

Evaluation of Differential Codebooks for IEEE 802.16m Amendment Working Document

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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: $\hat{\mathbf{D}} = \arg \max_{\mathbf{D}_i \in C_d} \|\mathbf{D}^H \mathbf{D}_i\|_F$

- 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: $\hat{\mathbf{D}} = \arg \max_{\mathbf{D}_i \in C_d} \|\mathbf{D}^H \mathbf{D}_i\|_F$

- Beamforming matrix reconstruction at BS:

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

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

	Rotation Scheme 1	Rotation Scheme 2
Design Principle	Quantize the right side combining weight space	Quantize a rotation matrix space
Properties	Difficult to adapt to the time correlation statistics no parameters related to the channel temporal statistics in the codebook design	Function of the temporal correlation statistics Codebook construction is function of the time correlation ρ
	High complexity <ul style="list-style-type: none"> • One codebook per rank • $\mathbf{Q}(t-1)$ based on multiple Householder transformation of $\hat{\mathbf{V}}(t-1)$ 	Low complexity <ul style="list-style-type: none"> • The same codebook for all ranks • $\mathbf{Q}(t-1) = \hat{\mathbf{V}}(t-1)$
	$N_t \times N_s$ space to quantize <ul style="list-style-type: none"> • no equivalence relation of the codebook <ul style="list-style-type: none"> – 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 \mathbf{D} but also on the quant. error induced in \mathbf{Q} • Some ambiguity when applying HH transformation for generating \mathbf{Q} (for columns from $N_t - N_s$ to N_t) •> sensitivity to quantization error difficult to control and assess 	N_t-dimensional unitary space <ul style="list-style-type: none"> • 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

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

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

Build based on

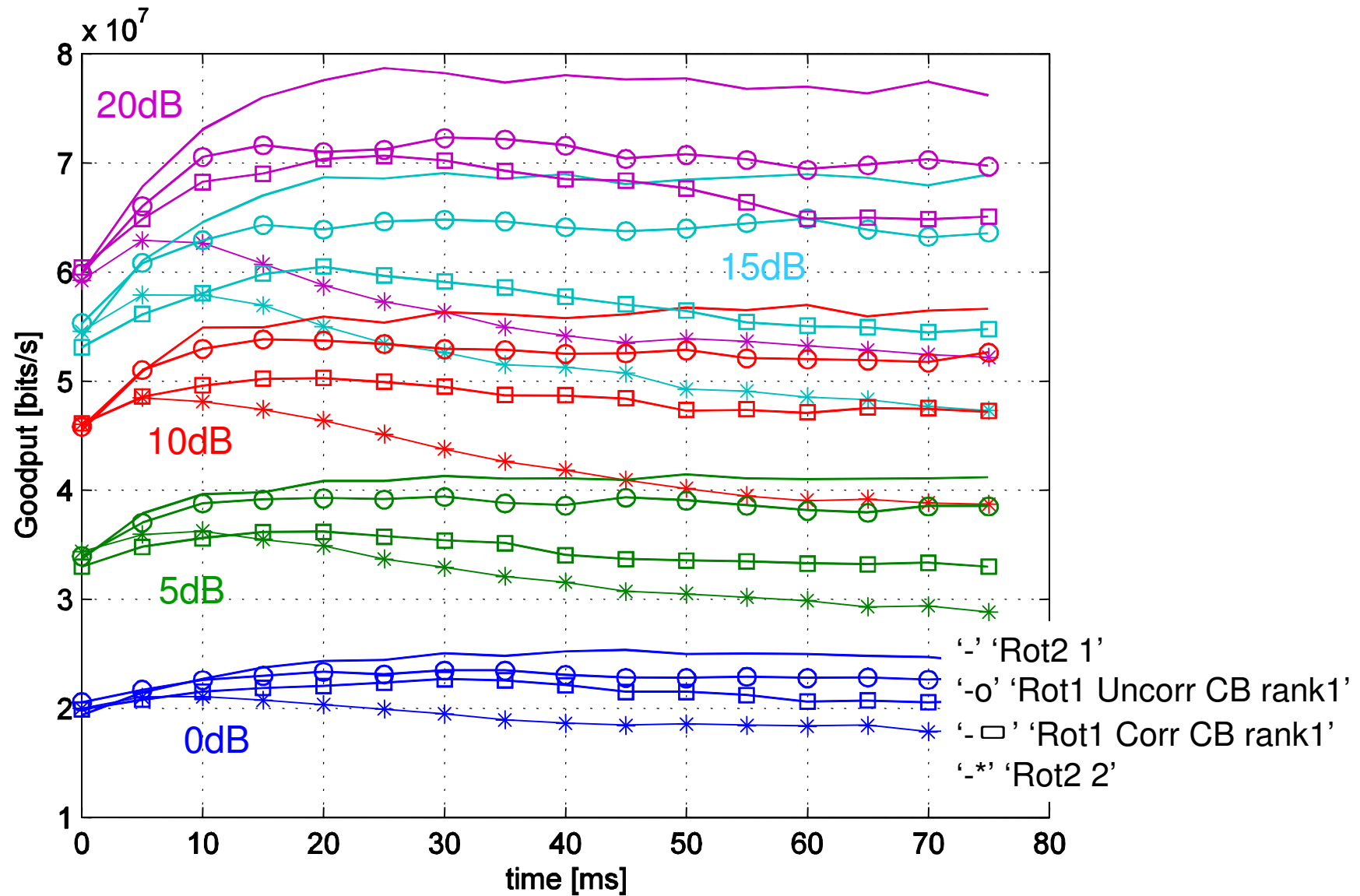
$$\hat{\mathbf{V}}(t-1) = \hat{\mathbf{Q}}(t-2) \hat{\mathbf{D}}(t-1)$$

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

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 Mazzaresse et al.)
	For all Ranks	'Rot2 2'	4 bit	C80216m-09_038r1_LGE_r1.doc (WookBong Lee et al.)

MU MIMO: uncorrelated (4λ , 15° AS)



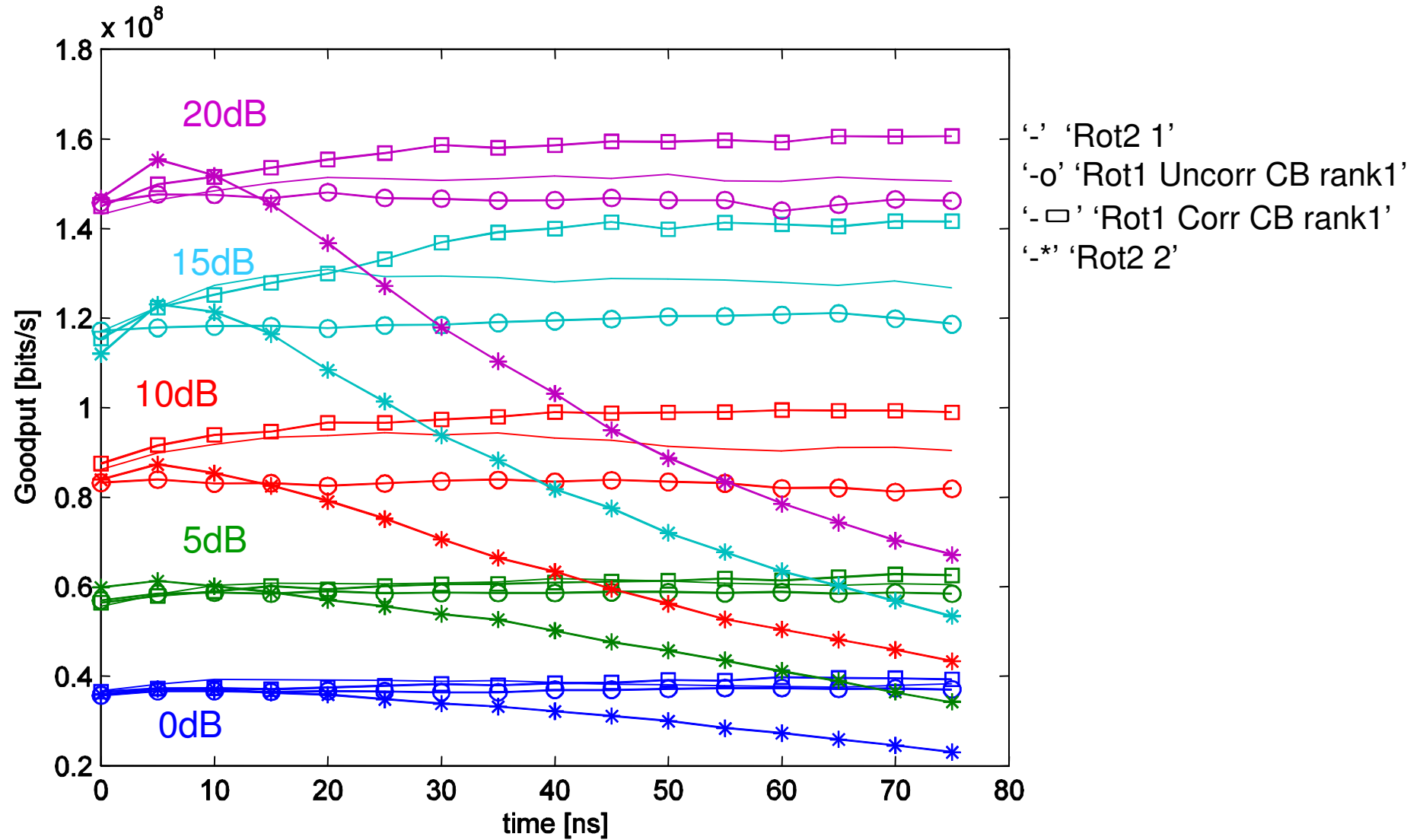
observations

- 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

- **Overall: 'Rot2 1' shows the best performance**

MU MIMO: correlated (0.5λ , 3° AS)



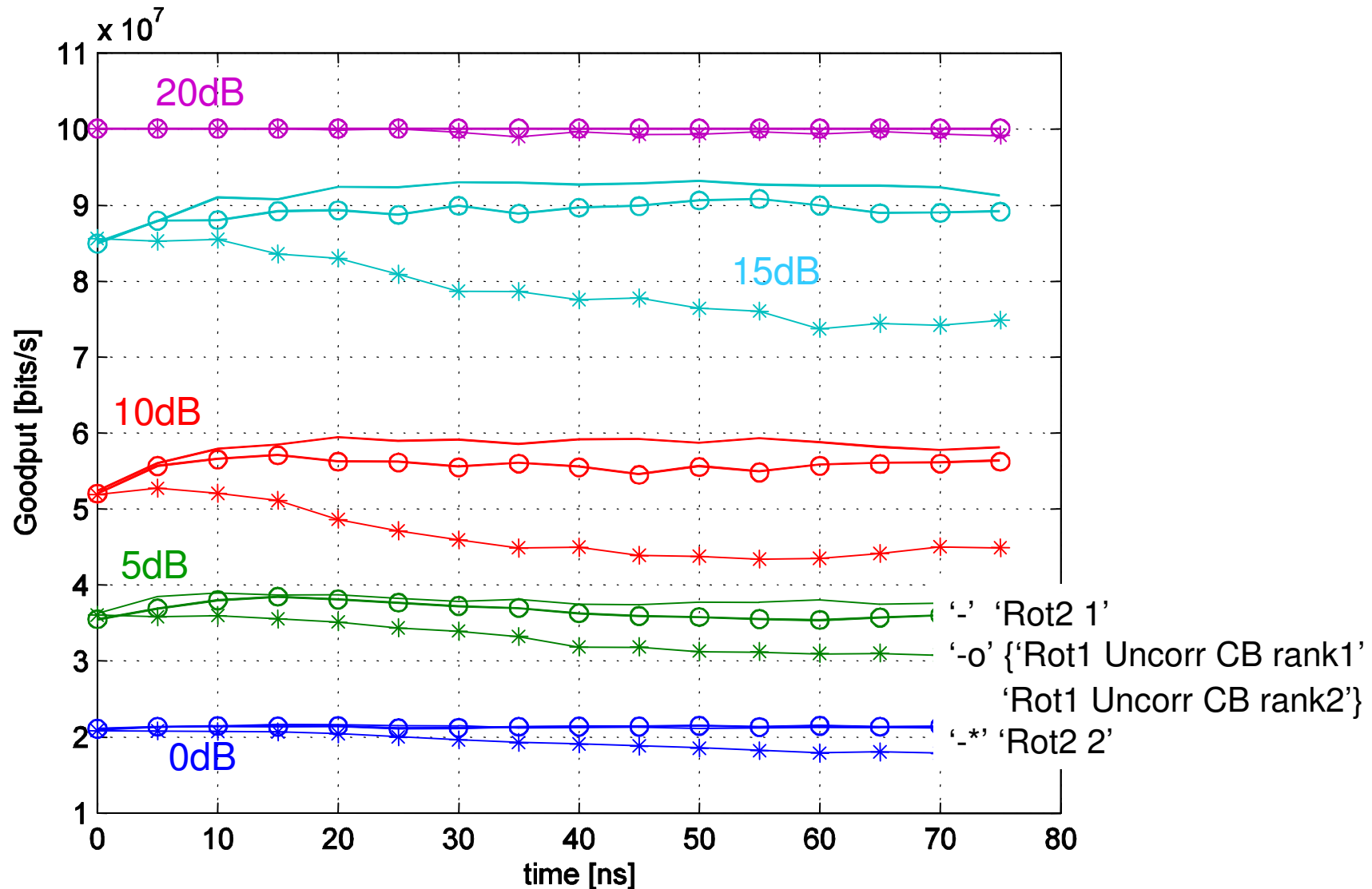
observations

- 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 (4λ , 15° AS)



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: $AS= 15$, $d/\lambda=4$
 - Correlated: $AS= 3$, $d/\lambda=0.5$
- 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