI reporting technique is suggested by several companies; for example, [1], [2] and [3].

In Section 2 we describe the system-level simulation. In sections 3 and 4, using system level simulations, we analyze both 2x2 and 4x2 (4 transmit antennas) multiple-input multiple-output (MIMO) system configurations. We show, assuming SVD based precoding with Uniform CQI and PMI feedback, that there is a considerable gain to be achieved in the case when fine granularity in both CQI and PMI are used. Further, the results show the effect of fine granularity in either space CQI for frequency selective scheduling gain, and PMI for precoding gain with MIMO systems.

In Section 5 we apply the concept of hybrid FB to differential coding schemes (detailed in [5] and [6]) that demonstrates low Uplink load with substantial gain.

## 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 differential codebook feedback for both 2x2 and 4x2 MIMO Systems.

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) (For 3-sector cell sites with fixed antenna patterns)	$A(\theta) = -\min \left[ 12 \left( \frac{\theta}{\theta_{3dB}} \right)^2, A_m \right]$ $\theta_{3dB} = 70 \text{ degrees}, A_m = 20 \text{ dB}$
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	$4\lambda$ for 2 Tx, $4\lambda$ for 4 Tx
Mobile Antenna Configuration RX	$0.5\lambda$ spacing

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 ( $\mu$ s/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 .18286 .25810 .33333 .40857 .48381 .55905 .33333 .40857 .48381 .55905 .40857 .48381 .55905 .63429 .70952 .78476 .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 (Uniform CQI and PMI Feedback)

In this section we present results for the uniform linear array (ULA) transmit antennas with  $4\lambda$  spacing and 2x2 and 4x2 single user (SU) MIMO configurations. Results for a Uniform Grid of CQI & PMI are simulated for granularities (i.e. Subband size in units of RB) of 1, 2, and 5. With these granularities 50, 25, and 10 CQI are reported for the same grid of PMI.

Figure 3 below shows 2x2 MIMO system results for the 2-bit differential codebook (CB) presented in [5], [6]. The results show that gain results with increased feedback for both CQI and PMI.

Figure 4 shows 4x2 MIMO system results for the 6-bit differential codebook presented in [5], and [6].

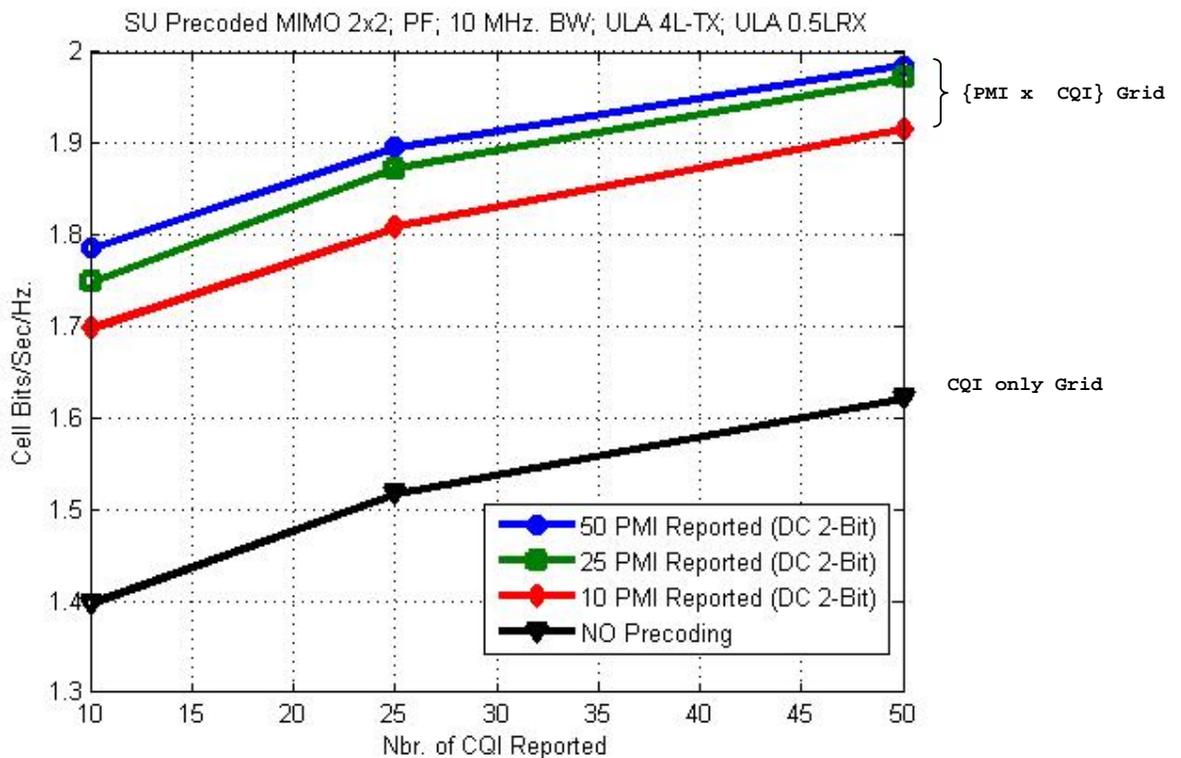


Figure 3. SU MIMO 2x2 System Cell Spectral Efficiency for Uniform {PMI x CQI}

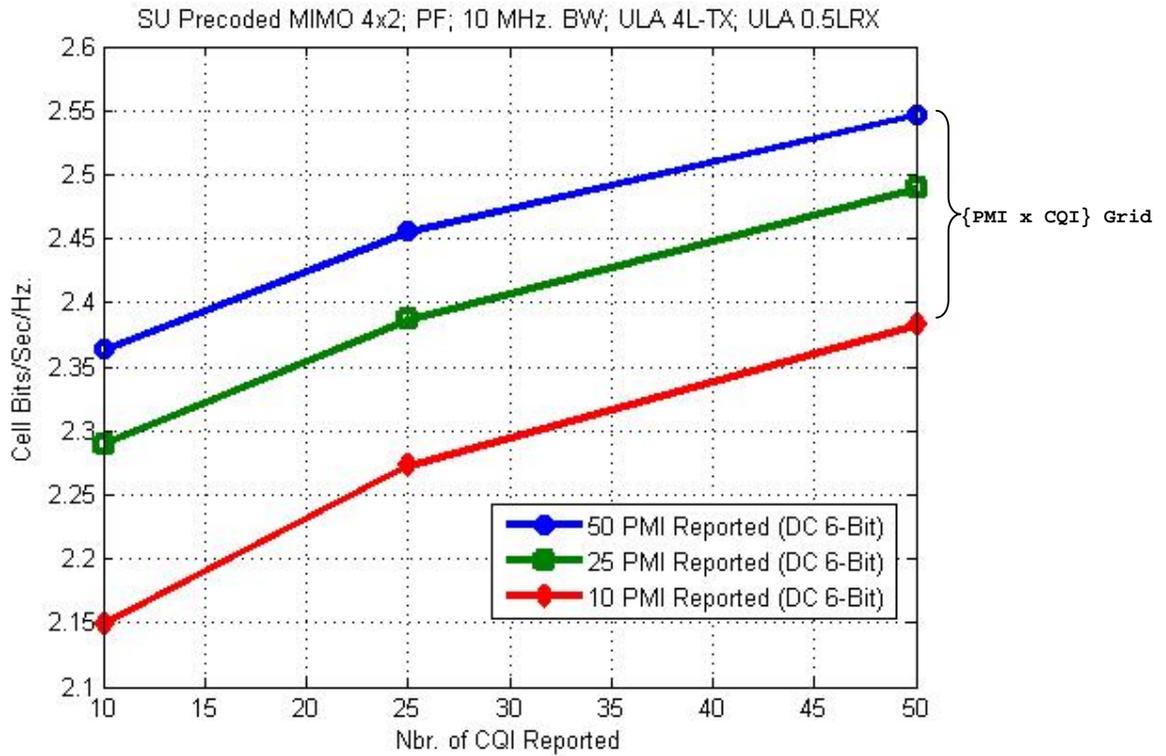


Figure 4. SU MIMO 4x2 System Cell Spectral Efficiency for Uniform {PMI x CQI}

From the Figs. 3 and 4 we make the following two observations:

- Finer granularity of the FB grid {CQI x PMI} feedback yield considerable gains when compared to the coarse granularity FB
- Throughput gain can be observed for the highest density of CQI feedback for both 2x2 and 4x2 MIMO

In the results, differential codebook feedback error propagation was not accounted for since the error propagation can be mitigated using downlink dedicated pilots.

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## 4 Feedback Calculation

Feedback requirement ( $FBu$ ), in bits, for Uniform<sup>1</sup> CQI and PMI is a function of both CQI granularity and precoding granularity, and may be expressed as follows:

$$FBu = N_{cqi\_rep} \cdot (2 \cdot Nb_{cqi}) + N_{pc\_rep} \cdot (Nb_{pc}) \quad \text{Eq(1)}$$

Where  $N_{cqi\_rep}$  is the number of reported CQIs and  $N_{pc\_rep}$  is the number of reported PMIs.  $Nb_{cqi}$  and  $Nb_{pc}$  are the number of required bits for CQI and precoding feedback (codebook), respectively.

Feedback requirement ( $FBm$ ) for Best-M CQI and Uniform PMI is a function of CQI granularity, sub-band (multiple RBs) location, precoding granularity, and may be expressed as follows:

$$FBm = N_{cqi\_rep} \cdot (2 \cdot Nb_{cqi} + Nb_{rb\_loc}) + N_{pc\_rep} \cdot (Nb_{pc}) + 2 \cdot Nb_{cqi\_ave} \quad \text{Eq(2)}$$

Where  $Nb_{rb\_loc}$  is the number of bits required to feedback sub-band location information, and  $Nb_{cqi\_ave}$  is the number of bits required to feedback average CQI, see Sec. 5 (same number of bits as  $Nb_{cqi}$ ).

Each Best-M CQI can represent multiple RBs, i.e. sub-band (SB). Depending on the number of RBs in a SB,  $Nb_{rb\_loc}$  can assume different values. For example, if the number of RBs in a SB is 5 (SB = 5), then  $Nb_{rb\_loc} = 4$ . In the case SB = 1 or 2 then  $Nb_{rb\_loc} = 6$  or 5, respectively.

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<sup>1</sup> Uniform feedback divides the usable bandwidth into equal segments. For each segment CQI and PMI are reported.

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## 5 Feedback Reduction Techniques

The Best-M feedback reduction technique can be used for the reduction of CQI feedback yet preserving frequency selective scheduling gain[1]. However, when using the Best-M technique precoding gain may be lost due to the non-preferred allocation of frequency resource to the UE by the Node-B scheduler. The Best-M technique coupled with Uniform precoding preserves precoding gain with sufficient granularity of PMI, and eliminates the need to utilize poorly matched PMI feedback in the case of non preferred resource allocated to the UE. This condition exists for both one-shot codebook and differential codebook. Best-M technique can not be coupled with the differential codebook PMI feedback since the scheduling algorithm may frequently change the location of Best-M sub-bands with the consequence of interrupting the sub-band continuity that is required for the differential codebook feedback technique to work. Therefore, we propose that Uniform PMI feedback be used together with the differential codebook in order to maintain continuity required for the differential codebook technique to be effective and preserve precoding gain.

We show in the following sections that if Best-M CQI feedback together with Uniform precoding utilizing differential feedback is used, near optimal system level throughput may be achieved. We consider the following feedback reduction techniques:

1. Uniform CQI and PMI,  $FBu$  calculated with ( $Nb_{pc} = 2,6$ ;  $Nb_{cqi} = 5$ ;  $N_{cqi\_rep} = 10,25,50$ ;  $N_{pc\_rep} = 25$ ), *differential codebook* based feedback.
2. Best-M CQI with 25 Uniform PMI,  $FBm$  calculated with ( $Nb_{pc} = 2,6$ ;  $Nb_{cqi} = 5$ ;  $N_{cqi\_rep} = 3,7,11$ ;  $N_{pc\_rep} = 25$ ;  $SB = 1$ ;  $Nb_{rb\_loc} = 6$ ), *differential codebook* based feedback.
3. Best-M CQI with 1 PMI,  $FBm$  calculated with ( $Nb_{pc} = 2,6$ ;  $Nb_{cqi} = 5$ ;  $N_{cqi\_rep} = 1,2,3,5$ ;  $N_{pc\_rep} = 25$ ;  $SB = 2$ ;  $Nb_{rb\_loc} = 5$ ), *differential codebook* based feedback.
4. Best-M CQI with 1 PMI,  $FBm$  calculated with ( $Nb_{pc} = 2,6$ ;  $Nb_{cqi} = 5$ ;  $N_{cqi\_rep} = 1,2,3,5$ ;  $N_{pc\_rep} = 25$ ;  $SB = 5$ ;  $Nb_{rb\_loc} = 4$ ), *differential codebook* based feedback.

In the Best-M CQI technique each CQI feedback corresponds to a single SB, and for the SBs that do not fall into the Best-M CQI pool a single average CQI is reported. Figures 5 and 6 show results for 2x2 and 4x2 MIMO systems, respectively. The results were obtained using differential codebook feedback technique presented in [5], [6].

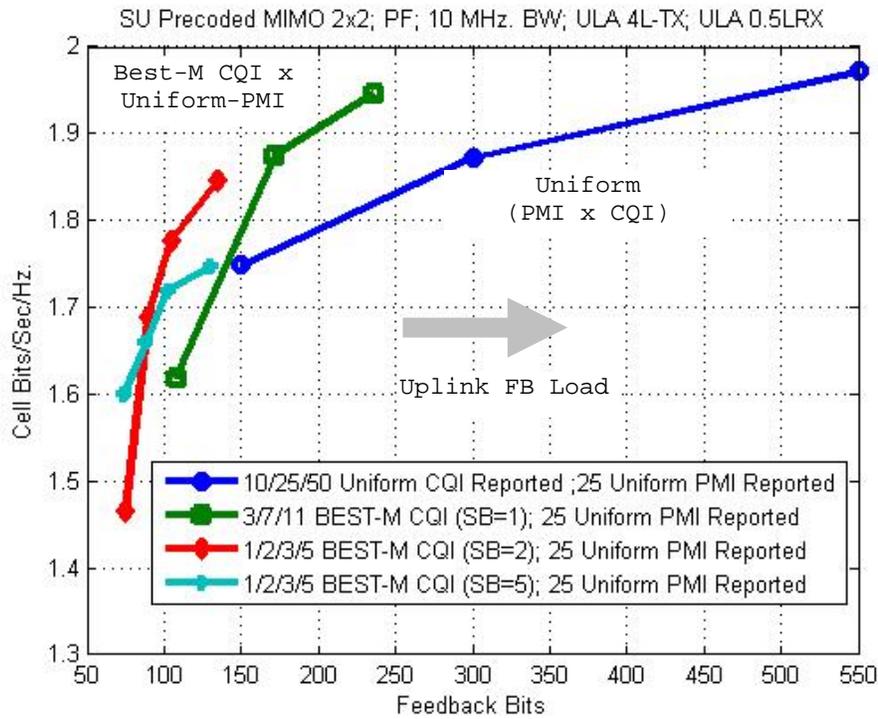


Figure 5. SU MIMO 2x2 System Cell Spectral Efficiency vs. Feedback

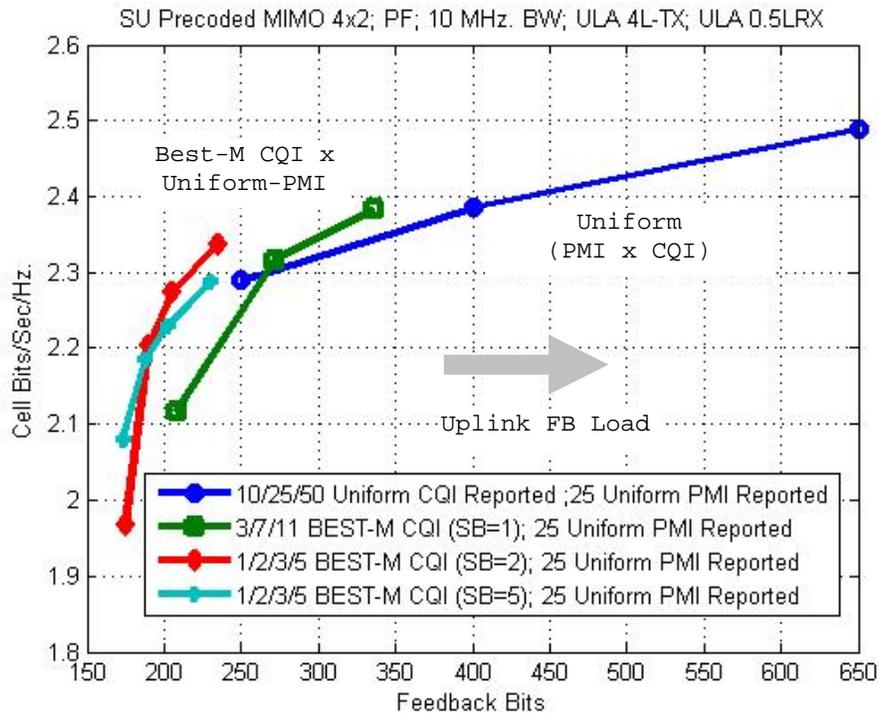


Figure 6. SU MIMO 4x2 System Cell Spectral Efficiency vs. Feedback Requirement

From the Figs. 5 and 6 we make the following two observations:

- Best-M CQI and Uniform PMI techniques significantly reduce feedback overhead.
- .Cost of PMI Feedback, with the Uniform PMI grid is less than the cost of CQI feedback with Best-M due to location overhead.

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## 6 Conclusions

In this presentation we show the following for an SVD based precoding 2x2 and 4x2 MIMO systems with frequency selective scheduling:

- Considerable gains can be achieved with finer CQI and PMI feedback.
- Gain from PMI feedback can be observed in the presence of high CQI feedback, illustrating gain beyond frequency selective scheduling gain for both the 2x2 and 4x2 MIMO systems.
- Feedback of both CQI and PMI should be adjusted according to Network factors and available resource per user [4].
- Feedback overhead can be reduced by using the Best-M CQI feedback combined with Uniform PMI feedback (differential codebook).
- Differential codebook technique approaches near floating point performance.
- Further evaluations of Feedback and Precoding should account for Feedback overhead in a similar fashion as provided in this presentation.

We propose Uniform precoding feedback covering the usable bandwidth within the network. In addition, we propose that the differential codebook feedback technique be used for EUTRA .

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## 7 References

- [1] R1-062491 Huawei – Overhead reduction of UL CQI signalling for E-UTRA DL
- [2] R1-051334 Motorola - CQI Feedback Scheme for EUTRA
- [3] R1-061246 Huawei - Unified uplink CQI signaling by efficient labeling
- [4] R1-072404 Broadcom - Consideration for CQI and Precoding Feedback Granularity for MIMO Operation in E-UTRAN
- [5] R1-070168 Broadcom – Beamforming Compact Codebook Method and Results in E-UTRA
- [6] R1-071188 Broadcom – Compact Codebook for Unitary Precoding MIMO with Support for Rank Reduction
- [7] R1-072407 CQI and Precoding Granularity Feedback Requirements - System Level Analysis
- [8] R1-062650 Texas Instruments - Codebook Design for E-UTRA MIMO Pre-coding
- [9] R1-070936 Panasonic - MIMO Codebook Design for MU/SU-MIMO
- [10] R1-070658 Qualcomm – UE Feedback with Precoding Granularity – System Analysis