3GPP TSG-RAN WG1 RAN49 **R1-072407**
Location **Kobe Japan**
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Title: **CQI and Precoding Granularity Feedback Requirements – System Level Analysis**

Document for: **Discussion/Decision**

1. Introduction

EUTRA is enhanced by frequency selective scheduling gains by UE feedback of channel quality indicator (CQI) and precoding in both time and frequency domains. In [1] it was shown that, for a 2x2 MIMO system using DFT precoding matrices together with frequency selective scheduling, there is a limited precoding gain resulting from the fine granularity precoding feedback.

In this submission, 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, that there is a considerable gain to be achieved in the case finer precoding feedback granularity together with finer CQI feedback granularity is used. In addition, we show advantages of using Best-M CQI feedback method together with Uniform precoding matrix information (PMI). The Best-M feedback method for CQI that reduces feedback overhead was presented in [2].

In addition, we show that if a 4-bit precoding codebook is used for 4 transmit antennas, large loss can occur when compared to the floating point precoding feedback. This loss can be minimized using differential codebook technique [3,4] with low feedback requirements (results were shown to be very close to the floating-point precoding results).

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 with floating-point feedback and 4-bit codebook for 4x2, and 2-bit codebook for 2x2 were used. The codebooks used in the simulation are designed such that their elements are uniformly sampling the unitary space (we found that this is close to optimal codebook design).

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)	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ θ_{3dB} = 70 degrees, A_m = 20 dB
Carrier Frequency / Bandwidth	2 GHz.
Channel model	Typical Urban (TU) MACRO, Statistical Channel Model.
UE speed	5 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
Mobile Antenna Configuration RX	0.5λ 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

SLS Parameter	Details
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 .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 4λ spacing and 2x2 and 4x2 single user (SU) MIMO configurations. The results are obtained in terms of mean cell throughput as a function of number of CQIs and PMIs reported. For example, if 10 CQIs and 25 PMIs are reported, each reported CQI is for 5 RBs and each reported PMI is for 2 RBs. The total number of RBs is 50. Figure 1 below shows results for the 2x2 MIMO system and Fig. 2 for the 4x2 MIMO system, floating point precoding.

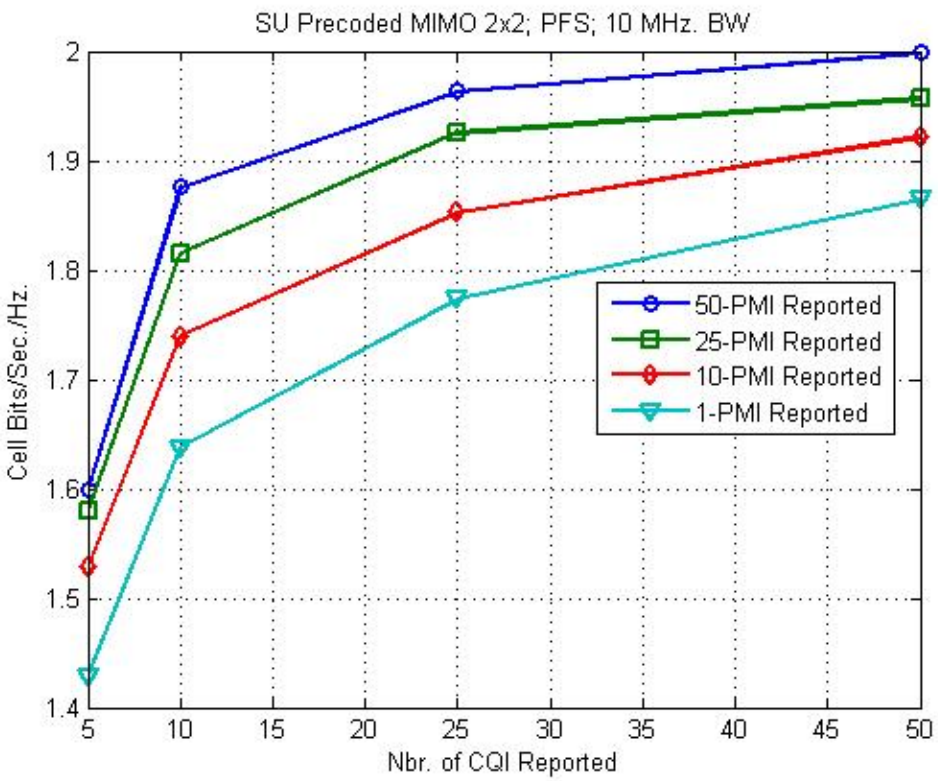

Figure 1. SU MIMO 2x2 System Cell Spectral Efficiency for Precoding and CQI Granularity

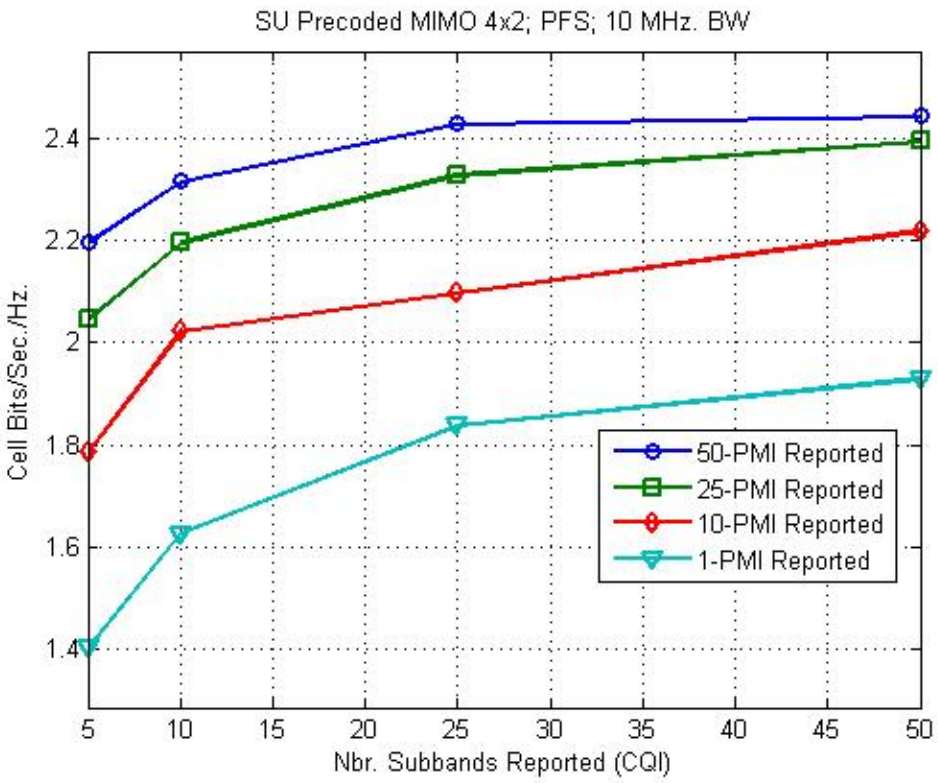

Figure 2. SU MIMO 4x2 System Cell Spectral Efficiency for Precoding and CQI Granularity

Results in Fig. 1 and Fig. 2 are summarized in Tables 3 and 4, respectively.

Table 3. Mean Cell Throughput SU 2x2 MIMO

	5 CQI Reported	10 CQI Reported	25 CQI Reported	50 CQI Reported
50 PMI reported	1.5988	1.8756	1.9638	1.9988
25 PMI reported	1.5800	1.8154	1.9262	1.9576
10 PMI reported	1.5289	1.7399	1.8535	1.9227
1 PMI reported	1.4295	1.6379	1.7741	1.8657

Table 4. Mean Cell Throughput SU 4x2 MIMO

	5 CQI Reported	10 CQI Reported	25 CQI Reported	50 CQI Reported
50 PMI reported	2.1975	2.3171	2.4295	2.4443
25 PMI reported	2.0470	2.1978	2.3305	2.3962
10 PMI reported	1.7870	2.0243	2.0990	2.2201
1 PMI reported	1.4036	1.6273	1.8384	1.9314

From Figs. 1 and 2 and Tables 3 and 4 we can observe that finer granularity CQI and PMI feedback yield considerable gains.

4. Feedback Calculation

Feedback requirement (*FBu*), in bits, for Uniform[1] CQI and PMI is a function of both CQI granularity and precoding granularity, and may be expressed as follows:

$$FBu = N_{cqi_rep} \cdot \left(2 \cdot Nb_{cqi}\right) + N_{pc_rep} \cdot \left(Nb_{pc}\right) \qquad \text{Eq(1)}$$

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, RB location, precoding granularity, and may be expressed as follows:

$$FBm = N_{cqi_rep} \cdot \left(2 \cdot Nb_{cqi} + Nb_{rb_loc}\right) + N_{pc_rep} \cdot \left(Nb_{pc}\right) + 2 \cdot Nb_{cqi_ave} \qquad \text{Eq(2)}$$

Where Nb_{rb_loc} is the number of bits (6 for the 10 MHz bandwidth) required to feedback RB 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}).

5. Feedback Reduction Techniques

Next, we consider the following feedback reduction techniques:

1. Uniform CQI and PMI, *FBu* calculated with (Nb_{pc} = 2,6; Nb_{cqi} = 5; N_{pc_rep} = N_{cqi_rep} = 10,25,50), *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,(15); N_{pc_rep} = 25), *differential codebook* based feedback.
3. Best-M CQI with 1 PMI, *FBm* calculated with (Nb_{pc} = 2,6; Nb_{cqi} = 5; N_{cqi_rep} = 3,7,11; N_{pc_rep} = 1), *differential codebook* based feedback.
4. Uniform CQI with 50 PMI, *FBu* calculated with (Nb_{pc} = 2,4; Nb_{cqi} = 5; N_{cqi_rep} = 10,25,50; N_{pc_rep} = 50), *one-shot codebook* based feedback.

In the Best-M CQI technique each CQI feedback corresponds to a single RB, and for the RBs that do not fall into the Best-M CQI pool a single average CQI is reported. Figures 3 and 4 show results for the 2x2 and 4x2 MIMO systems, respectively. The results 1 – 3 were simulated using floating point codebook feedback. The floating point codebook feedback results are representative of the results using differential codebook [3,4].

[1] Uniform feedback divides the usable bandwidth into equal segments. For each segment CQI and PMI are reported.

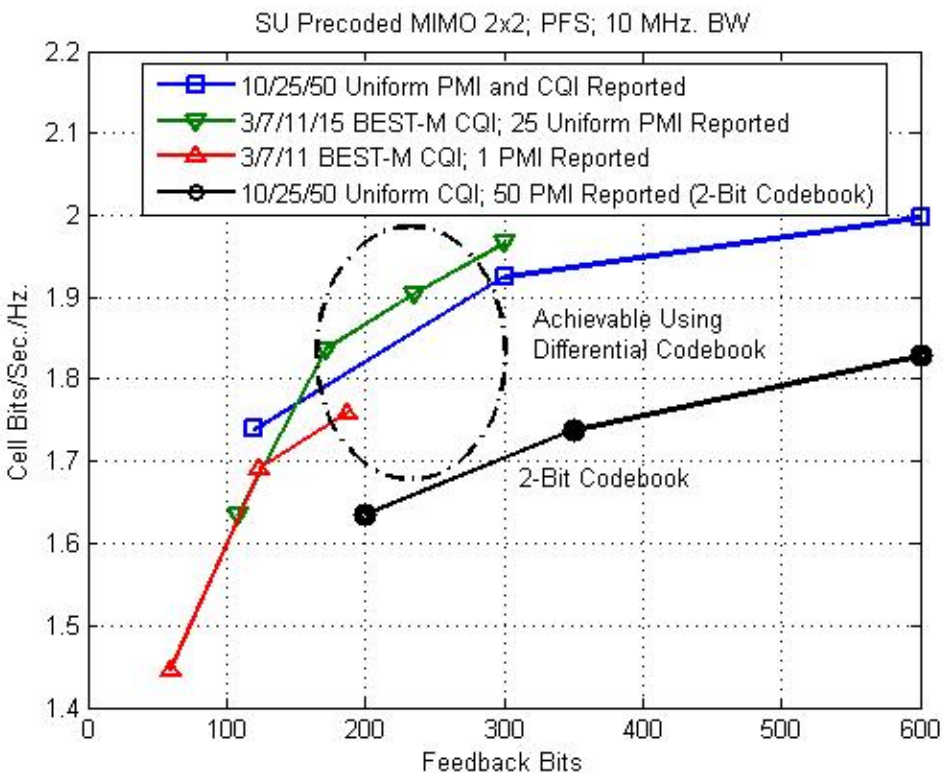

Figure 3. SU MIMO 2x2 System Cell Spectral Efficiency vs. Feedback Requirement

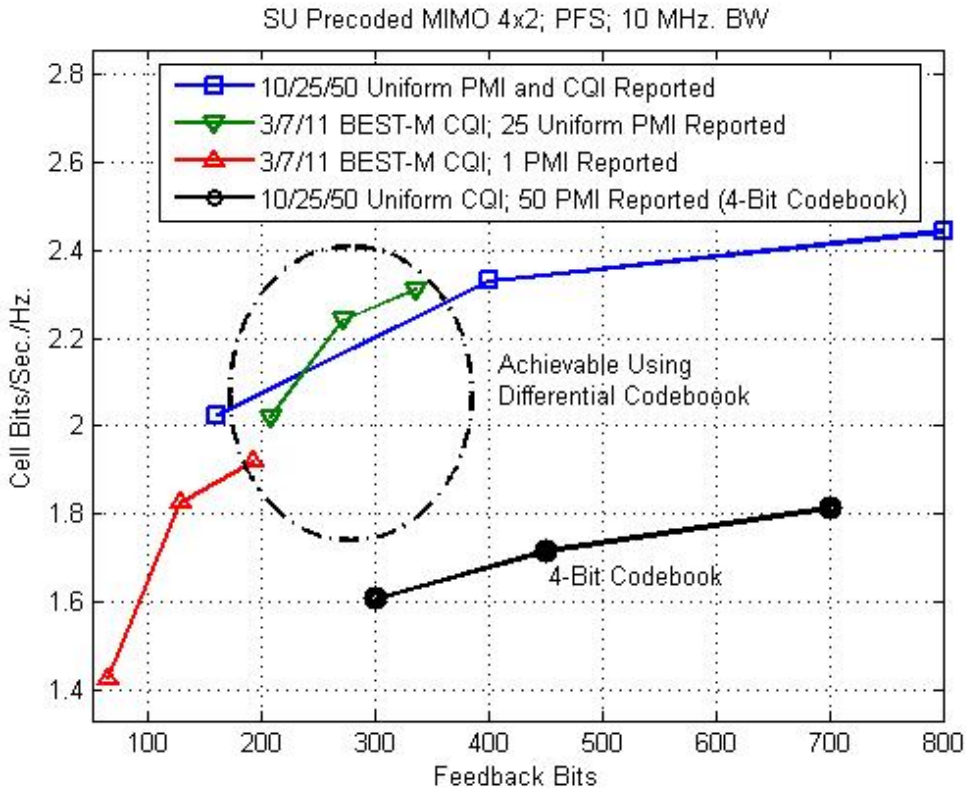

Figure 4. SU MIMO 4x2 System Cell Spectral Efficiency vs. Feedback Requirement

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

- Best-M CQI together with Uniform PMI technique is superior in performance to the Best-M with a single PMI technique for the same feedback requirements.
- 4-bit codebook precoding technique yields considerable loss when compared to the floating-point or differential codebook precoding.

6. Conclusions

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

- Considerable gains can be achieved with finer CQI and PMI feedback.
- Feedback overhead can be reduced by using the Best-M CQI feedback combined with Uniform PMI feedback.
- 4-bit codebook precoding technique yields considerable loss when compared to the floating-point precoding. The loss can be minimized using differential codebook precoding technique.
- Differential codebook technique approaches floating point performance.
- The gain of differential codebook technique over 4-bit codebook technique for 4x2 MIMO is ~ 35%
- The gain of differential codebook technique over 2-bit codebook technique for 2x2 MIMO is ~ 10%

We propose that the differential codebook technique should be used for EUTRA .

7. References

[1] R1-070558 Qualcomm Europe – UE Feedback with Precoding Granularity – System Analysis

[2] R1-062491 Huawei – Overhead reduction of UL CQI signalling for E-UTRA DL

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

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