Improved Differential Codebooks for IEEE 802.16m Amendment Working Document

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Re: Category: AWD comments / Area: Chapter 15.3.7 (DL-MIMO)
"Comments on AWD 15.3.7 DL-MIMO"

Base Contribution: S80216m-09_1530r4

Purpose:
Discussion and approval

Background

- In Cairo meeting, a differential feedback method (based on rotation scheme 1) has been adopted

Based on previous precoder V(t-1)

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

Codebook

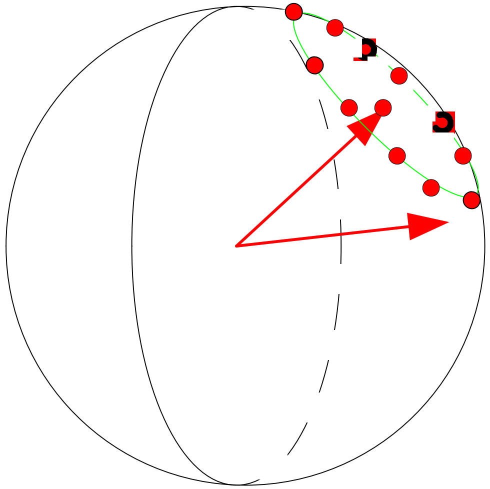
- This contribution proposes an improvement of the current AWD differential feedback mode

Motivation to change AWD 4Tx rank 1 differential codebook

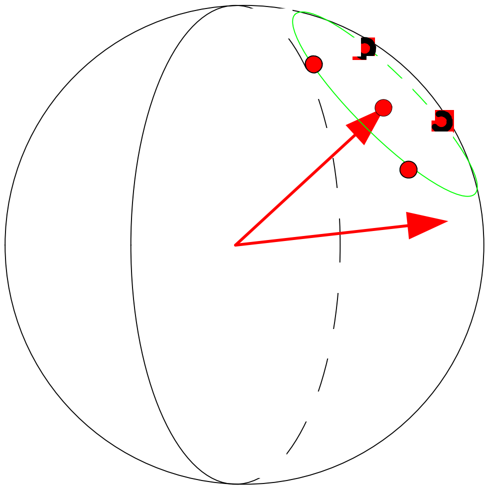
- 4bit 4Tx AWD differential codebook has been optimized (for all ranks) for spatially uncorrelated channels
  - Doesn’t provide much gain in spatially semi-correlated and correlated channels
  - Rank 1 design very important in spatially semi-correlated and correlated channels because propagation conditions not known in advance for all users
  - Robust design better if we can keep good performance overall
- SLS results in 0927r5 (Qinghua Li et al.) shows that 4bit 4Tx AWD differential codebook provides only 0.3% gain over a 3bit 4Tx AWD differential codebook (using same spherical cap size)
  - some codewords of a 4bit could be used to improve performance in other scenarios, while keeping loss strictly less than 0.3% in uncorrelated channels

- Robust 4Tx design proposed: Change 4Tx rank 1 AWD by a new differential codebook that
  - is based on the current differential feedback method adopted in AWD $\mathbf{V}(t) = \mathbf{Q}_{\mathbf{V}(t-1)}\mathbf{D}(t)$ but defines a new codebook **D**(t) and new matrix **Q** for rank 1
  - Re-uses same spherical cap size as current AWD but re-assigns 4 codewords to improve performance in correlated channels.
  - Its performance loss in uncorrelated channels should be strictly less than 0.3% compared to AWD codebook based on 0927r5 SLS results (Qinghua Li et al.)
  - significantly outperforms AWD differential codebook in spatially correlated channels
- Same design philosophy applied to 8Tx
  - rank 1 8Tx differential codebook proposed

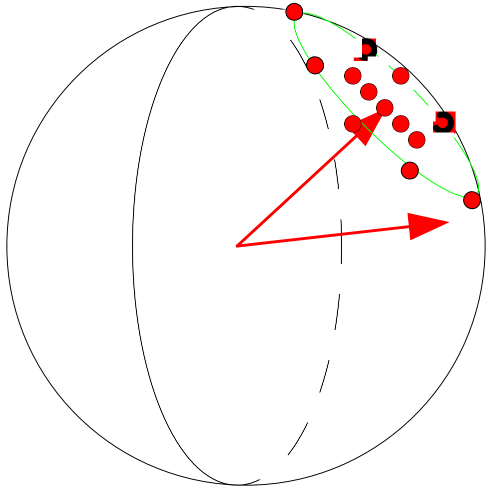
Design methodology



4Tx 4 bit AWD design
(C80216m-09_0927r5.ppt):
-15 codewords on the circumference of a 20° spherical cap
-1 codeword in the middle of the spherical cap



4Tx 3 bit design
(C80216m-09_0927r5.ppt) :
-7 codewords on the circumference of a 20° spherical cap
-1 codeword in the middle of the spherical cap



NEW 4Tx 4 bit design
-11 codewords on the circumference of a 20° spherical cap
-1 codeword in the middle of the spherical cap
-4 DFT-like vectors within the spherical cap

4bit AWD design outperforms 3bit by 0.3% in uncorrelated channels (0927r5)
Given the proposed design, the NEW 4bit will have a loss strictly smaller than 0.3% compared to AWD 4bit in uncorrelated channels

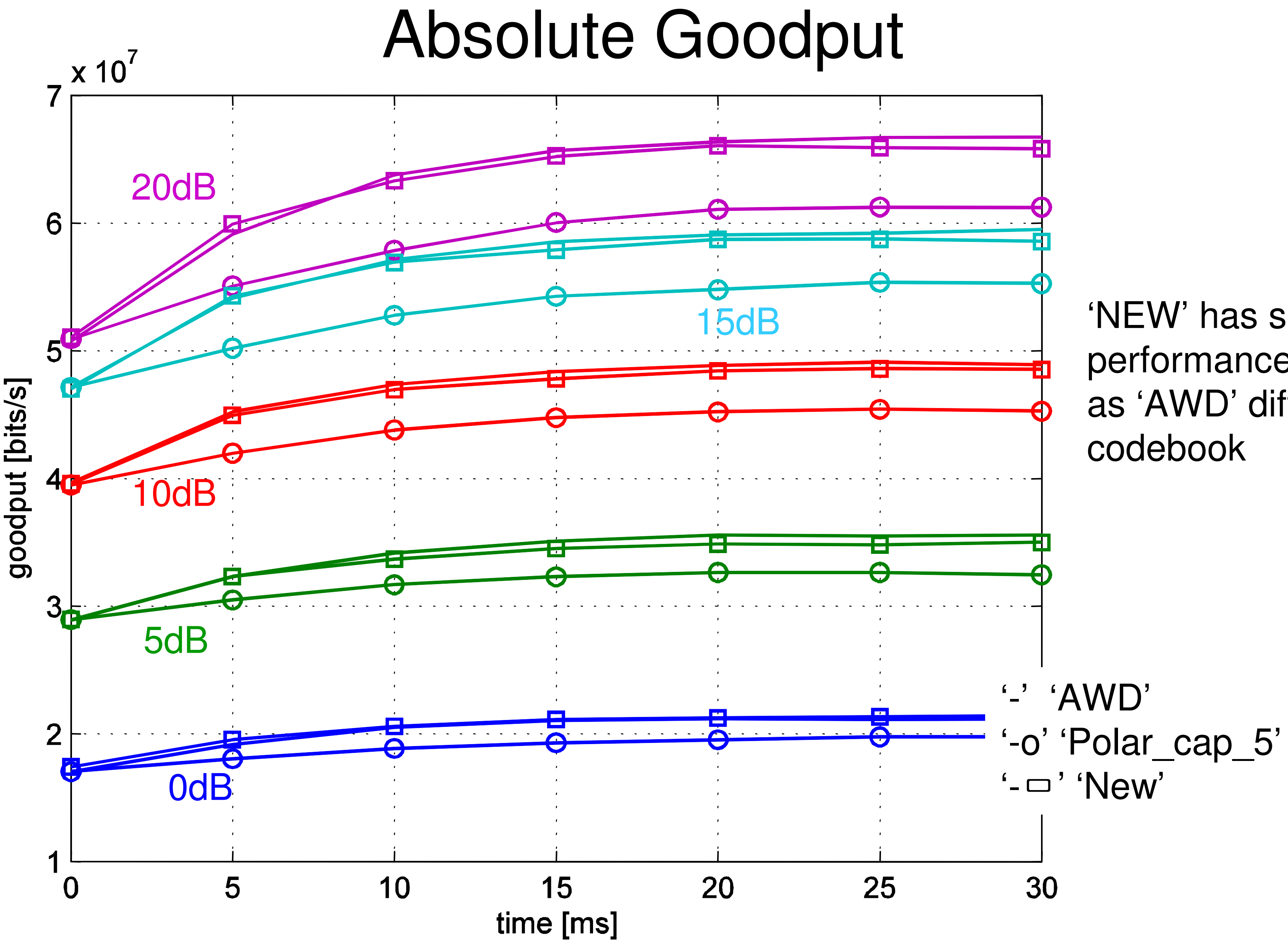
4 Tx differential codebook with 4bit base codebook

Differential 4Tx codebooks

	rank	label	Codebook size	Design philosophy	reference
Rotation schemes 1	Rank 1	'AWD'	4 bit	Designed for **spatially uncorrelated** channels (20° polar cap size)	AWD
	Rank 1	'Polar_cap_5'	4 bit	Designed for **spatially correlated** channels (5° polar cap size)	C80216m-09_0927r5.ppt (Qinghua Li et al.)
	Rank 1	'New'	4 bit	• Designed for **spatially uncorrelated and correlated** channels • Re-uses the same procedure as 'AWD' differential mode procedure $\mathbf{V}(t)=\mathbf{Q}_{\mathbf{V}(t-1)}\mathbf{D}(t)$ (i.e. right quantization) but defines a new codebook **D(t)** and new matrix **Q** for rank 1	C80216m-09_1530.doc (Bruno Clerckx et al.)

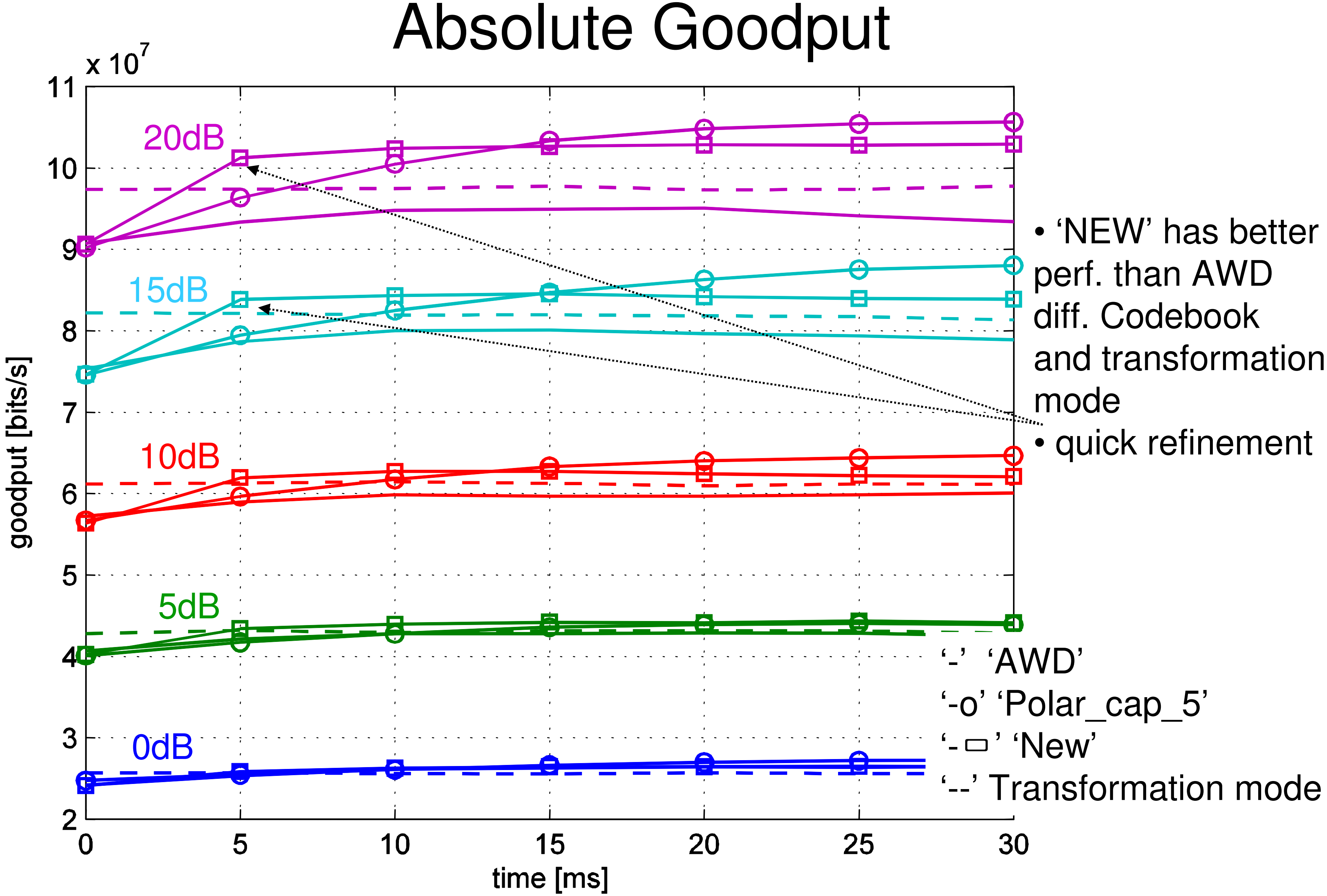
Note: The complexity of all 2 codebooks are the same since they are using the same procedure $\mathbf{V}(t)=\mathbf{Q}_{\mathbf{V}(t-1)}\mathbf{D}(t)$

4x2 MU MIMO: uncorrelated (4 λ, 15° AS), 3km/h



'NEW' has same performance as 'AWD' diff. codebook

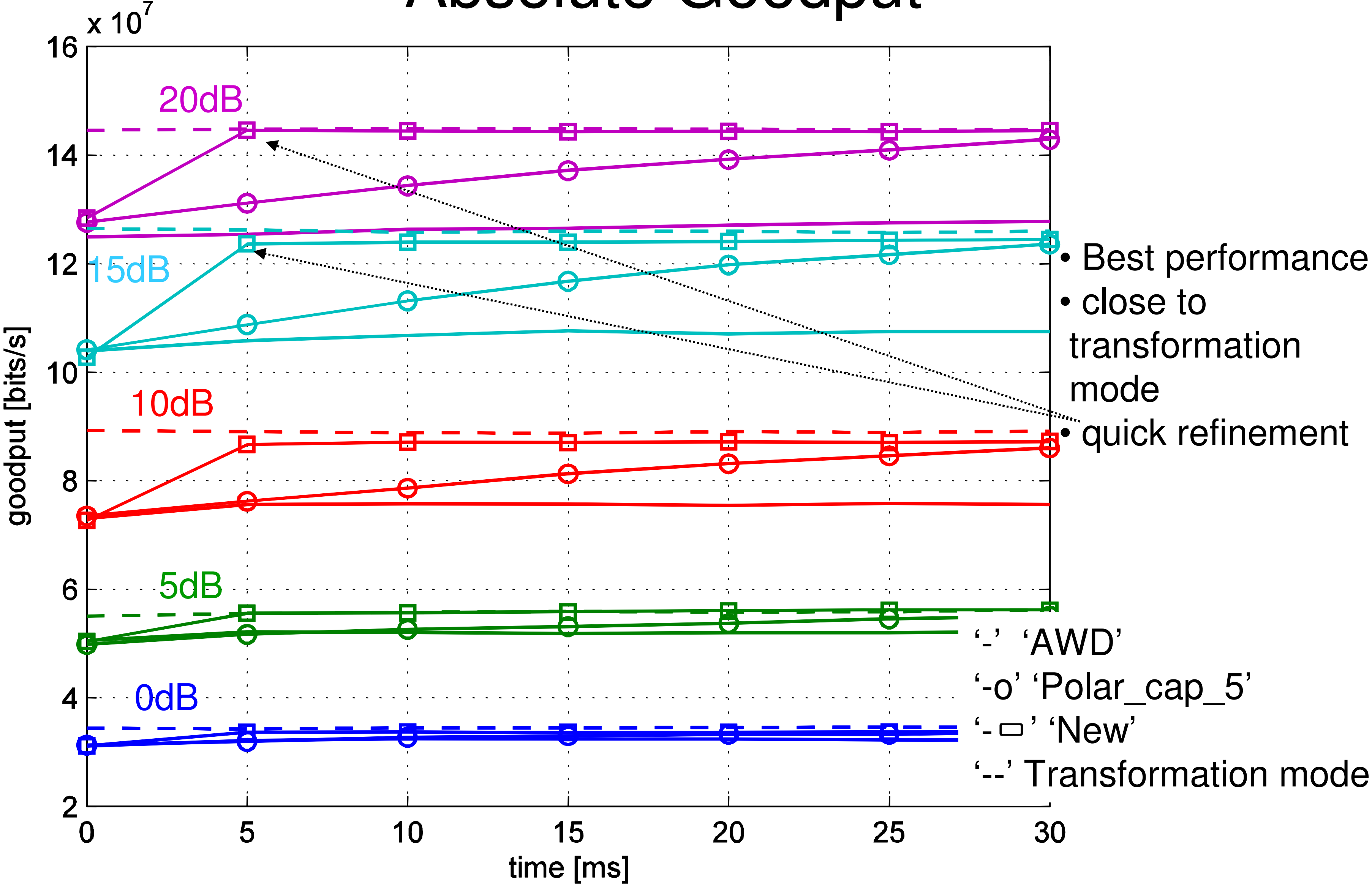
4x2 MU MIMO: semi-correlated (4 λ, 3° AS), 3km/h



- 'NEW' has better perf. than AWD diff. Codebook and transformation mode
- quick refinement

4x2 MU MIMO: correlated (0.5 λ, 3° AS), 3km/h

Absolute Goodput



4x2 MU-MIMO Performance comparisons

Performance gain over AWD 4bit base codebook

- **Spatially uncorrelated scenarios (4λ,15°)**

SNR	0dB	5dB	10dB	15dB	20dB
Gain of 'AWD' differential codebook over AWD (4bit) base codebook	18.37%	17.18%	17.89%	19.57%	23.58%
Gain of 'Polar_cap_5' differential codebook over AWD (4bit) base codebook	10.76%	9.18%	10.70%	12.04%	14.30%
Gain of 'New' differential codebook over AWD (4bit) base codebook	17.12%	15.48%	17.24%	19.23%	22.34%
Gain of transformed codebook over AWD (4bit) base codebook	Transformed codebook has about the same performance as base codebook in spatially uncorrelated channels				

- **Spatially semi-correlated scenarios (4λ,3°)**

SNR	0dB	5dB	10dB	15dB	20dB
Gain of 'AWD' differential codebook over AWD (4bit) base mode	7.03%	4.24%	3.62%	4.68%	3.30%
Gain of 'Polar_cap_5' differential codebook over AWD (4bit) base codebook	6.47%	6.90%	9.44%	11.66%	11.79%
Gain of 'New' differential codebook over AWD (4bit) base codebook	7.67%	8.01%	9.14%	10.90%	11.16%
Gain of transformed codebook over AWD (4bit) base codebook	3.58%	7.36%	7.98%	9.74%	8.05%

- **Spatially correlated scenarios (0.5λ,3°)**

SNR	**0dB**	**5dB**	**10dB**	**15dB**	**20dB**
Gain of ‘AWD’ differential codebook over AWD (4bit) standard mode	3.26%	2.62%	3.05%	2.53%	1.27%
Gain of ‘Polar_cap_5’ differential codebook over AWD (4bit) standard mode	4.71%	6.24%	9.43%	10.78%	6.69%
Gain of ‘New’ differential codebook over AWD (4bit) standard mode	6.98%	9.32%	16.92%	17.72%	10.73%
Gain of transformed codebook over AWD (4bit) base codebook	10.30%	11.85%	21.08%	21.00%	13.41%

4x2 MU-MIMO Performance comparisons

Performance gain over AWD differential codebook

	SNR	0dB	5dB	10dB	15dB	20dB
Uncor-related (4λ,15°)	Gain of 'New' over AWD differential codebook	1.15%	-1.27%	-0.88%	-0.66%	-0.34%
	Gain of 'Polar_cap_5' over AWD differential codebook	-6.21%	-6.74%	-6.63%	-6.32%	-7.15%

	SNR	0dB	5dB	10dB	15dB	20dB
Semi-Correl-ated (4λ,3°)	Gain of 'New' over AWD differential codebook	0.55%	2.56%	3.78%	4.97%	7.52%
	Gain of 'Polar_cap_5' over AWD differential codebook	1.40%	1.02%	3.9%	4.68%	7.02%

	SNR	0dB	5dB	10dB	15dB	20dB
Correl-ated (0.5λ,3°)	Gain of 'New' over AWD differential codebook	3.69%	6.26%	12.88%	13.52%	12.36%
	Gain of 'Polar_cap_5' over AWD differential codebook	1.82%	2.07%	6.86%	8.25%	7.63%

4x2 MU-MIMO Performance comparisons

Performance gain of ‘NEW’ differential codebook over transformed codebook

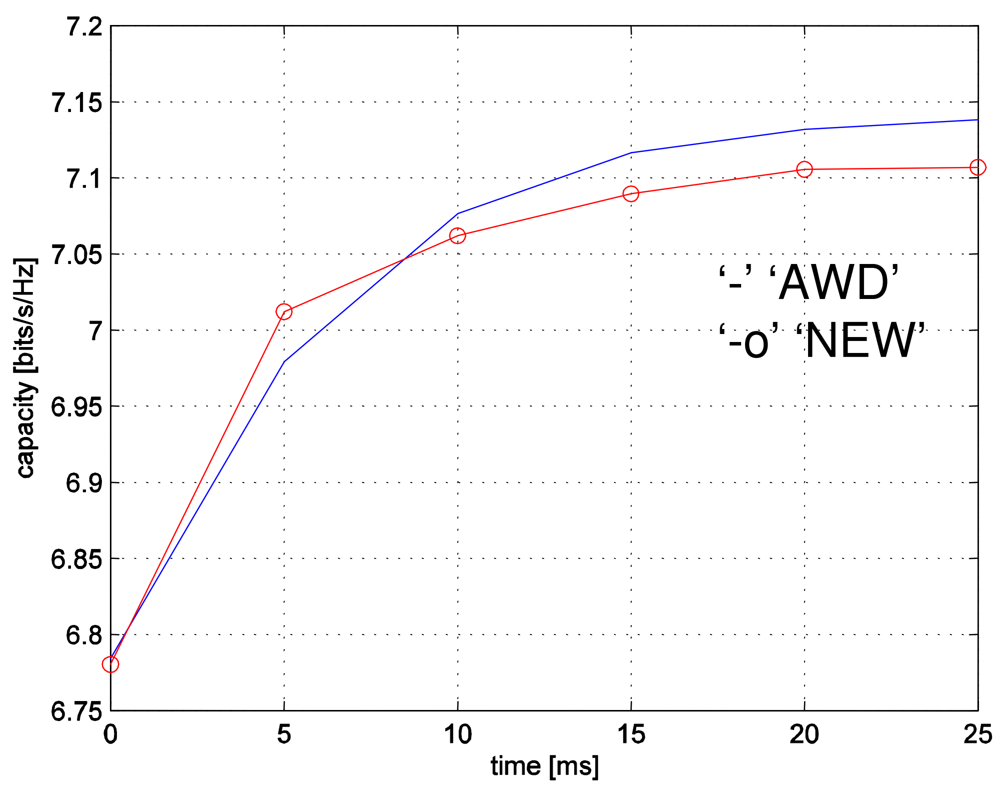
SNR	**0dB**	**5dB**	**10dB**	**15dB**	**20dB**
Spatially uncorrelated (4λ,15°)	~ 18.37%	~ 17.18%	~ 17.89%	~ 19.57%	~ 23.58%
Spatially Semi-correlated (4λ,3°)	1.57%	1.08%	0.48%	1.11%	3.33%
Spatially correlated (0.5λ,3°)	-3.33%	-1.10%	-4.52%	-3.98%	-1.77%

4Tx MU-MIMO performance

	Spatially Uncorrelated	**Spatially Semi-correlated**	**Spatially Correlated**
'AWD' differential codebook	The best performance among all modes	Slight refinement	No refinement
'Polar_cap_5' differential codebook	No refinement	Slight refinement	Good refinement but too slow
'New' differential codebook	The best performance among all modes (very similar performance as AWD diff. codebook)	The best performance among all modes	The best performance among differential codebooks
Transformed codebook	No gain (Same performance as AWD base codebook)	Small gain	The best performance

Impact on rank 3 SU-MIMO performance

- Rank 3 differential codebook is based on rank 1 codebook **D** and matrix **Q** generation method
- Since rank 1 is changed, rank 3 performance is changed



4 Tx differential codebook with 6bit base codebook

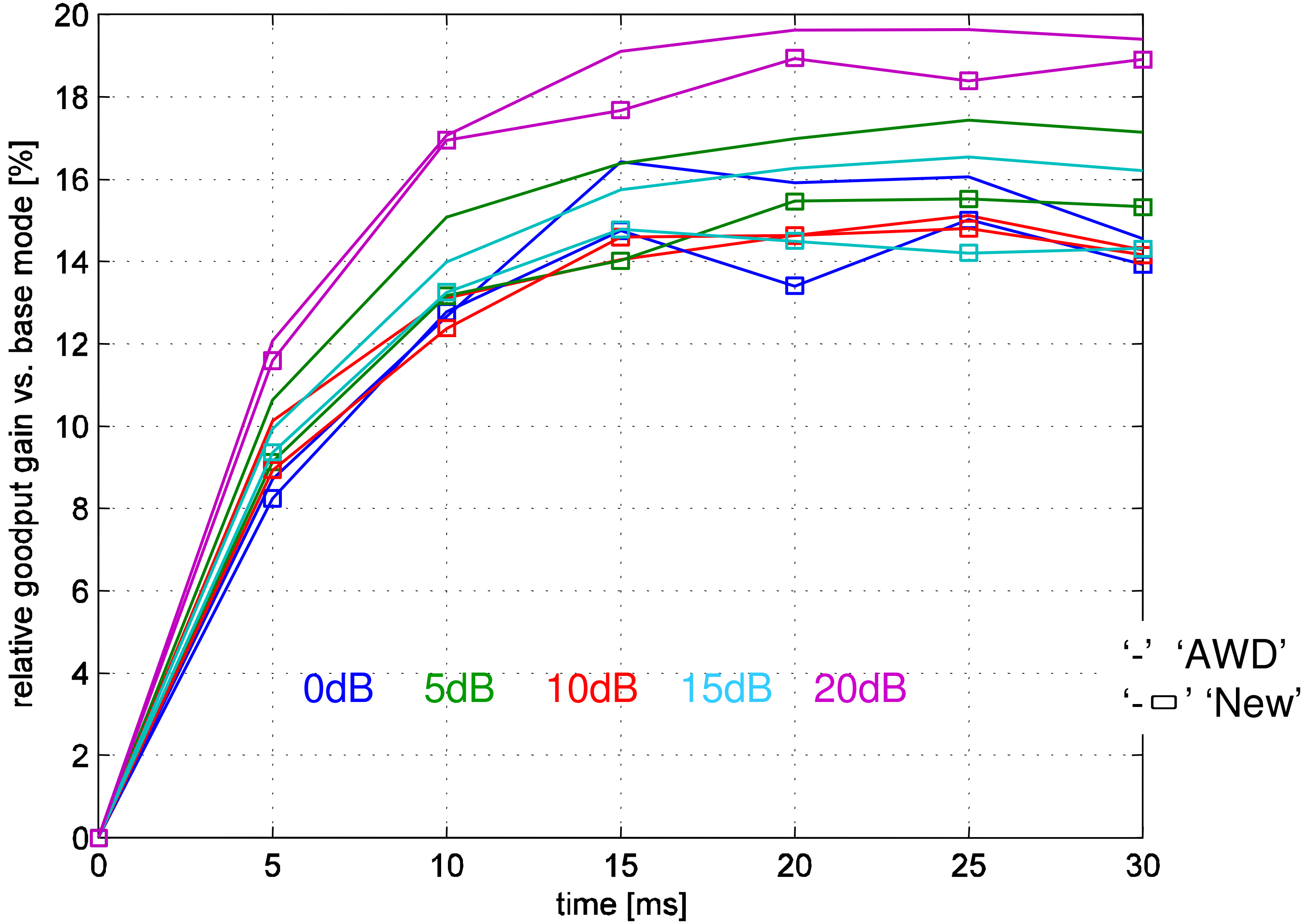
Differential 4Tx codebooks

	rank	label	Codebook size	Design philosophy	reference
Rotation schemes 1	Rank 1	'AWD'	4 bit	Designed for **spatially uncorrelated** channels (20° polar cap size)	AWD
	Rank 1	'New'	4 bit	• Designed for **spatially uncorrelated and correlated** channels • Re-uses the same procedure as 'AWD' differential mode procedure $\mathbf{V}(t)=\mathbf{Q}_{\mathbf{V}(t-1)}\mathbf{D}(t)$ (i.e. right quantization) but defines a new codebook **D(t)** and new matrix **Q** for rank 1	C80216m-09_1530.doc (Bruno Clerckx et al.)

Note: The complexity of all 2 codebooks are the same since they are using the same procedure $\mathbf{V}(t)=\mathbf{Q}_{\mathbf{V}(t-1)}\mathbf{D}(t)$

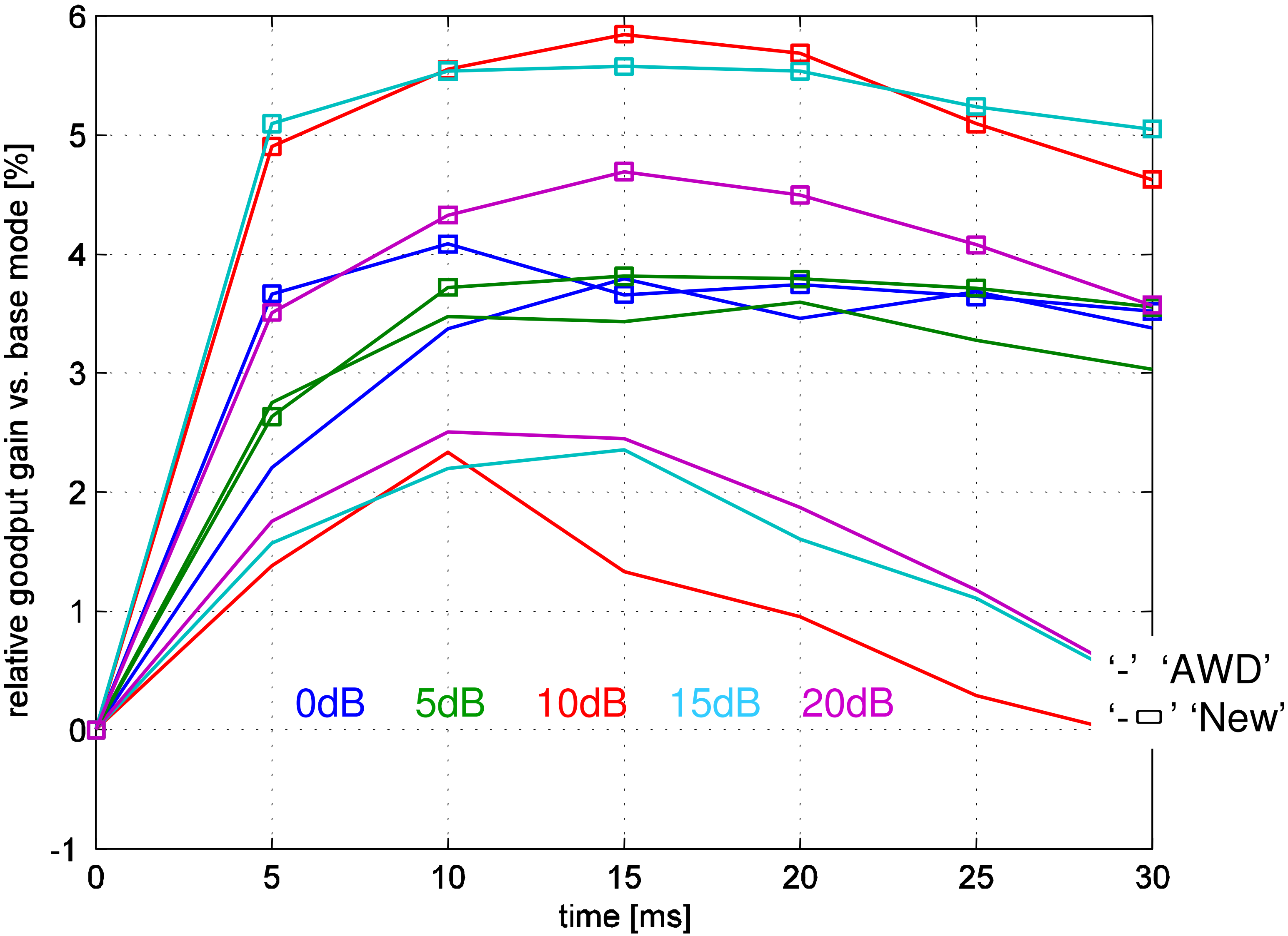
4x2 MU MIMO: uncorrelated (4 λ, 15° AS), 3km/h

Relative Goodput gain over AWD 6bit base codebook



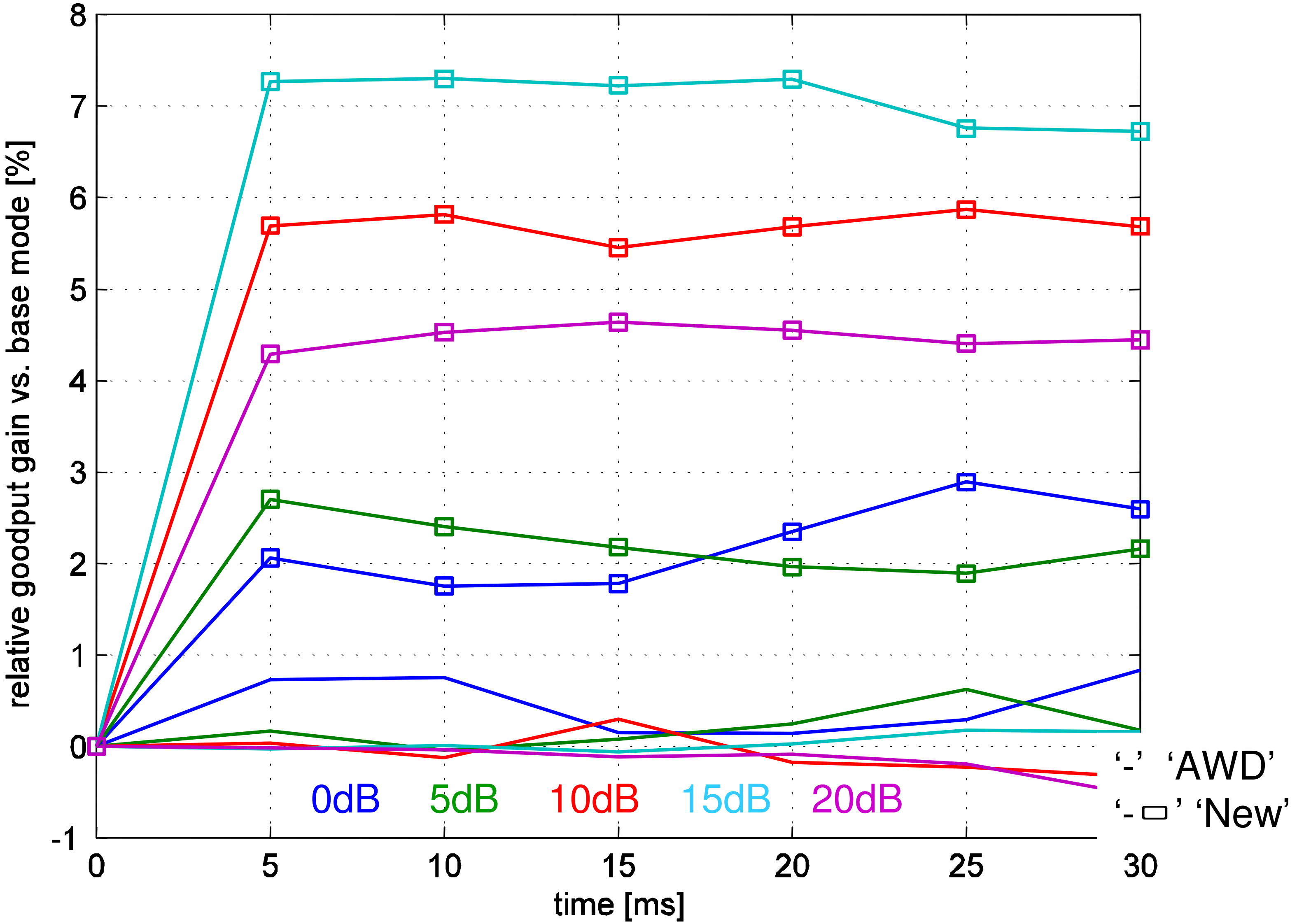
4x2 MU MIMO: semi-correlated (4 λ, 3° AS), 3km/h

Relative Goodput gain over AWD 6bit base codebook



4x2 MU MIMO: correlated (0.5 λ, 3° AS), 3km/h

Relative Goodput gain over AWD 6bit base codebook



4x2 MU-MIMO Performance comparisons

Performance gain over AWD 6bit base codebook

- Spatially uncorrelated scenarios (4λ,15°)

SNR	0dB	5dB	10dB	15dB	20dB
Gain of 'AWD' differential codebook over AWD (4bit) base codebook	12.03%	13.38%	11.61%	12.66%	15.27%
Gain of 'New' differential codebook over AWD (4bit) base codebook	11.16%	11.80%	11.35%	11.49%	14.63%

- Spatially semi-correlated scenarios (4λ,3°)

SNR	0dB	5dB	10dB	15dB	20dB
Gain of 'AWD' differential codebook over AWD (4bit) base mode	2.84%	2.79%	0.89%	1.31%	1.45%
Gain of 'New' differential codebook over AWD (4bit) base codebook	3.19%	3.03%	4.53%	4.58%	3.52%

4x2 MU-MIMO Performance comparisons

Performance gain over AWD 6bit base codebook

- Spatially correlated scenarios (0.5λ,3°)

SNR	**0dB**	**5dB**	**10dB**	**15dB**	**20dB**
Gain of ‘AWD’ differential codebook over AWD (4bit) standard mode	0.41%	0.17%	-0.07	0.04	-0.14
Gain of ‘New’ differential codebook over AWD (4bit) standard mode	1.92%	1.90%	4.88%	6.08%	3.84%

4x2 MU-MIMO Performance comparisons

Performance gain over AWD differential codebook

	SNR	0dB	5dB	10dB	15dB	20dB
Uncor-related (4λ,15°)	Gain of 'New' over AWD differential codebook	-0.92%	-0.84%	-0.82%	-0.48%	-0.91%

	SNR	0dB	5dB	10dB	15dB	20dB
Semi-Correl-ated (4λ,3°)	Gain of 'New' over AWD differential codebook	1.71%	0.1%	3.36%	4.40%	1.53%

	SNR	0dB	5dB	10dB	15dB	20dB
Correl-ated (0.5λ,3°)	Gain of 'New' over AWD differential codebook	2.03%	0.97%	5.89%	5.51%	1.89%

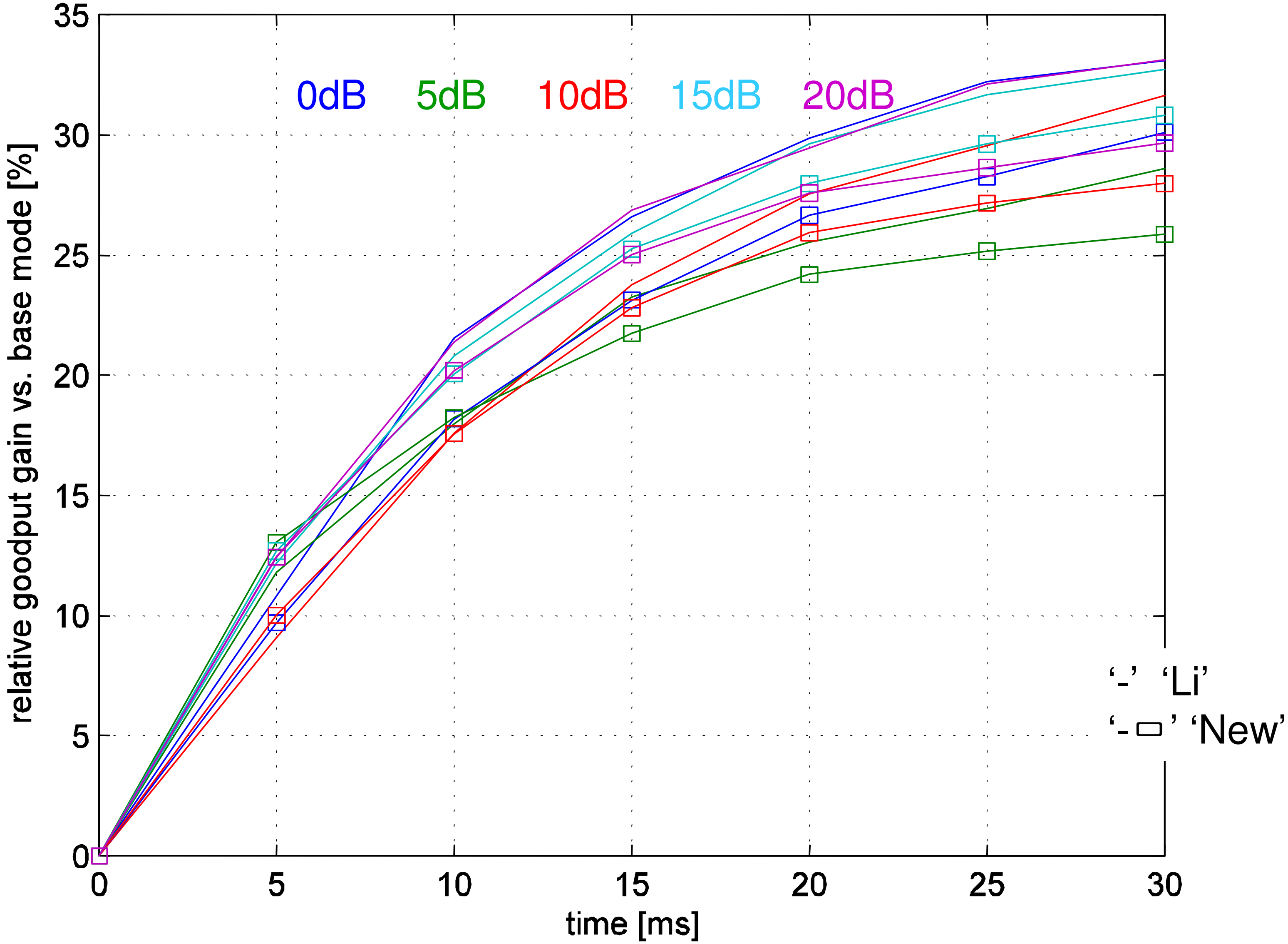
8 Tx

Differential 8Tx codebooks

	rank	label	Codebook size	Design philosophy	reference
Rotation schemes 1	Rank 1	‘Li’	4 bit	• Designed for **spatially uncorrelated** channels • Re-uses the same procedure as ‘AWD’ differential mode procedure (i.e. right quantization).	C80216m-09_1429.doc (Qinghua Li et al.)
	Rank 1	‘New’	4 bit	• Designed for **spatially uncorrelated and correlated** channels • Re-uses the same procedure as ‘AWD’ differential mode procedure (i.e. right quantization).	C80216m-09_1530.doc (Bruno Clerckx et al.)

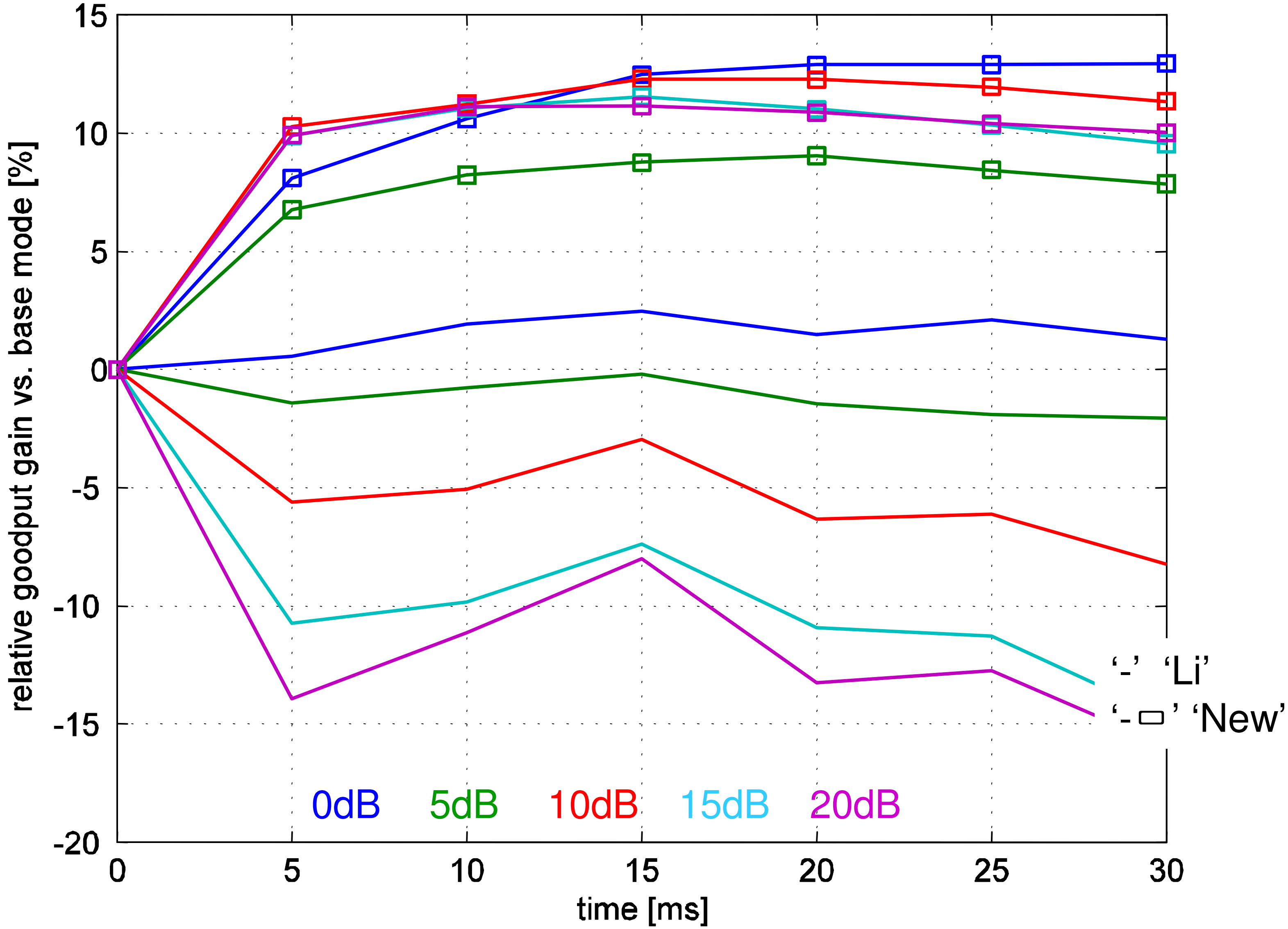
8x2 MU MIMO: uncorrelated (4 λ, 15° AS), 3km/h

Relative Goodput gain over base mode



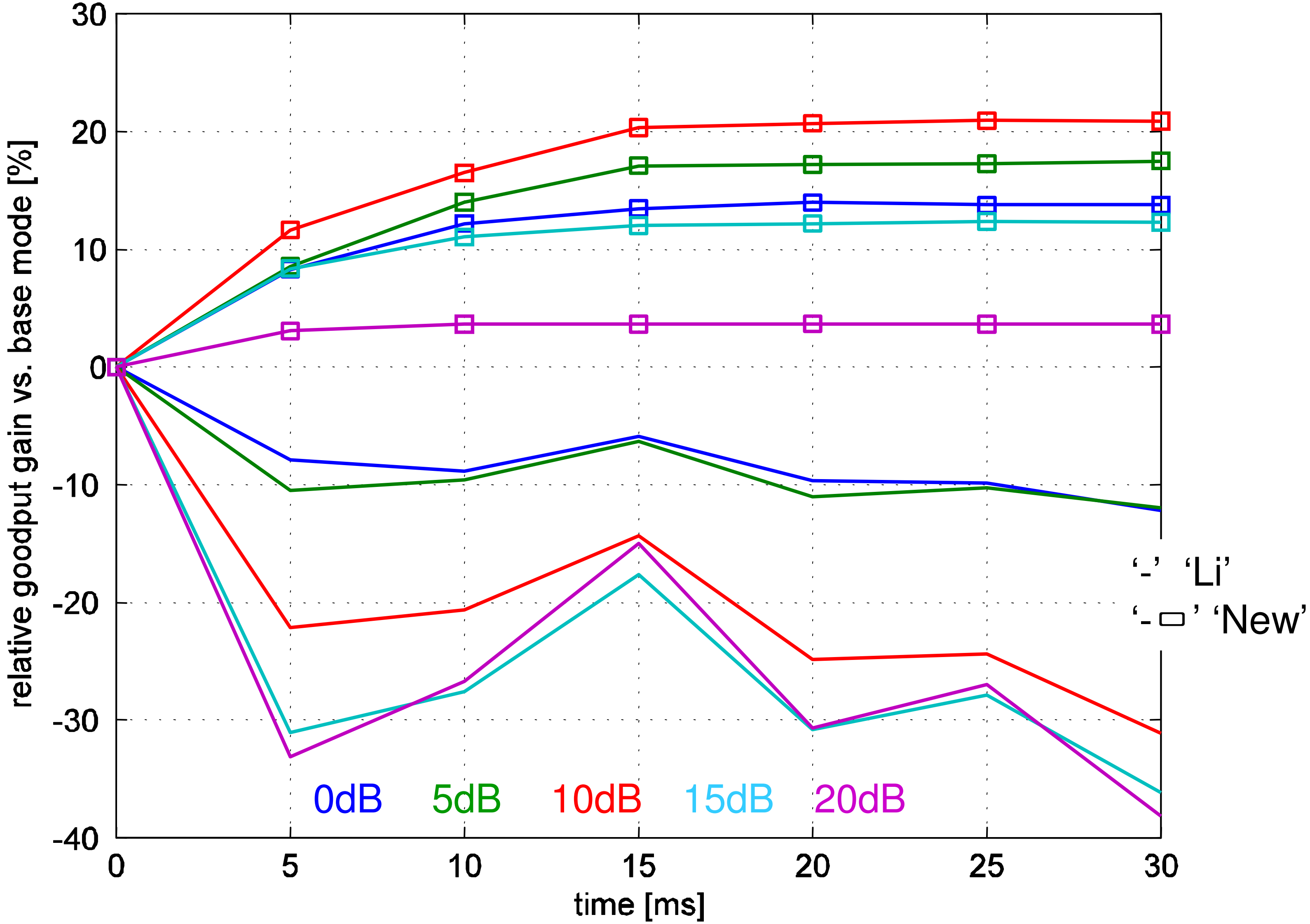
8x2 MU MIMO: semi-correlated (4 λ, 3° AS), 3km/h

Relative Goodput gain over base mode



8x2 MU MIMO: correlated (0.5 λ, 3° AS), 3km/h

Relative Goodput gain over base mode



8x2 MU-MIMO Performance comparisons

Performance gain over AWD 4bit base codebook

	SNR	0dB	5dB	10dB	15dB	20dB
Uncor-related (4λ,15°)	Gain of 'Li' differential codebook over AWD (4bit) standard mode	21.74%	19.15%	19.87%	21.84%	22.19%
	Gain of 'New' differential codebook over AWD (4bit) standard mode	19.63%	18.32%	18.78%	20.91%	20.50%

Semi-correl-ated (4λ,3°)	Gain of 'Li' differential codebook over AWD (4bit) standard mode	1.4%	-1.11%	-4.90%	-9.26%	-10.71%
	Gain of 'New' differential codebook over AWD (4bit) standard mode	9.99%	7.01%	9.91%	9.05%	9.06%

Correl-ated (0.5λ,3°)	Gain of 'Li' differential codebook over AWD (4bit) standard mode	-7.76%	-8.53%	-19.65%	-24.43%	-24.36%
	Gain of 'New' differential codebook over AWD (4bit) standard mode	10.78%	13.09%	15.85%	9.75%	3.04%

8x2 MU-MIMO Performance comparisons

Performance gain over 'Li' differential codebook

	SNR	0dB	5dB	10dB	15dB	20dB
Uncor-related (4λ,15°)	Gain of 'New' over 'Li' differential codebook	-0.93%	-0.32%	-0.21%	-1.02%	-0.64%

	SNR	0dB	5dB	10dB	15dB	20dB
Semi-Correl-ated (4λ,3°)	Gain of 'New' over 'Li' differential codebook	5.64%	6.71%	13.22%	16.15%	18.02%

	SNR	0dB	5dB	10dB	15dB	20dB
Correl-ated (0.5λ,3°)	Gain of 'New' over 'Li' differential codebook	18.59%	23.08%	42.57%	48.53%	35.84%

Conclusions

- Current AWD differential codebook is optimized for spatially uncorrelated channels and is not robust in spatially correlated channels
- A single differential codebook jointly designed for both spatially uncorrelated, semi-correlated and correlated channels is proposed
- The proposed rank 1 codebook design for 4Tx and 8Tx
  - In spatially uncorrelated channels,
    - Significantly outperforms the standard and adaptive mode
    - Achieves similar performance as AWD differential codebook (for 4Tx) and 'Li' codebook (for 8Tx)
  - In spatially semi-correlated channels,
    - Significantly outperforms the standard mode
    - Outperforms AWD differential codebook (for 4Tx) and 'Li' codebook (for 8Tx)
    - Outperforms the adaptive mode
  - In spatially correlated channels,
    - Significantly outperforms AWD differential codebook and 'Li' codebook
    - Significantly outperforms other differential codebook specifically designed for spatially correlated channels
    - Come very close to the performance of the adaptive mode
  - Enables quicker refinement compared to other candidate differential codebooks
- We propose to adopt this 'NEW' rank 1 design as the rank 1 differential feedback mode for codebook based feedback
  - The best performance and robustness in spatially uncorrelated, semi-correlated and uncorrelated channels
  - Same complexity as current AWD differential codebook
  - less sensitive to error propagation thanks to its quicker refinement
    - Significant throughput enhancement already achievable after a single differential feedback

Simulation Assumptions

- Channel model: Pedestrian B channel model, 3km/h, linear array
  - Uncorrelated: AS= 15, d/λ=4
  - Semi-correlated: AS=3, d/λ=4
  - Correlated: AS= 3, d/λ=0.5
- 10 MHz
- HARQ (Chase Combining, non-adaptive) with 3 retransmissions
  - Delay first transmission: 8 subframes
  - Delay between re-transmissions: 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, MMSE CQI and PMI selection
- No CQI transmission errors
- ZFBF with rank adaptation
- LLRU (4 PRUs)
- Base codebook: 4bit subset AWD C80216m-09_0513r2.doc
- Ideal antenna calibration
- No constraint on PAPR
- adaptive mode: correlation matrix feedback every 80ms and unquantized
- Differential codebook throughput calculated over 30 ms (i.e. reset period=30ms)

Text proposal

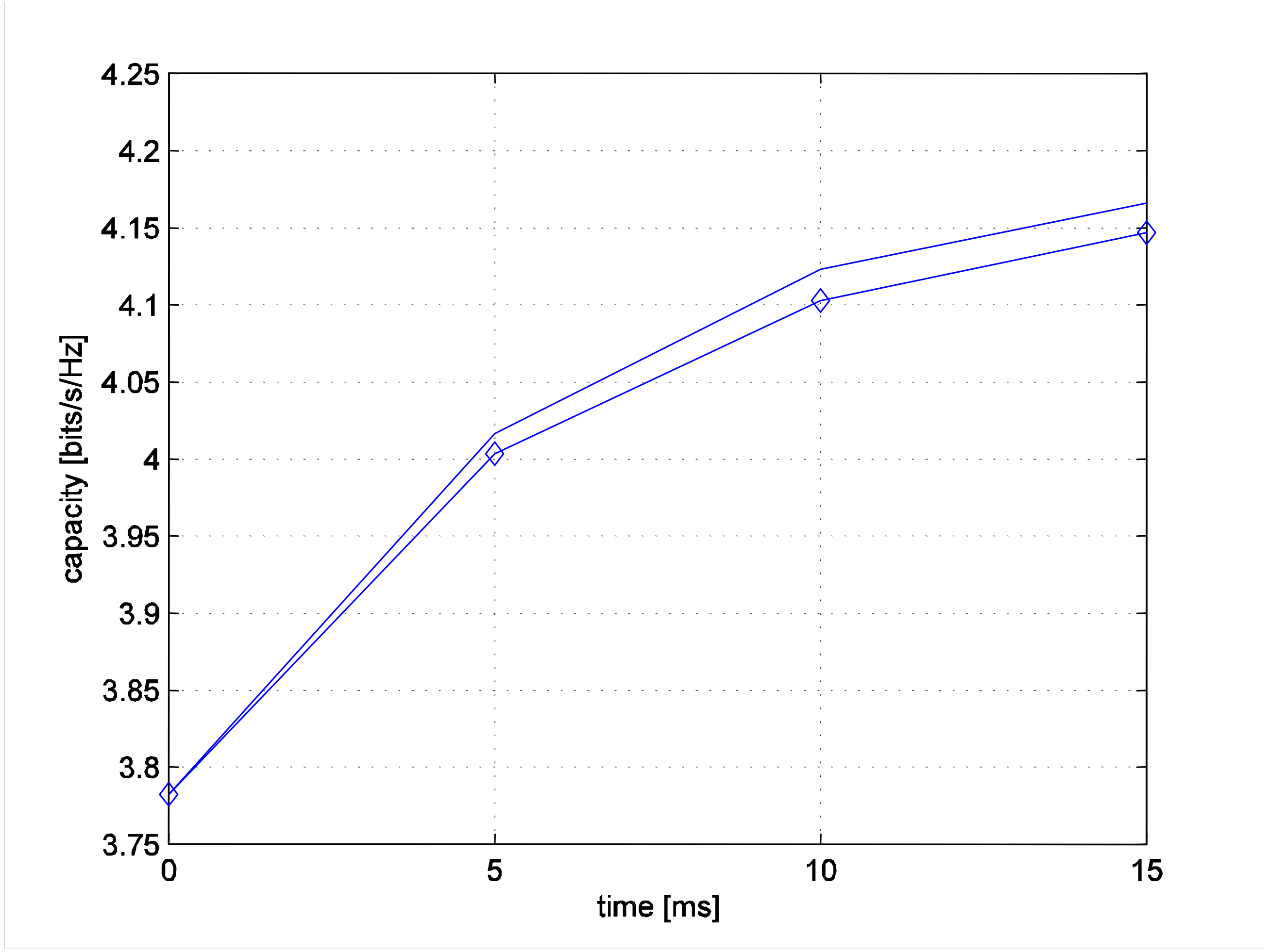
- Refer to C80216m-09_1530r3

Appendix: results using simple capacity expression

Simulation assumption

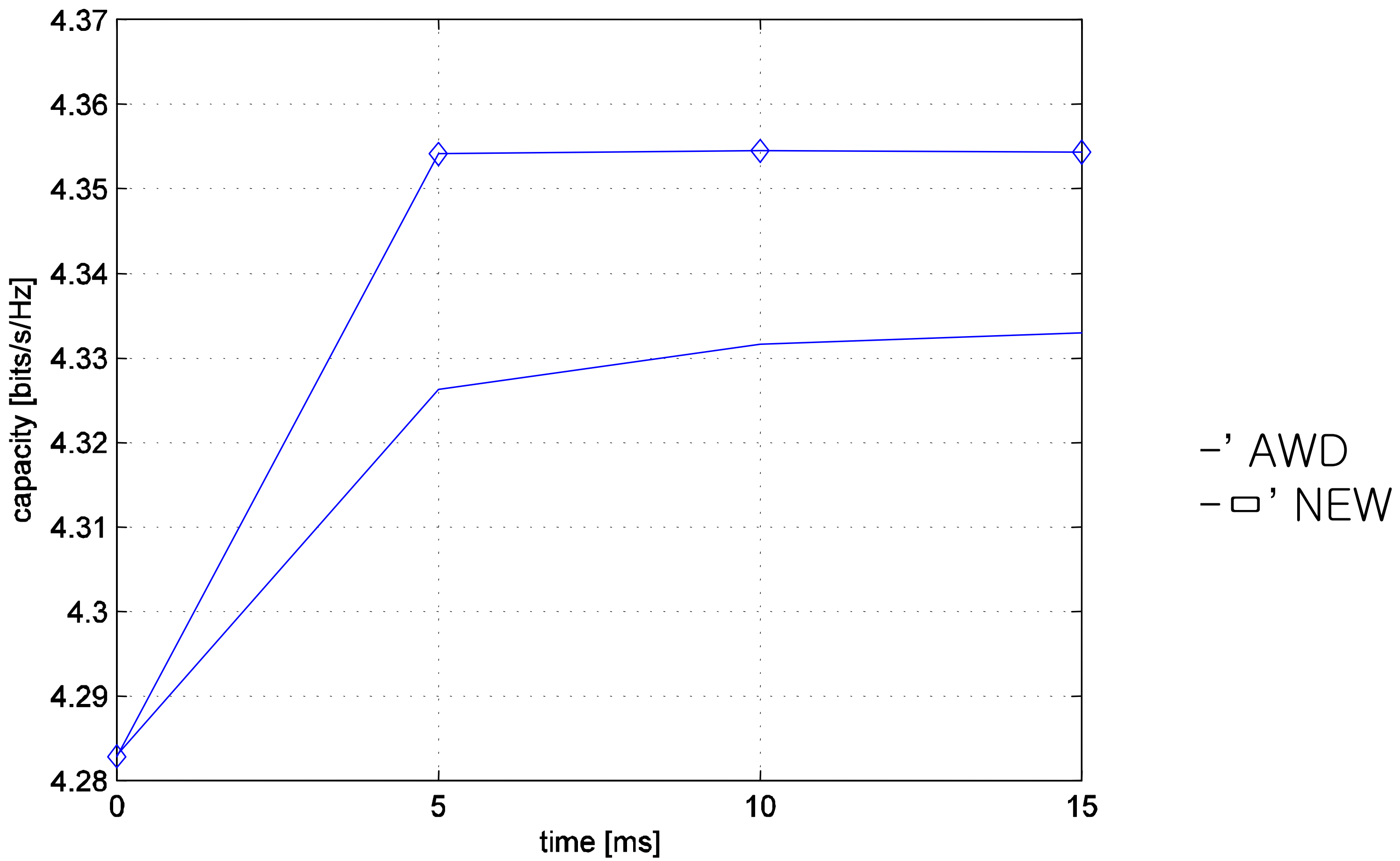
- Link level
- Channel capacity
- Compare to AWD codebook
  - AWD codebook.
  - C80216m-09-1530.
- SNR 5dB
- Single spatial stream
- 4bit 4Tx base codebook

Spatially i.i.d. channel, 4x2, SU-MIMO
1 stream, 1user

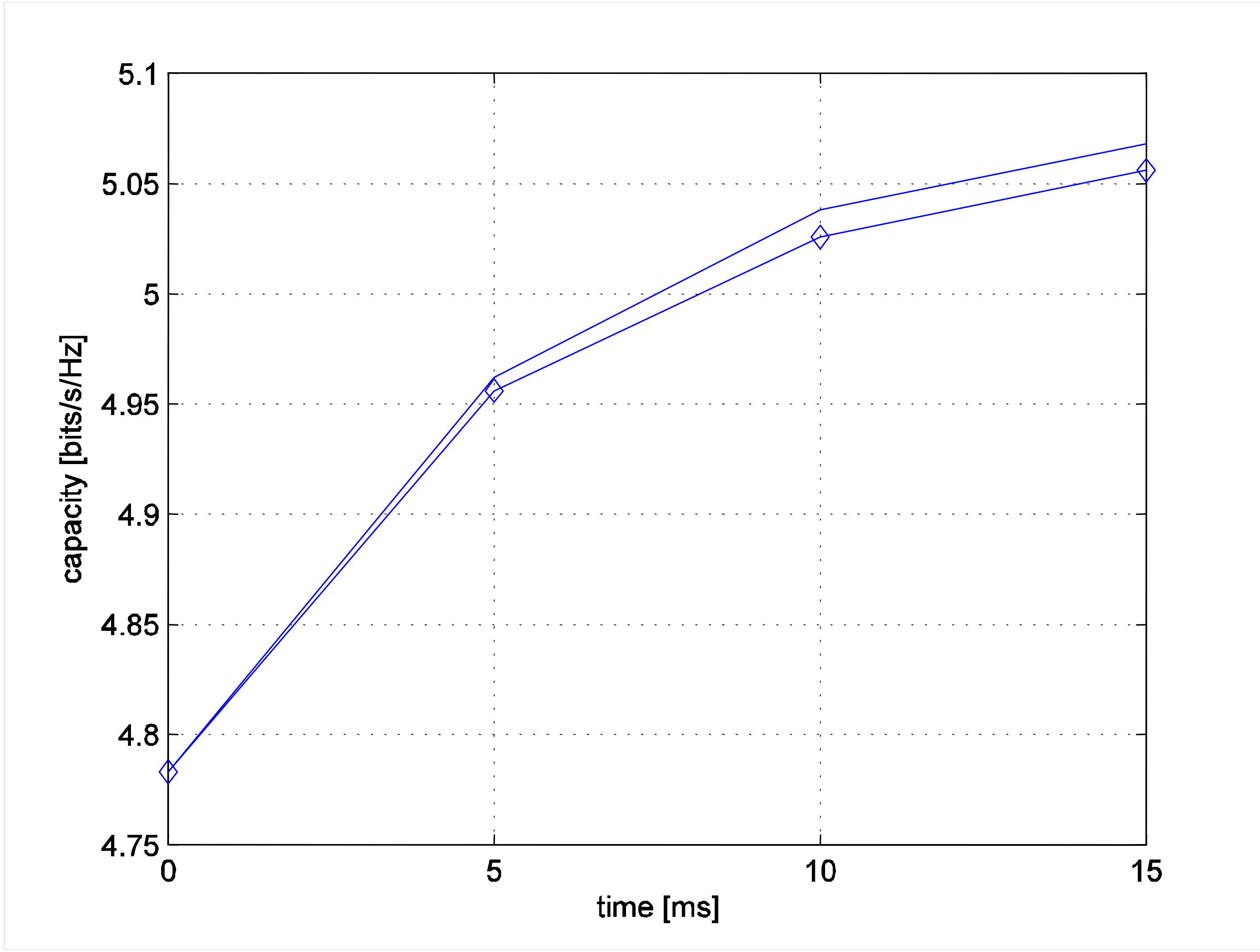


'–' AWD
'–▭' NEW

correlated channel, 4x2, SU-MIMO 1 stream, 1user



uncorrelated channel, 4x2, SU-MIMO 1 stream, 10 users



AWD
’ NEW

correlated channel, 4x2, SU-MIMO 1 stream, 10 users