

Agenda Item: 6.5.3

Source: NEC Group

Title: On the precoding codebook design for EUTRA MIMO

Document for: Discussion and Decision

1 Summary

In this contribution, we first describe the proposed codebook structure for the multi-rank beamforming (MRBF) scheme in more detail. This contribution also presents link-level simulation results on the achievable data rates by employing 2×2 and 4×2 MIMO systems in OFDM downlink for E-UTRA. The performance of the precoding schemes using different codebook structures along with the optimal precoding bounds are presented. It is shown that while all the presented precoding schemes achieve similar performances, the MRBF scheme results in lower complexity.

We believe appropriate precoding structure is necessary to simultaneously address the trade-off between several important factors: higher throughput gain, lower feedback overhead, lower memory requirement, and lower computational complexity.

2 Codebook Structure

The precoding codebook consists of semi-unitary matrices of different sizes corresponding to different ranks. Please refer to Figure 1. The partial codebook for each rank is derived from a set of vector codebooks as described in [4] and depicted in Figures 2 and 3. Using the successive structure, there is a unique correspondence between the vector codebooks and the precoding codebook. However, the vector codebook can be stored more efficiently and requires less memory. Moreover, the vector codebook allows for applying the successive beamforming technique described in [3, 4] which considerably

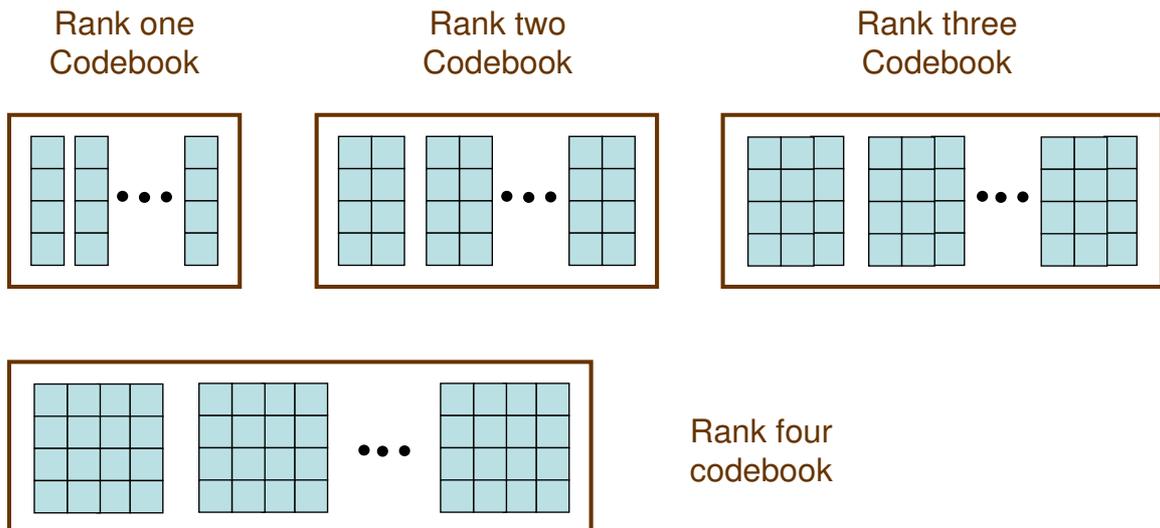


Figure 1: Representation of rank specific codebook for 4x4 MIMO

reduces the complexity of the UE operation in picking the precoder index. Thus, the vector codebook is stored at the UE, while either vector or matrix representation of the codebook (in Figure 2) can be stored at Node B.

On the one hand, we show that there is no notable performance loss in using the proposed structured codebook in comparison to the rank-specific codebook without any structure, where each partial codebook is optimized separately (Figure 11). On the other hand, we show that using the proposed structured codebook, the MRBF scheme achieves similar or better performance compared with the other schemes using different codebook structures while allowing considerable reduction in UE complexity.

3 Simulation scenarios and channel models

The important simulation parameters are listed in Table 1. We consider 2x2 and 4x2 MIMO configurations and evaluate the performance under two different channel models: SCM Urban Micro and i.i.d. Rayleigh flat fading channel model. The simulation parameters are listed in Table 1.

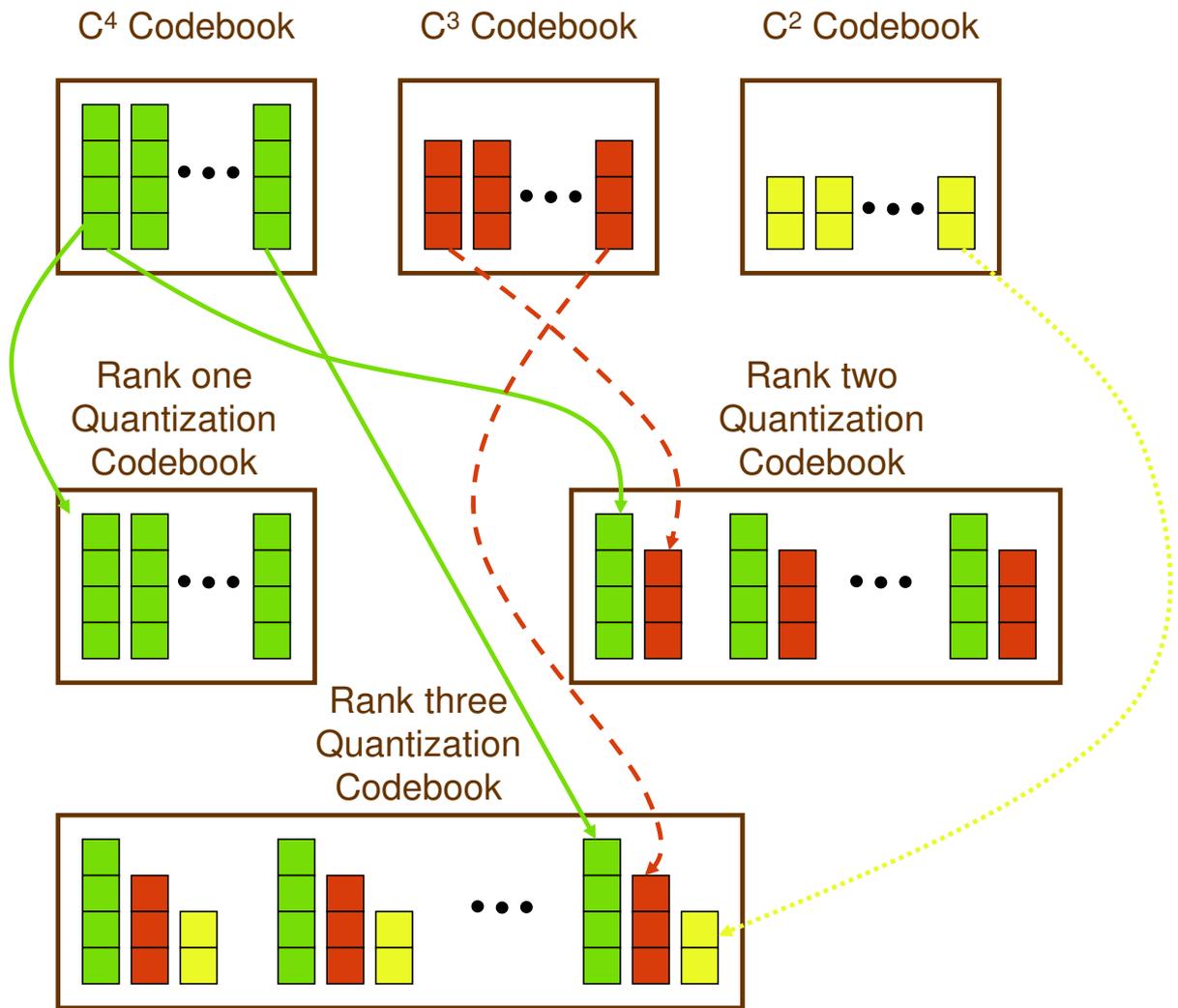


Figure 2: Representation of rank specific codebook derived from 3 vector codebook of 4, 3, and 2-dimensional vectors.

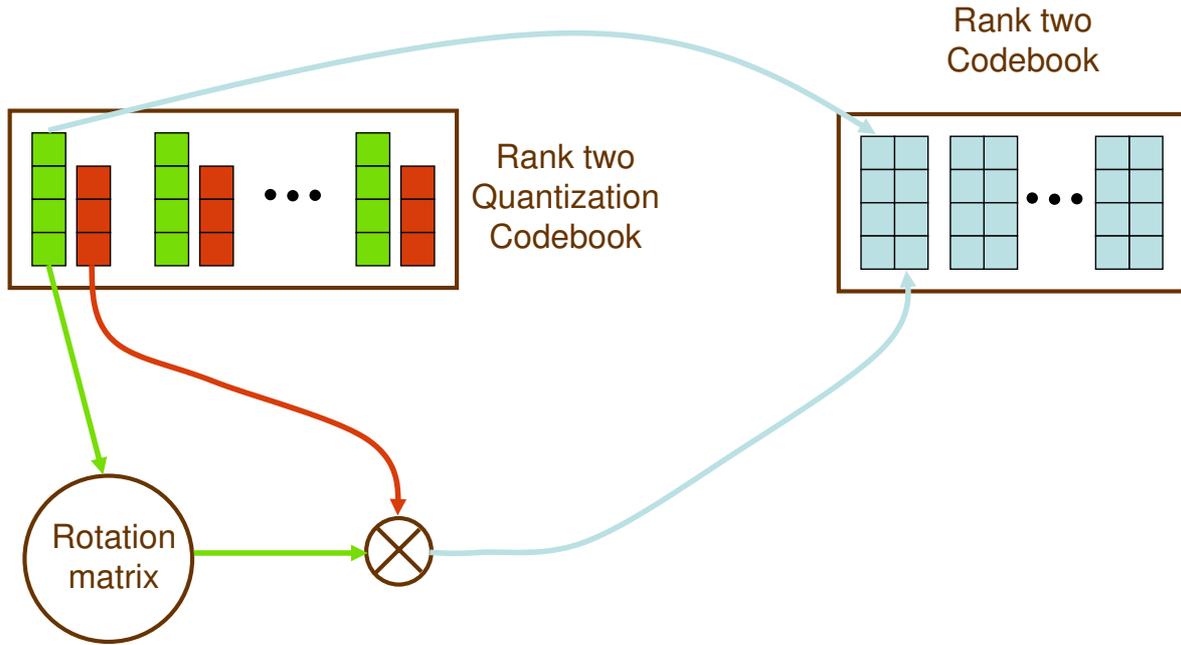


Figure 3: Example of Regenerating transmission codebook from quantization codebook for rank two.

Parameter	Assumption
Access	OFDM
RF carrier frequency	2.0 GHz
Bandwidth	5.0 MHz
Number of paths (Multi-path model)	6
Sub-carrier spacing	15.0 kHz
Sampling frequency	7.68 MHz
Number of occupied sub-carriers	300
Number of OFDM symbols per TTI	12 (6 x 2)
Number of data symbols per TTI	3600 (1800 x 2)
Symbol rate	7.2 M/s
CP length	4.82 micro second
FFT point	512
Number of antennas at BS	4
Number of antennas at MS	2
Number of feedback bits	3, 5 for 2x2 configuration and 6, 8 for 4x2 configuration
CQI description	5 bits
Channel model	Urban Micro SCM: 3kmph
Channel estimation	Ideal channel estimation
Tx and Rx antenna correlation	Without spatial correlation
Precoding block sizes	Per two RBs or whole bank precoding

Table 1: Simulation parameters

4 Simulation Results

Figure 4 shows the performance of multi-rank beamforming (MRBF) [1-4] for the 2x2 configuration using SCM Urban Micro model. It is observed that precoding per chunk is considerably better than precoding per whole band (i.e., using one precoder over the whole band). The same result is also obtained in [4] for SCME. These results reveal that, for 2x2 MIMO configuration, precoding should be done on a per chunk basis to be effective. The same figure also show marginal gain can be obtained by increasing the codebook size from 3 to 5. Furthermore, per chunk precoding using 5 bit codebook almost achieves the ultimate capacity with CSIT for most of the SNR range.

Figure 5 compares the performance of MRBF with 3 bit codebook and SVAP [5] (with rank control and preferred virtual antenna selection) that uses a 2 bit feedback with precoding bounds (infinite feedback) as well as with the antenna cycling as a baseline scheme that uses no FBI feedback. It is seen that MRBF with 3 bit feedback per cluster using LMMSE decoding achieves similar or better performance than that of SVAP with 2 bit feedback per cluster using SIC decoding. It is also observed that per cluster precoding bound with a constant precoding rank of 2 (denoted by PC/R=2) is considerably lower than the per cluster precoding bound with rank control (denoted by PC/RC). This observation confirms the importance of coherent feedback rank control. Finally, we note that per tone precoding bound with rank control (denoted by PT/RC) is very close to the optimal capacity bound with CSIT, i.e., for the sake of throughput analysis, the gain in power control via waterfilling can be captured by using only rank control.

In 4x2 case, we consider three different codebook structures and corresponding precoding schemes: (1) the MRBF scheme using vector codebook, (2) column subset selection (CSS) scheme using matrix codebooks, and (3) Householder (TI-HH) codebook [2] with CQI metric selection. Figures 7-10 show the performance of MRBF versus those of TI-HH and CSS schemes for 5 and 7 bits FBI feedback per cluster (precoding block size) for cluster sizes of 2 and 25 resource blocks, respectively. It is observed that all three

schemes yield similar performances. The CSS and TI-HH schemes compute CQI metric for all precoders of rank 1 and 2 in order to determine the optimal rank and precoder index. While both the CSS and TI-HH codebook structures allow for more efficient and faster computation of CQI metric, the selection criteria is still computationally intensive. MRBF, on the other hand, operates as follows

1. First, the rank is chosen only based on the estimate of the channel and the transmit power
2. For the computed rank, the corresponding number of right singular vectors are determined.
3. Successive quantization is used to determine the precoding index
4. The CQI is only computed for the corresponding precoder

Thus, the MRBF scheme allows for considerable complexity reduction at the UE.

5 Conclusion

In this contribution, we have shown the effectiveness of the MRBF scheme employing structured semi-unitary codebook to reduce the complexity of the precoding while maintaining a performance very close to that of the optimal (rank specific and unstructured) codebook. Thus, we recommend the MRBF scheme as a candidate for MIMO precoding scheme for EUTRA.

References

- [1] R1-051455, NEC Group, “MIMO techniques for Downlink E-UTRA” *TSG-RAN WG1 Meeting #43*, Seoul, Republic of Korea, November 7th - 11th 2005
- [2] R1-062650, TI, “Codebook design for E-UTRA MIMO precoding” *TSG-RAN WG1 Meeting #46bis*, Seoul, Republic of Korea, October 9th - 13th 2006

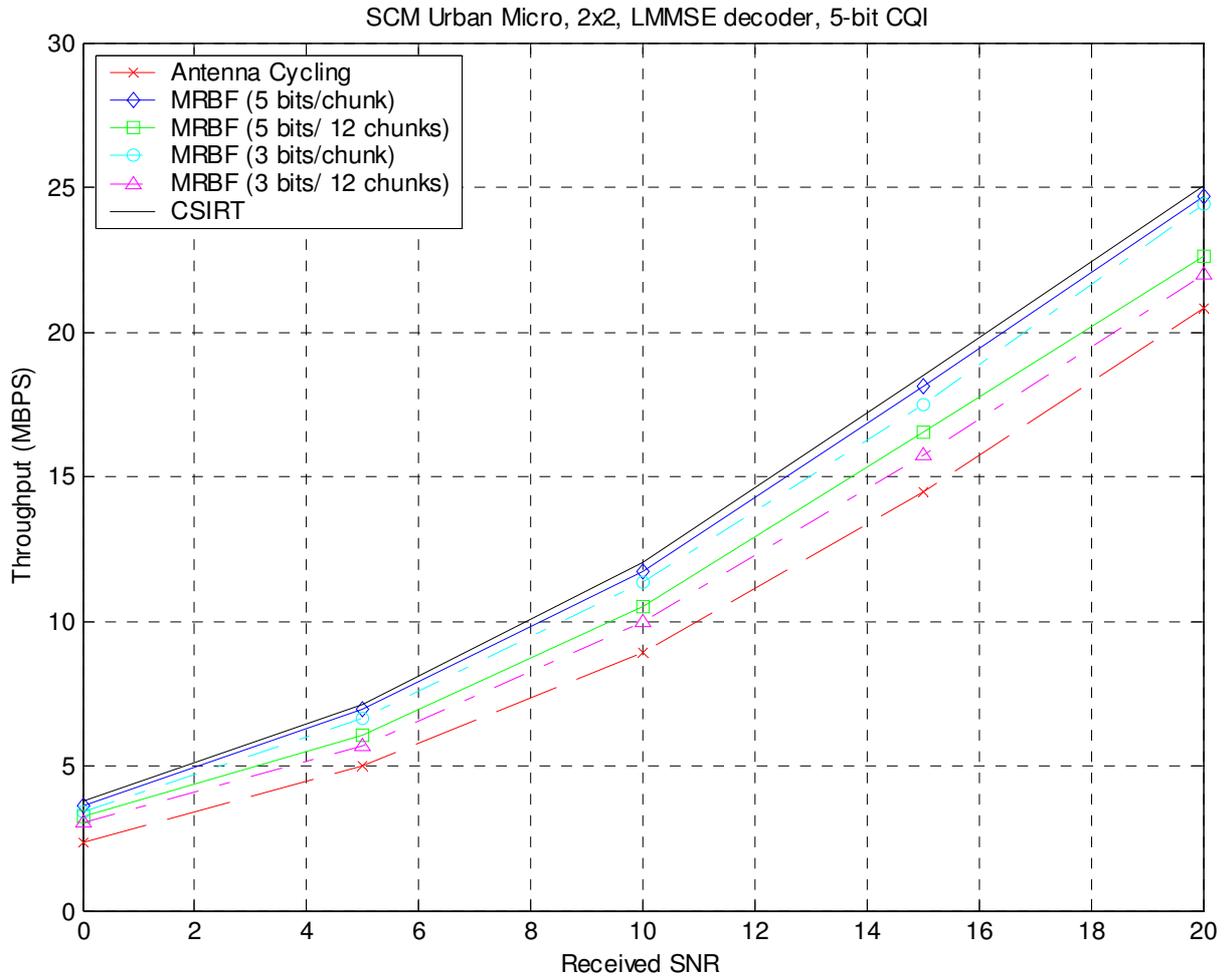


Figure 4: Throughput comparison of 2x2 multi-rank beamforming for per chunk and whole band precoding with different feedback loads (Urban Micro SCM)

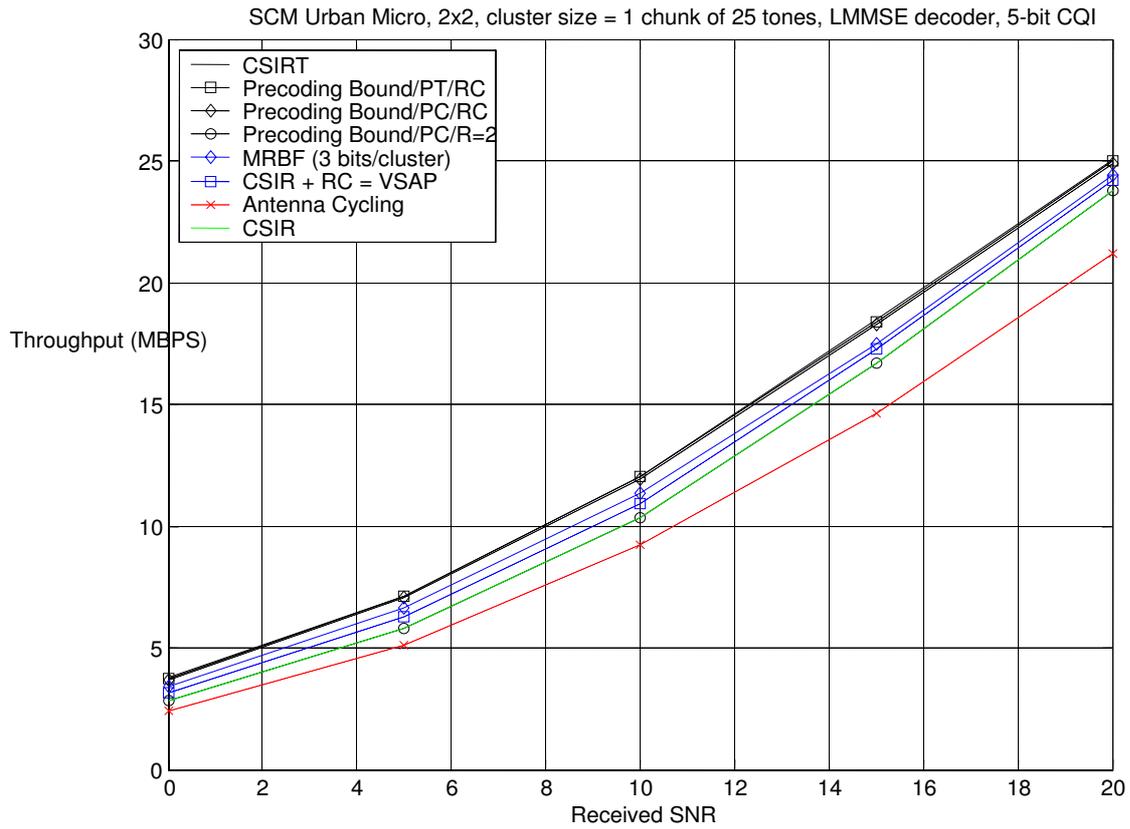


Figure 5: Throughput comparison of 2x2 multi-rank beamforming for per chunk precoding with different precoding bounds (Urban Micro SCM)

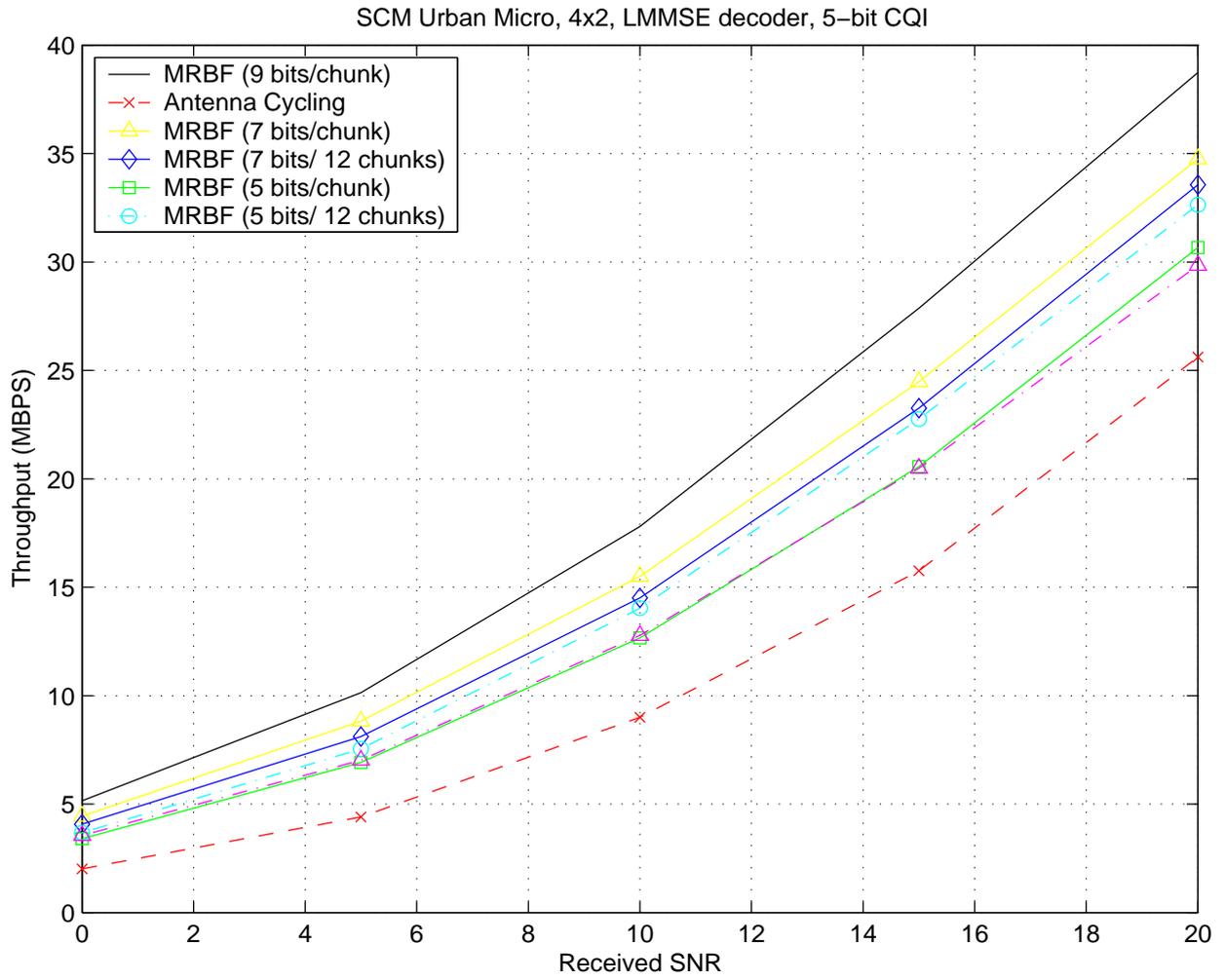


Figure 6: Throughput comparison of 4x2 multi-rank beamforming for per chunk and whole band precoding with different feedback loads (Urban Micro SCM)

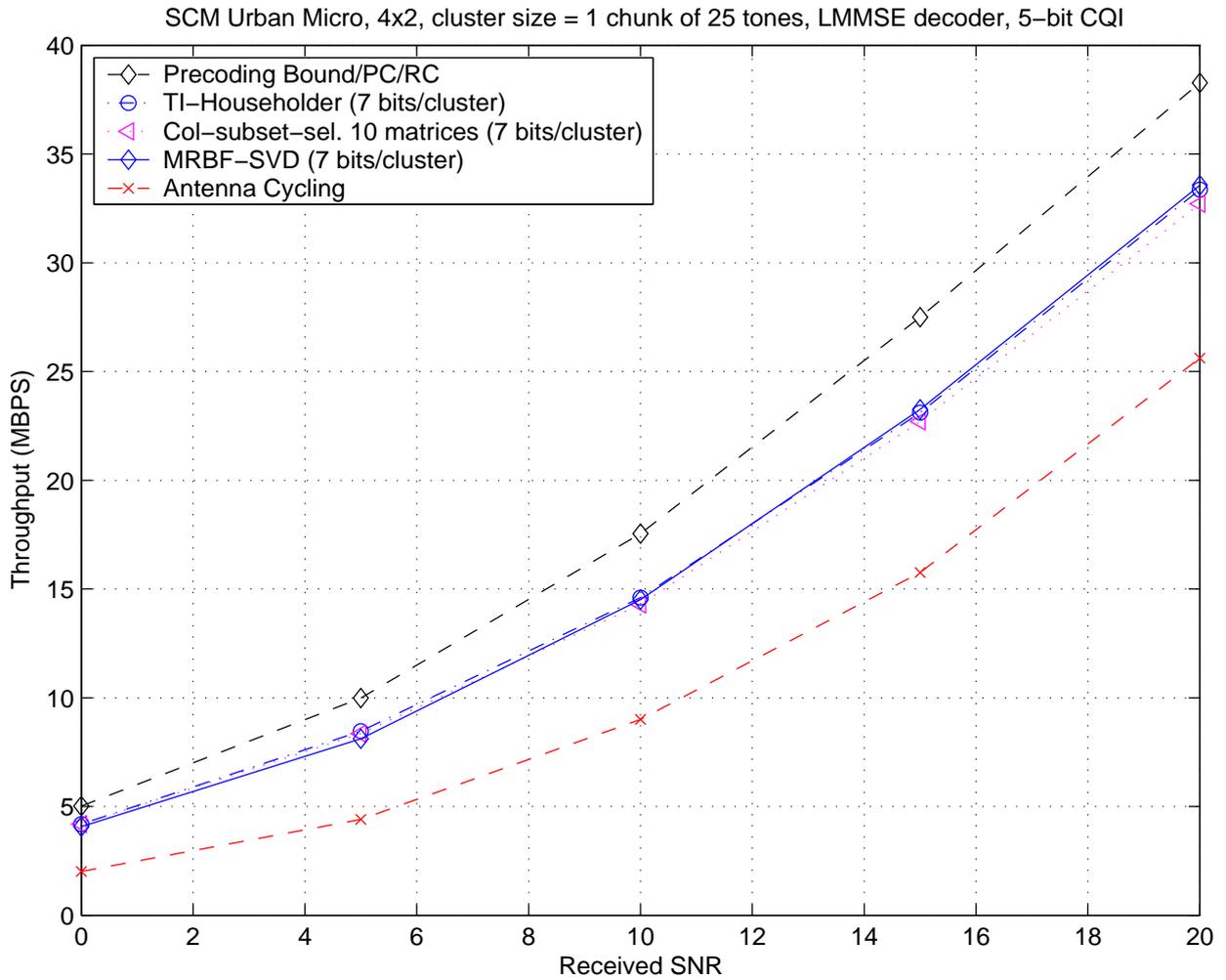


Figure 7: Throughput comparison of 4x2 multi-rank beamforming for per chunk precoding with different precoding bounds (Urban Micro SCM)

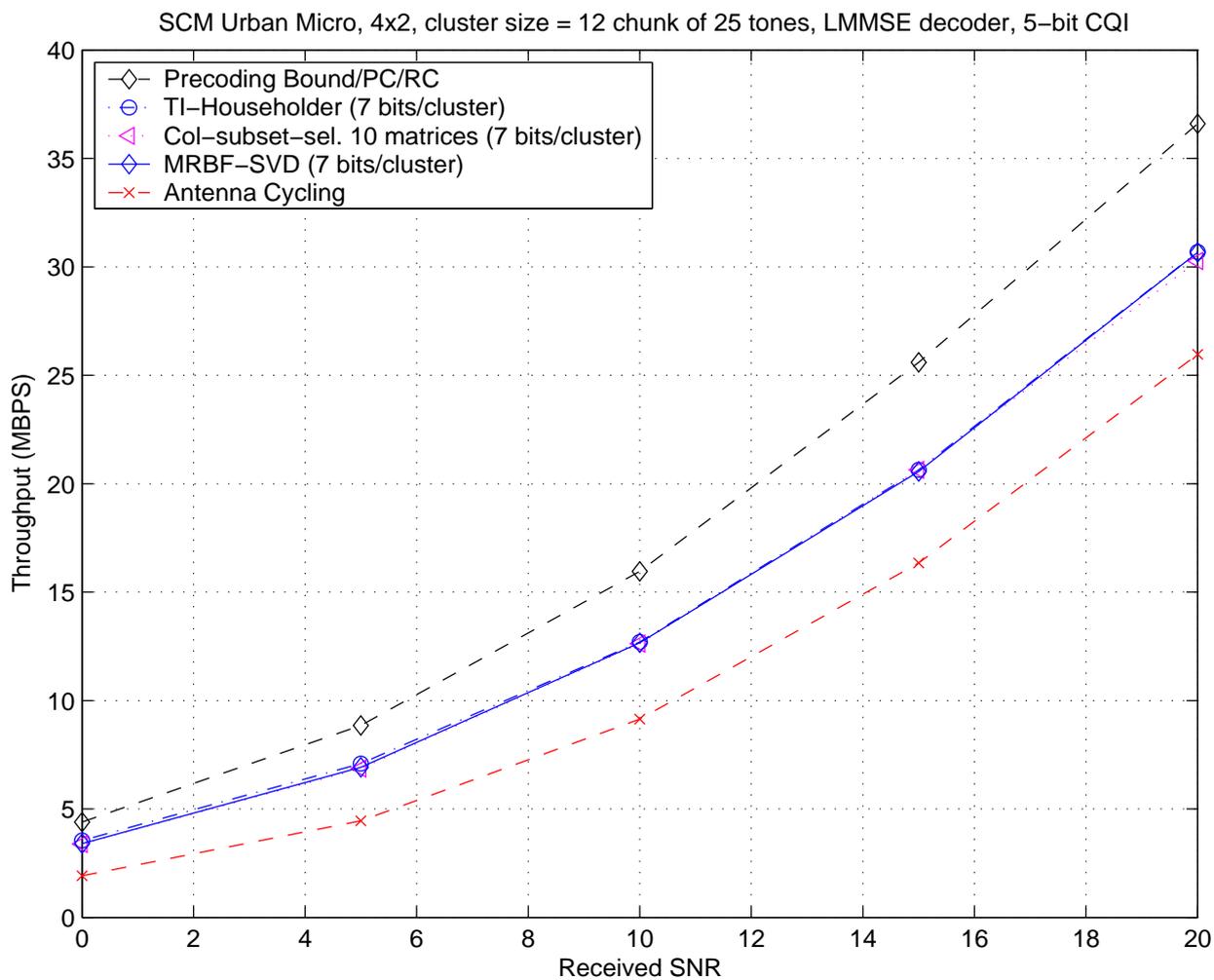


Figure 8: Throughput comparison of 4x2 multi-rank beamforming for the whole band with different precoding bounds (Urban Micro SCM)

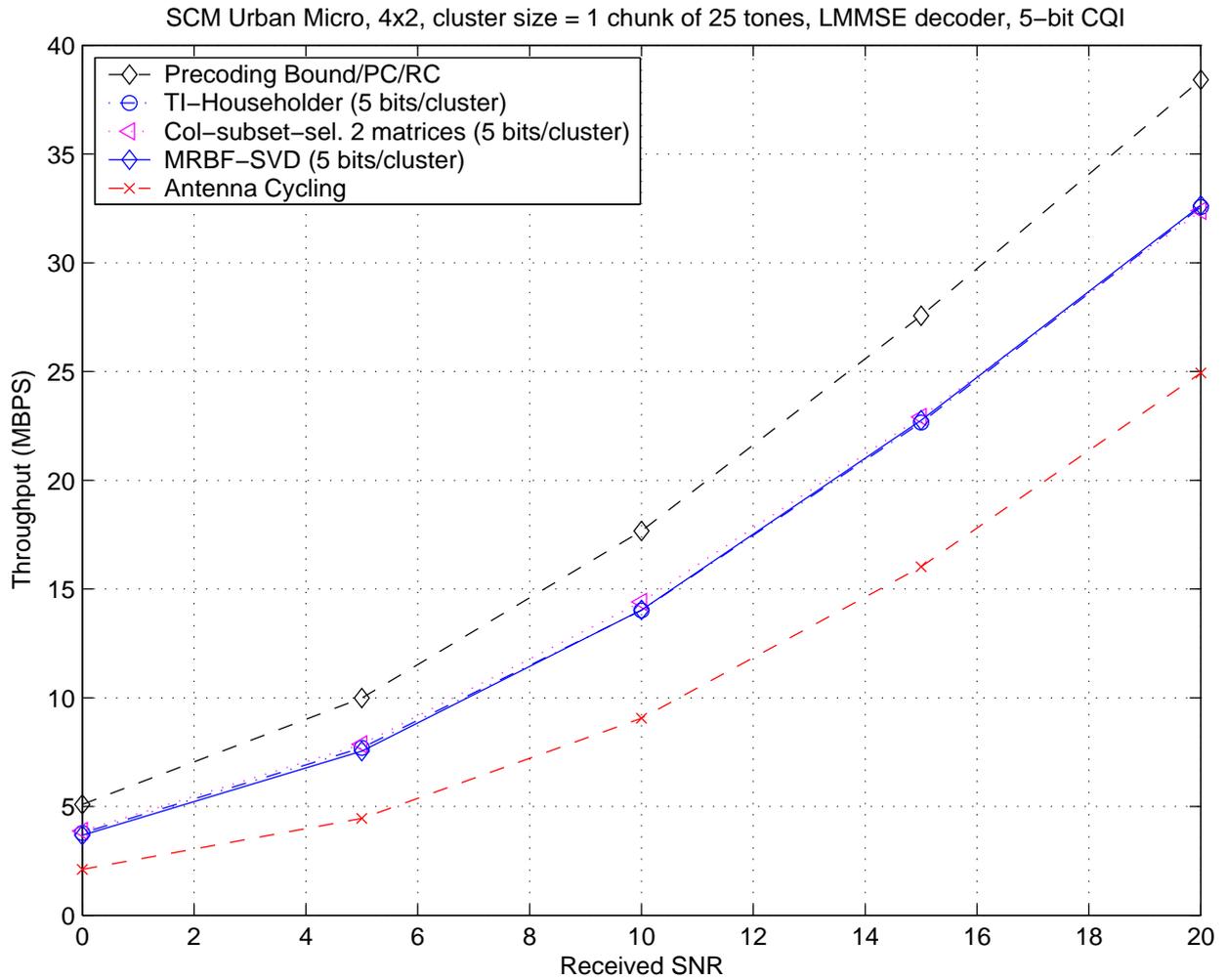


Figure 9: Throughput comparison of 4x2 multi-rank beamforming for per chunk precoding with different precoding bounds (Urban Micro SCM)

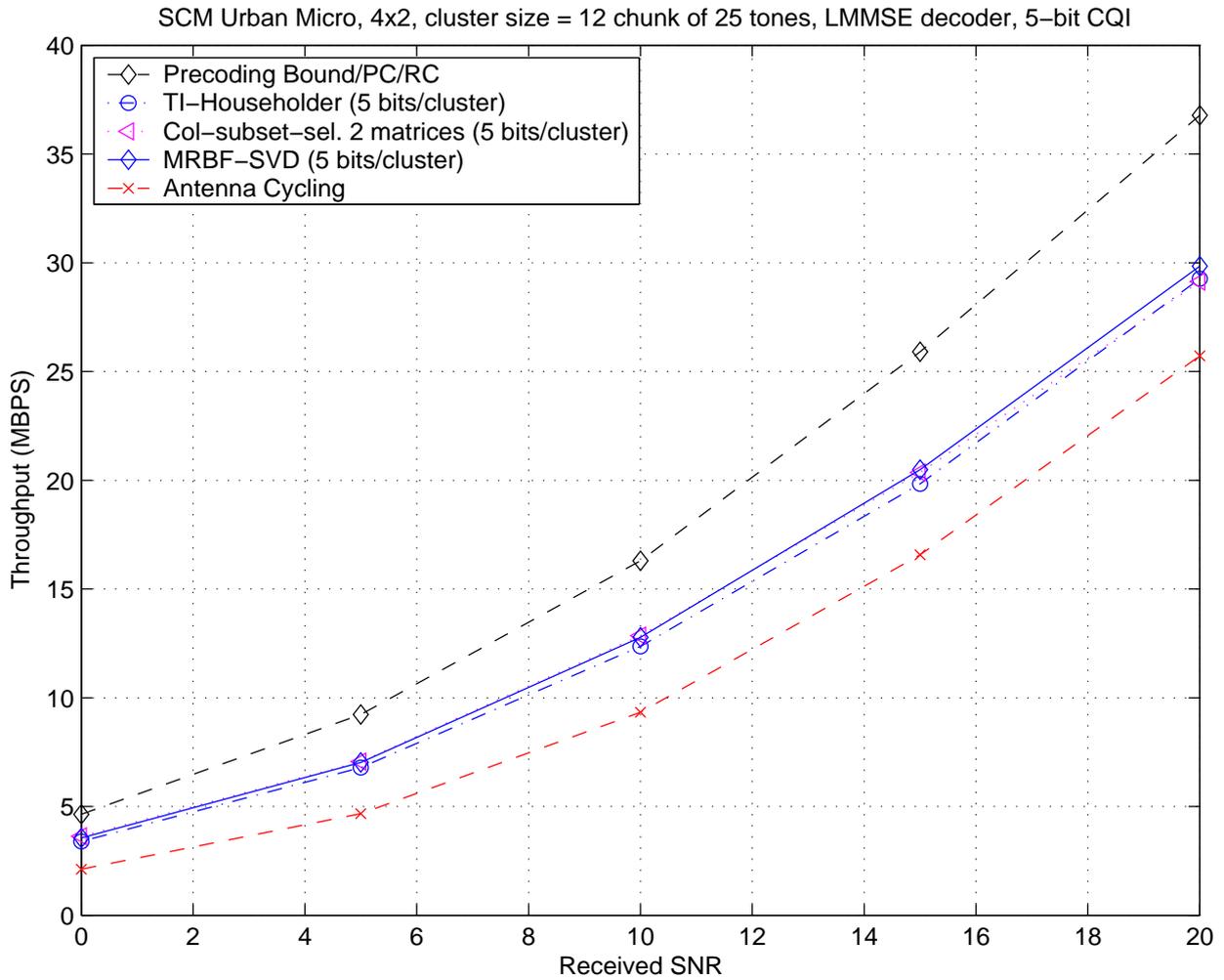


Figure 10: Throughput comparison of 4x2 multi-rank beamforming for the whole band with different precoding bounds (Urban Micro SCM)

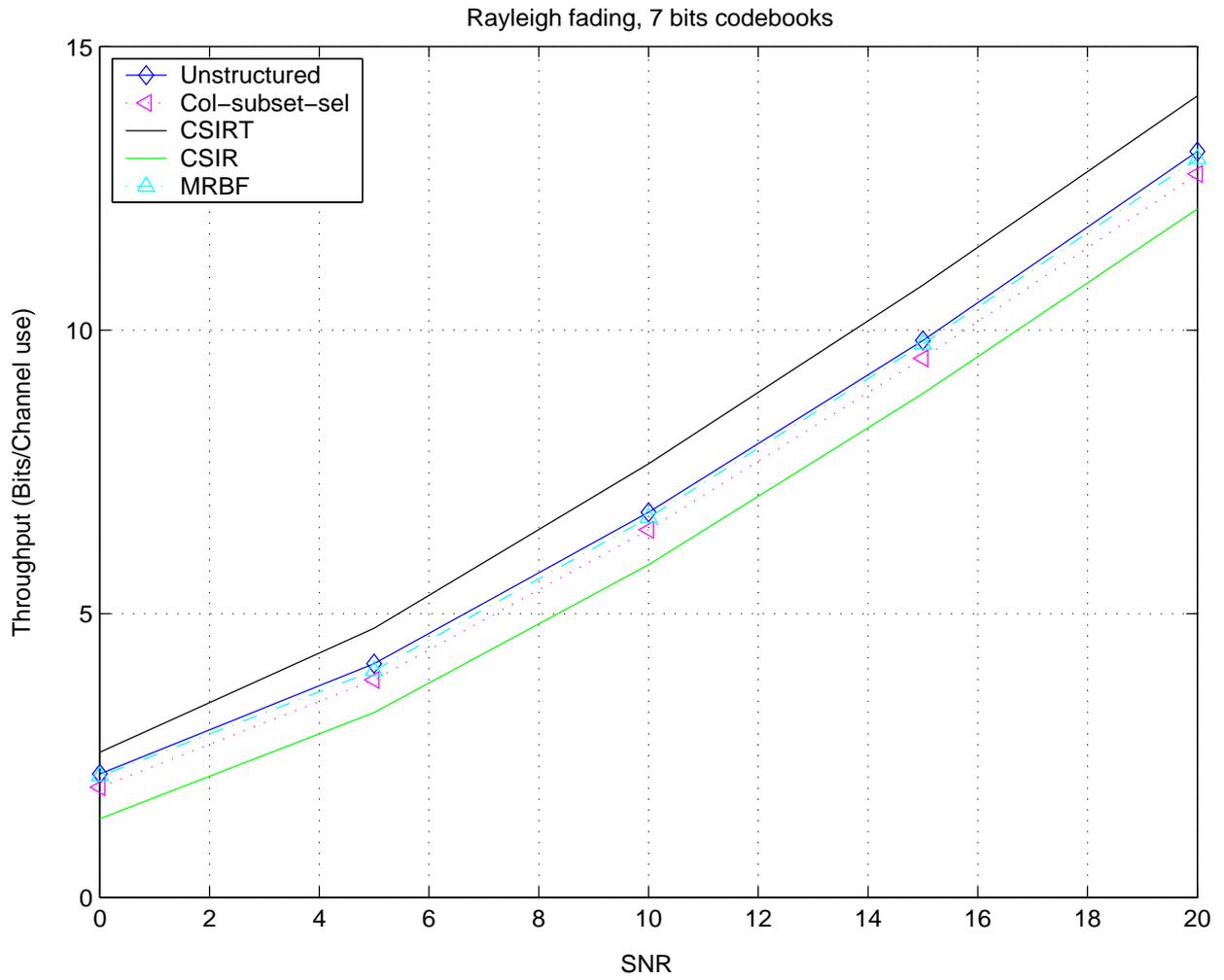


Figure 11: Throughput versus SNR. Comparison of structured versus unstructured codebooks.

- [3] R1-060362, NEC Group, “MIMO techniques for Downlink E-UTRA: Detailed description and Simulation results” *TSG-RAN WG1 Meeting #44*, Denver, Colorado, USA, February 13th - 17th 2006
- [4] R1-062122, NEC Group, “Link Analysis of Multi-rank Beamforming” *3GPP TSG-RAN WG1 #46*, Tallinn, Estonia, Aug 28 - Sep 1, 2006