Evaluation of Differential Codebooks for IEEE 802.16m Amendment Working Document

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C80216m-09_0677.doc

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Discussion and approval

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Background

- This contribution presents the performance evaluation of differential codebooks
- SDD supports a differential feedback mode for codebook based precoding in DL SU and MU-MIMO
- In San Diego meeting, SDD supports "rotation based schemes".

2 kinds of rotation based schemes

[C80216m-09_0058r4.doc]

- Rotation Scheme 1: right quantization
  - Differentiation at SS: $\mathbf{D} = \mathbf{Q}^H(t-1)\mathbf{V}(t)$
  - Quantization at SS: $\hat{\mathbf{D}} = \arg\max_{\mathbf{D}_i \in C_d} \left\| \mathbf{D}^H \mathbf{D}_i \right\|_F$
  - Beamforming matrix reconstruction at BS:

$$\hat{\mathbf{V}}(t) = \mathbf{Q}(t-1)\hat{\mathbf{D}}$$

  - Beamforming at BS: $\mathbf{y} = \mathbf{H}\hat{\mathbf{V}}(t)\mathbf{s} + \mathbf{n}$

Our Proposal

- Rotation Scheme 2: left quantization
  - Differentiation at SS: $\mathbf{D} = \mathbf{V}(t)\mathbf{Q}^H(t-1)$
  - Quantization at SS: $\hat{\mathbf{D}} = \arg\max_{\mathbf{D}_i \in C_d} \left\| \mathbf{D}^H \mathbf{D}_i \right\|_F$
  - Beamforming matrix reconstruction at BS:

$$\hat{\mathbf{V}}(t) = \hat{\mathbf{D}}\mathbf{Q}(t-1) \qquad \mathbf{Q}(t-1) = \hat{\mathbf{V}}(t-1)$$

  - Beamforming at BS: $\mathbf{y} = \mathbf{H}\hat{\mathbf{V}}(t)\mathbf{s} + \mathbf{n}$

<table>
<tr><th></th><th>Rotation Scheme 1</th><th>Rotation Scheme 2</th></tr>
<tr><td>Design Principle</td><td>Quantize the right side combining weight space</td><td>Quantize a rotation matrix space</td></tr>
<tr><td rowspan="3">Properties</td><td>Difficult to adapt to the time correlation statistics
no parameters related to the channel temporal statistics in the codebook design</td><td>Function of the temporal correlation statistics
Codebook construction is function of the time correlation ρ</td></tr>
<tr><td>High complexity
• One codebook per rank
• Q(t-1) based on multiple Householder transformation of $\hat{\mathbf{V}}(t-1)$</td><td>Low complexity
• The same codebook for all ranks
• $\mathbf{Q}(t-1) = \hat{\mathbf{V}}(t-1)$</td></tr>
<tr><td>Nt x Ns space to quantize
• no equivalence relation of the codebook
– No distance measure related to system performance
– No guarantee that the Cbk does not overquantize the space
• The quantization error not only depends on the rank of D but also on the quant. error induced in Q
• Some ambiguity when applying HH transformation for generating Q (for columns from Nt-Ns to Nt)
•> sensitivity to quantization error difficult to control and assess</td><td>Nt-dimensional unitary space
• Proof of the equivalence relation which decreases the volume of the codebook space
• The base differential codebook is in Riemannian manifold -> distance measure can be defined
•> Compactly packed rotation codebook</td></tr>
</table>

Rotation schemes 1: a smaller quantization error ?

- C80216m-09_0058r4.doc claim that Rotation schemes 1 “quantizes a smaller dimension, hence resulting in denser codebook and smaller quantization errors” is questionable

$$\hat{\mathbf{V}}(t) = \hat{\mathbf{Q}}(t-1)\hat{\mathbf{D}}(t)$$

- Quantization error in D appears at 2 levels
- Householder operation in Q boosts and spreads the quantization error

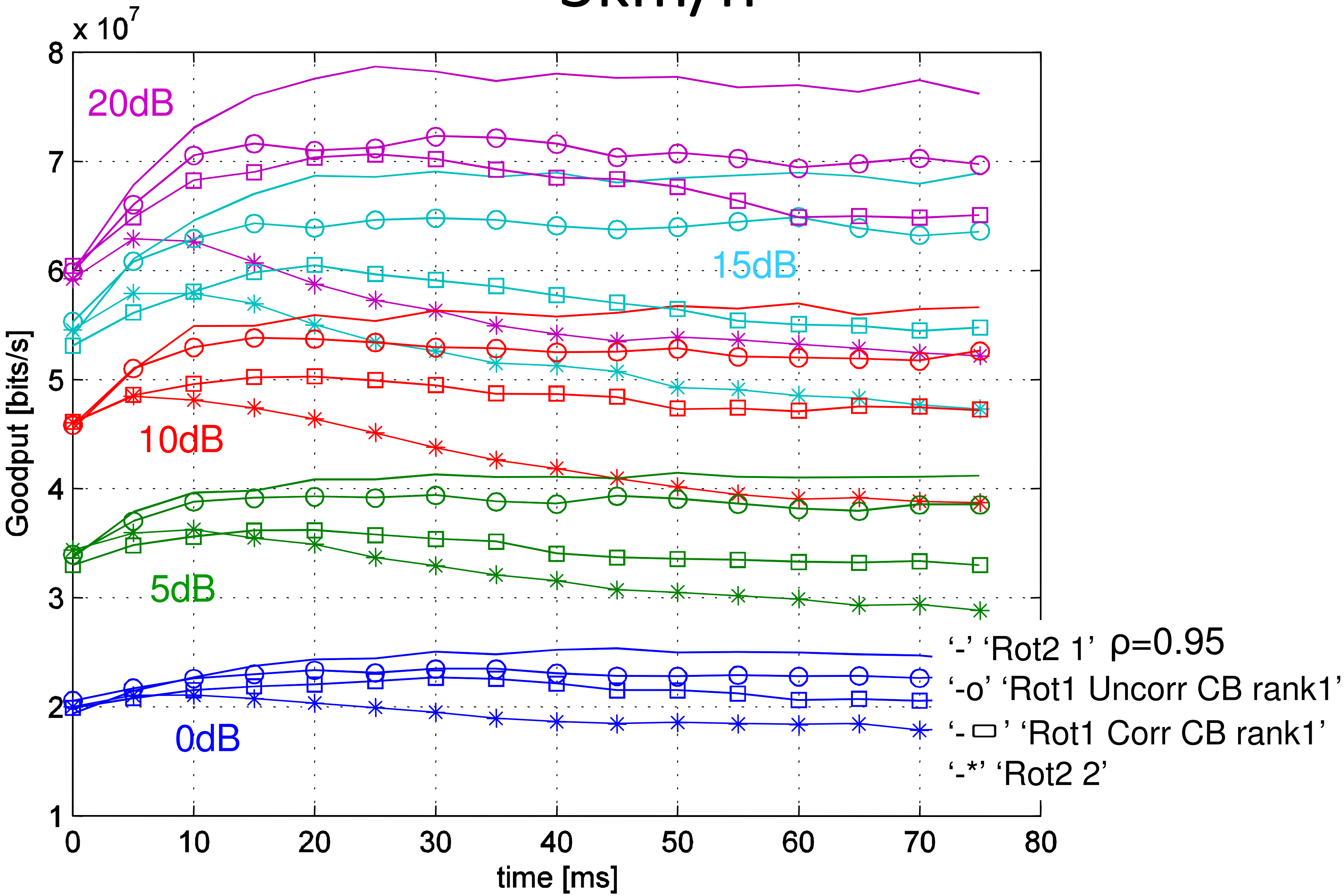
Build based on

$$\hat{\mathbf{V}}(t-1) = \hat{\mathbf{Q}}(t-2)\hat{\mathbf{D}}(t-1)$$

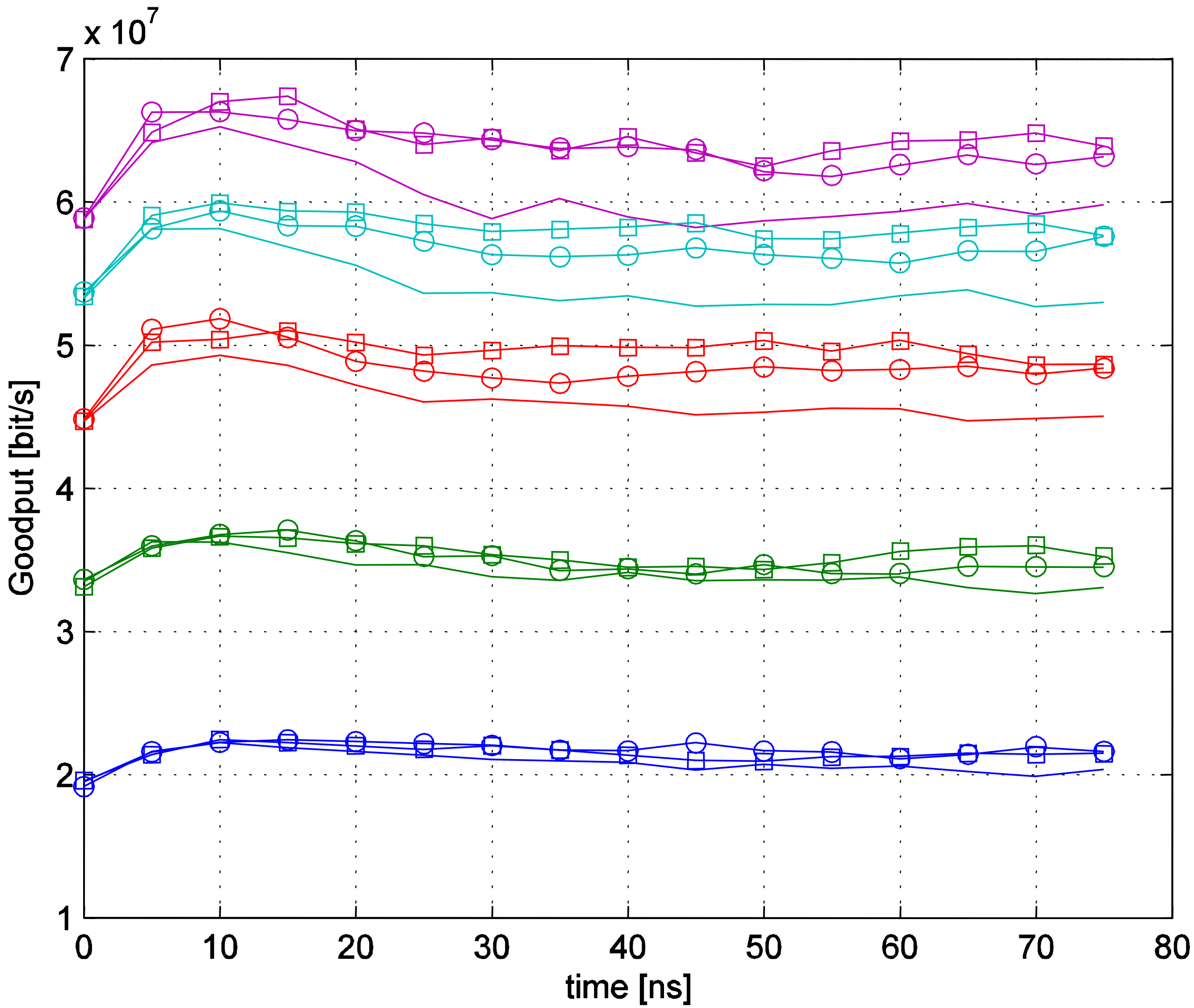
Differential codebooks

	rank	label	Codebook size	reference
Rotation scheme 1	Rank 1	‘Rot1 Uncorr CB rank1’	3 bit	C80216m-09_0528.ppt (Guangjie Li et al.)
		‘Rot1 Corr CB rank1’	3 bit	
	Rank 2	‘Rot1 Uncorr CB rank2’	3 bit	
Rotation scheme 2	For all Ranks	‘Rot2 1’	4 bit	C80216m-09_0677.doc (David Mazzarese et al.)
	For all Ranks	‘Rot2 2’	4 bit	C80216m-09_038r1_LGE_r1.doc (WookBong Lee et al.)

MU MIMO: uncorrelated (4 λ, 15° AS), 3km/h



MU MIMO: uncorrelated (4 λ, 15° AS), 6km/h



'Rot2 1'

'-' ρ=0.95
'-o' ρ=0.9
'-□' ρ=0.85

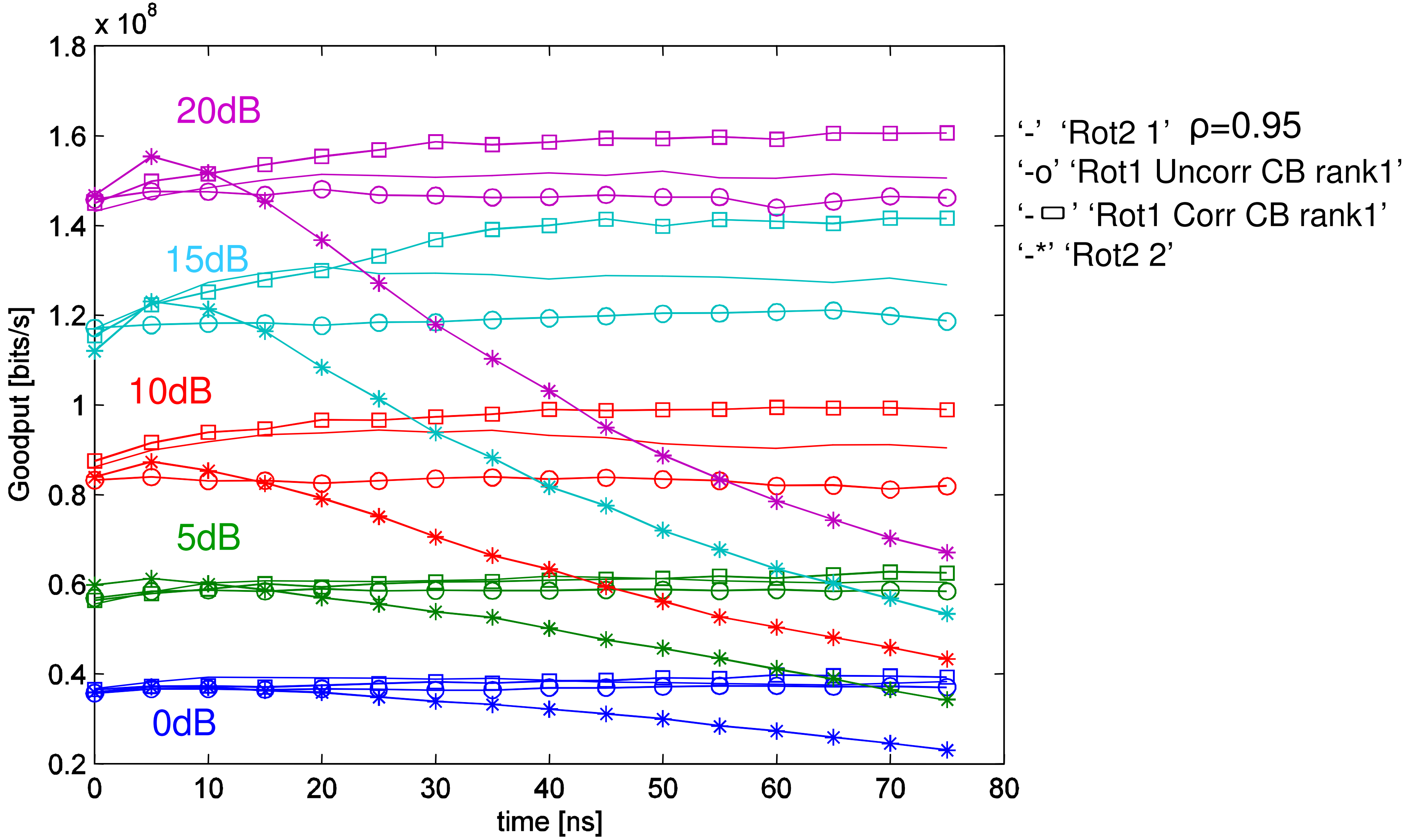
observations

- Good refinement for ‘Rot2 1’ and ‘Rot1 Uncorr CB rank1’
- ‘Rot1 Corr CB rank1’ optimized for small spacing shows loss or weak refinement in uncorrelated channels
- ‘Rot2 2’ shows significant loss due to small distance on the Riemannian manifold

	Distance on Riemannian manifold	properties
‘Rot2 1’	0.9822	**Equally spaced** codebook
‘Rot2 2’	0.0266	**Not equally spaced** codebook

- ‘Rot2 1’ easily adapts to mobile speed (i.e. parameter ρ)
- **Overall: ‘Rot2 1’ shows the best performance and flexibility**

MU MIMO: correlated (0.5 λ, 3° AS), 3km/h



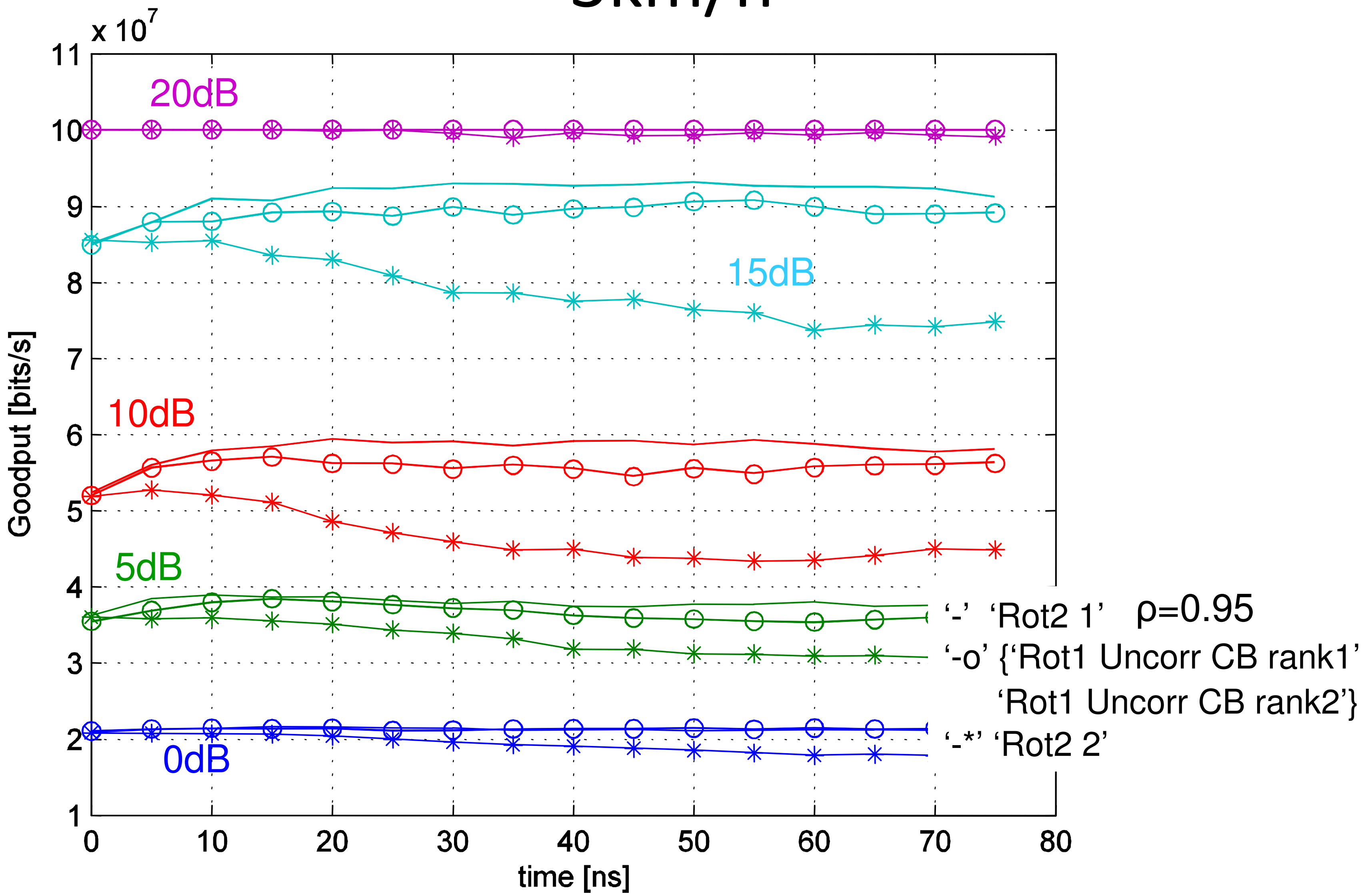
observations

- Differential codebook less beneficial in correlated channels than in uncorrelated channels
- Good refinement for ‘Rot1 Corr CB rank1’
- Good Robustness for ‘Rot2 1’
  - Moderate refinement in correlated channels
- ‘Rot1 Uncorr CB rank1’ shows no throughput improvement compared to base codebook
- **Overall: ‘Rot1 Corr CB rank1’ shows the best performance**

MU-MIMO: summary

	Uncorrelated	Correlated
‘Rot1 Uncorr CB rank1’	good refinement	No refinement
‘Rot1 Corr CB rank1’	Not robust enough	The best: excellent refinement
‘Rot2 1’	The best: excellent refinement	Robust: moderate refinement
‘Rot2 2’	Loss	Loss

CL SU MIMO: uncorrelated (4 λ, 15° AS), 3km/h



SU-MIMO: summary

	Uncorrelated
{'Rot1 Uncorr CB rank1','Rot1 Uncorr CB rank2'}	moderate refinement
'Rot2 1'	The best: excellent refinement
'Rot2 2'	Loss

Conclusions

- We propose to adopt ‘Rot2 1’ as the differential feedback mode for codebook based feedback
  - the best performance in SU and MU MIMO uncorrelated channels and robust in correlated channels
  - Lower complexity compared to rotation schemes 1
  - Easily adaptable to various environment and mobile speed
- Adopt text proposal #12 in C80216m-09_0677.doc

Appendix: Simulation Assumptions

- Channel model: Pedestrian B channel model, 3km/h, linear array
  - Uncorrelated: AS= 15, d/λ=4
  - Correlated: AS= 3, d/λ=0.5
- 10 MHz
- HARQ (Chase Combining, non-adaptive) with 3 retransmissions
  - Delay first transmission: 6 subframes
  - Delay between re-transmissions: 1 frame (8 subframes)
  - Delay between 2 midamble (update of the differential precoder): 1 frame (8 subframes)
- CQI, PMI feedback period: every frame (5 ms)
- Link Adaptation (PHY abstraction): QPSK 1/2 with repetition 1/2/4/6, QPSK 3/4, 16QAM 1/2, 16QAM 3/4, 64QAM 1/2, 64QAM 2/3, 64QAM 3/4, 64QAM 5/6
- Ideal channel estimation
- MMSE receiver
- No CQI transmission errors
- ZFBF, CL SU MIMO with SCW and rank adaptation
- LLRU (4 PRUs)
- Base codebook: 4bit subset C80216m-08/577
- Ideal antenna calibration
- No constraint on PAPR