Evaluation of Codebook and Differential Feedback for DL Closed-Loop SU-MIMO

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*<http://standards.ieee.org/faqs/affiliationFAQ.html>

Re: SDD Session 56 Cleanup, Call for PHY Details; in response to the Call for Contributions and Comments on Project 802.16m System Description Document (SDD) 802.16m-08/033 for Session 57.

Purpose: To evaluate different codebook candidates and differential feedback for CL SU-MIMO schemes

Introduction

- This contribution compares different codebook candidates with/without differential feedback.
- Both system-level and link-level simulation results are provided.
- Evaluated schemes include:
  - IEEE 802.16e codebook [1]
  - DFT-based codebook [2]
  - IEEE 802.16e codebook with differential feedback[3]*
  - DFT-based codebook with differential feedback[3]*

*Also see appendix

System-Level Performance Comparison

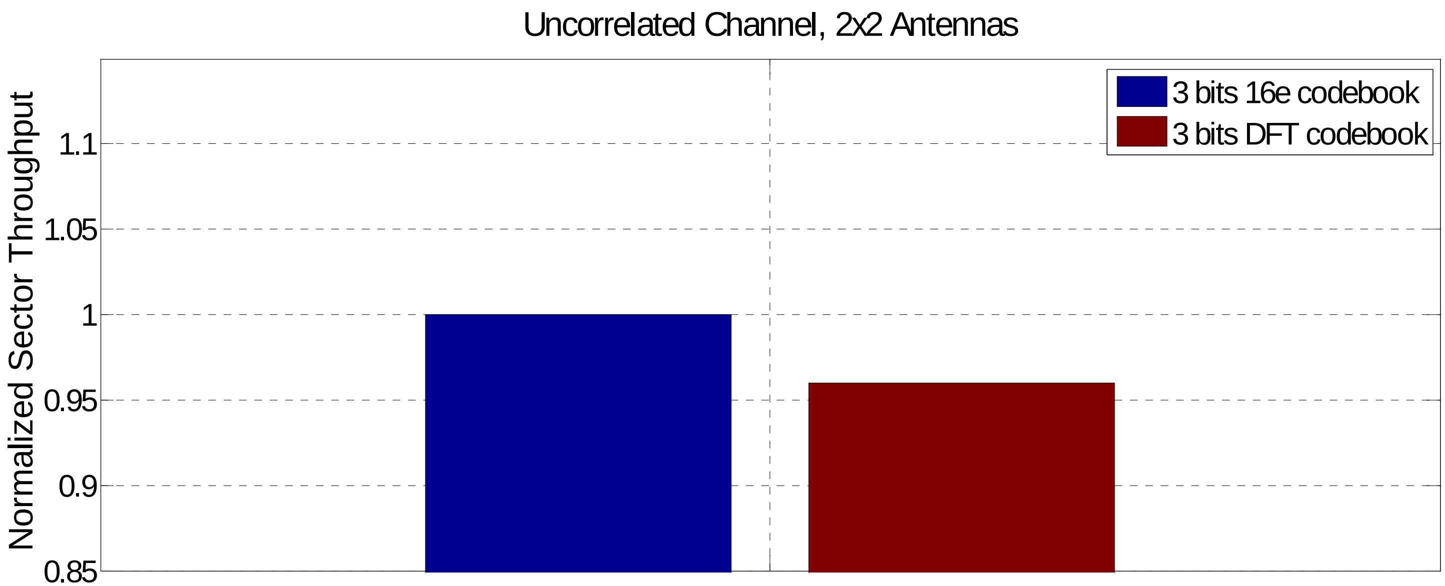
Simulation Parameters (1/2)

Parameters	Assumptions
OFDM parameters	10 MHz (1024 subcarriers)
Number of OFDM symbols per subframe	6
Permutation / Channelization	Localized
Number of total RU in one subframe	48
Number of RU for PMI and CQI calculation	4
Number of RU for rank calculation	Whole band
Rank feedback period	Every 1 super-frame (20ms)
CQI, PMI feedback period	Every 1 frame (5ms)
CQI, PMI feedback delay	1 frame (5ms)
MCS levels	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
MIMO receiver	Linear Minimum Mean Squared Error (LMMSE)
Data Channel Estimation	Perfect channel estimation
Feedback Channel Estimation	Perfect feedback channel estimation
Link to System Mapping	RBIR
HARQ Retransmission	Chase Combining, Maximum 4 re-transmissions.

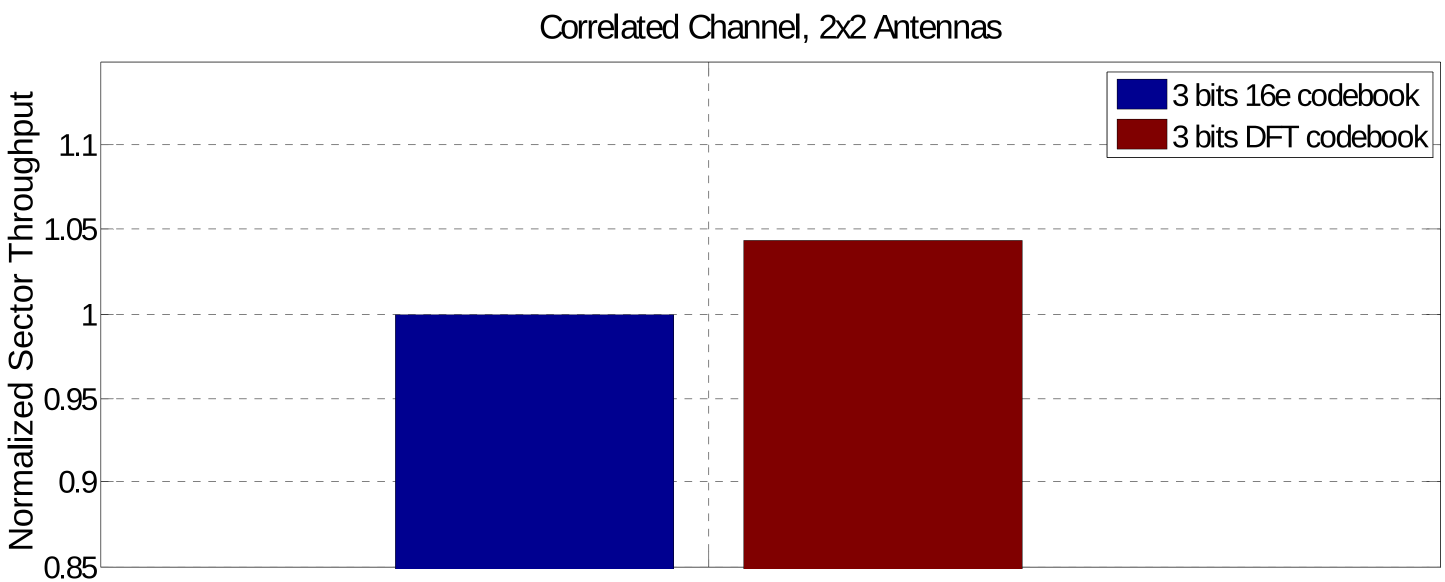
Simulation Parameters (2/2)

Parameters	Assumptions
Cellular Layout	Hexagonal grid, 19 cell sites, 3 sectors per site
Distance-dependent path loss	L=130.19 + 37.6log$_{10}$(.R), R in kilometers
Inter site distance	1.5km
Shadowing standard deviation	8 dB
Antenna pattern (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
Scheduling Criterion	Proportional Fair
Users per sector	10
Other Cell interference	56 dominant interferers
Channel Models	ITU Ped-B
Mobile Speed (km/h)	3 km/h
Number of Antennas	2 transmitter, 2 receiver [2Tx, 2Rx] 4 transmitter, 2 receiver [4Tx, 2Rx]
Channel Scenario	Mandatory Scenario (Baseline configuration in [1]) - Spatially Correlated Channel : 4 lambda antenna spacing with angular spread of 3 degree - Uncorrelated Channel : Zero Correlation

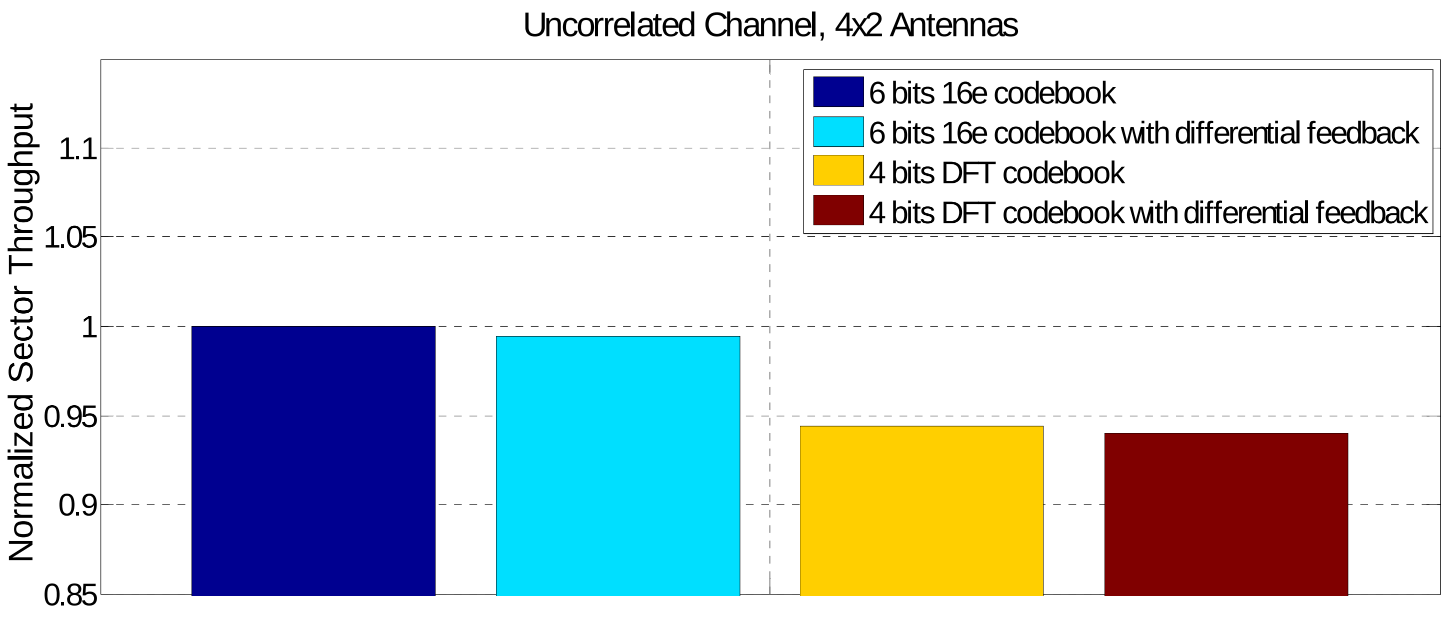
Uncorrelated Channel: 2x2 Antennas



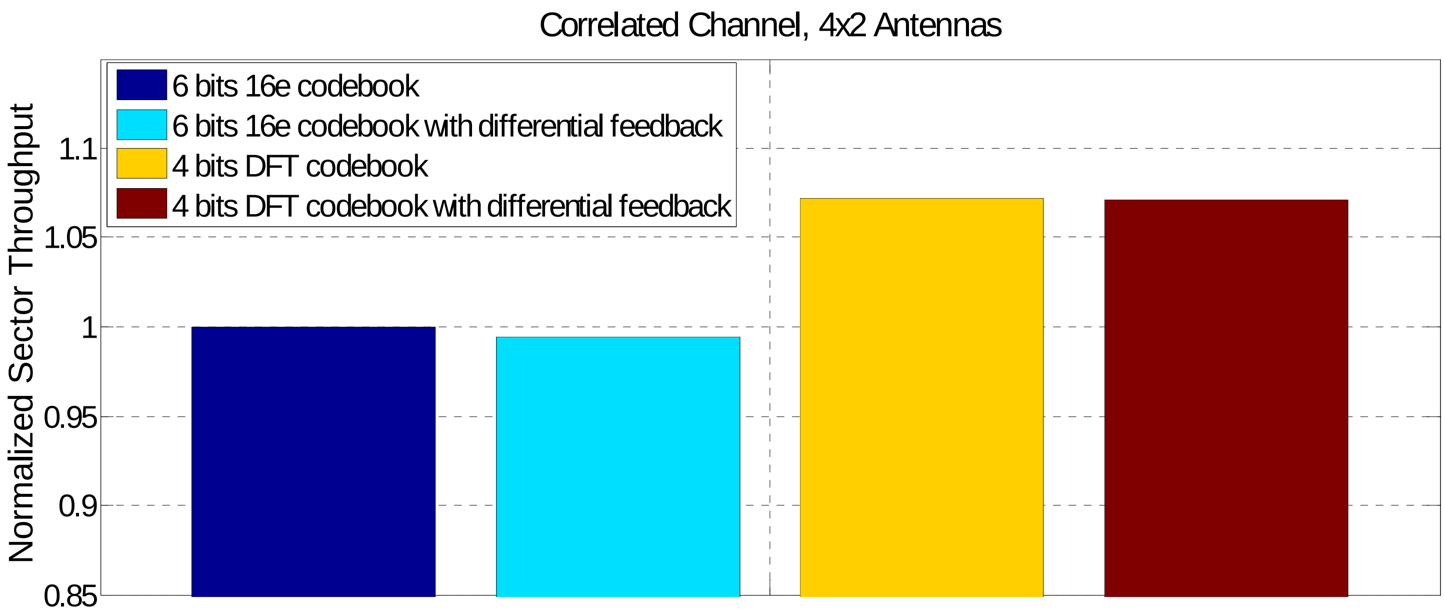
Correlated Channel: 2x2 Antennas



Uncorrelated Channel: 4x2 Antennas



Correlated Channel: 4x2 Antennas



Feedback Overhead Comparison

	16e	DFT	16e with differential feedback	DFT with differential feedback
2 Tx ant 2 Rx ant	3bits	3bits	N/A	N/A
4 Tx ant 2 Rx ant	6bits	4bits	3bits	2bits

Summary of SLS Results

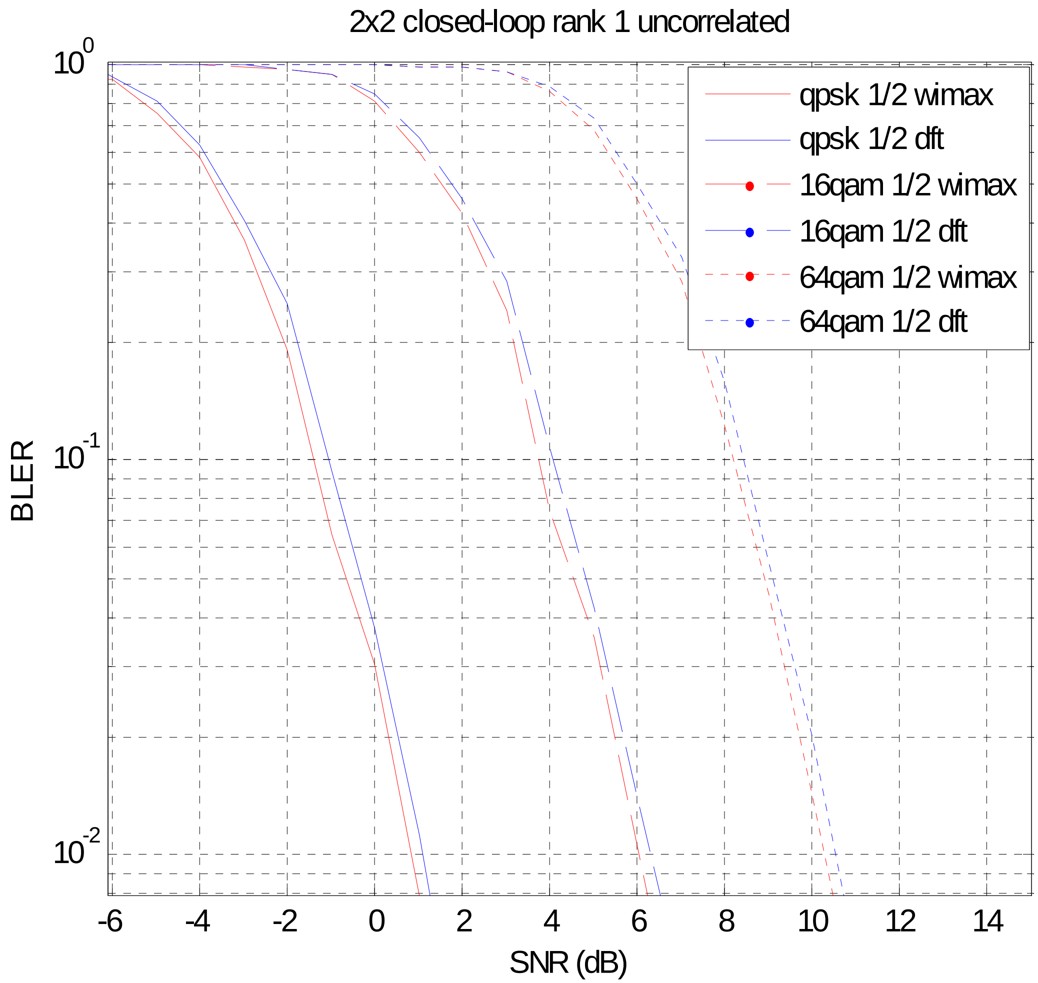
- In uncorrelated channels, 16e codebook outperforms DFT-based codebook by 4% ~ 6%.
- In correlated channels, DFT-based codebook outperforms 16e codebook by 4% ~ 6%.
- 16e or DFT with Differential feedback has less than 1% throughput loss, while saving overhead significantly, e.g., 50%.

Link-Level Performance Comparison

Simulation Parameters

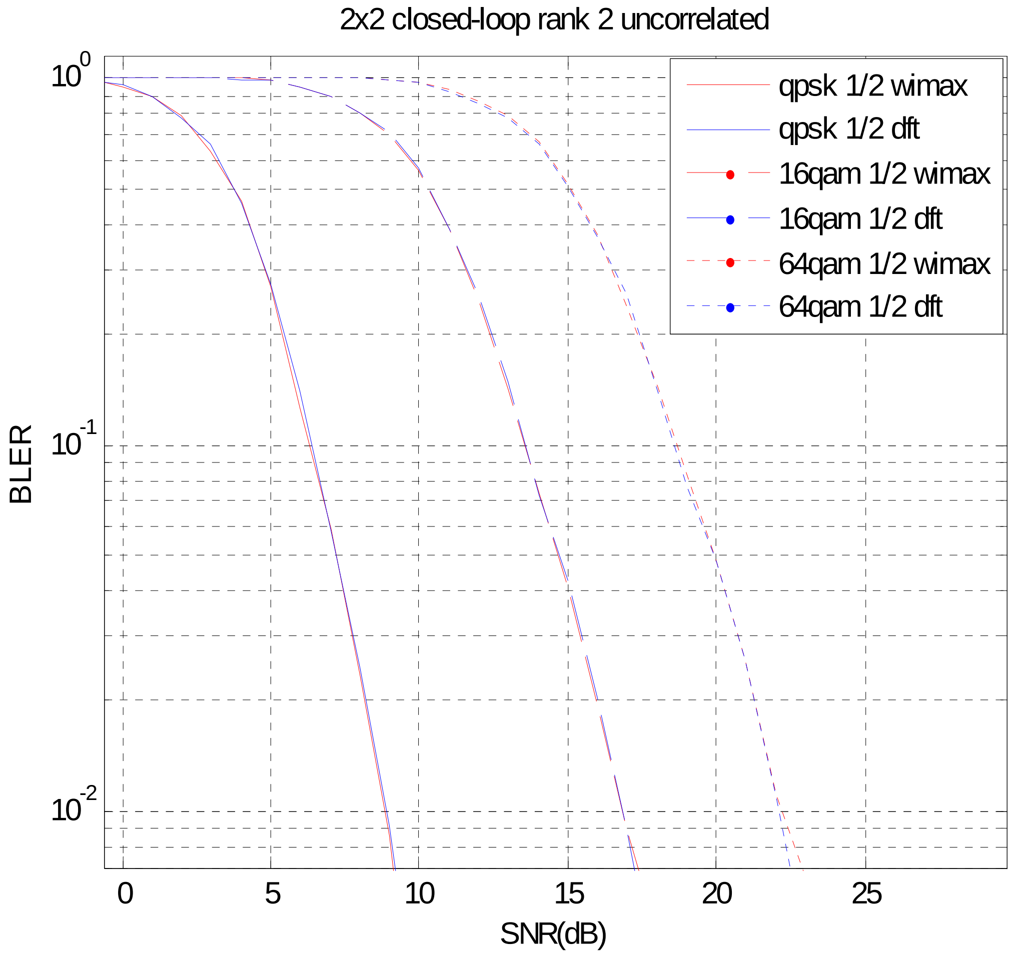
- **Channelization**
  - 10 MHz bandwidth with 48 physical RUs (PRU)
  - RU size is 18x6
  - 4 RUs allocated to a user
  - Localized channelization.
- **Antenna**
  - 2 or 4 Tx, 2 Rx
  - uncorrelated
  - 0 dB receive power imbalance
- **Fading channel**
  - PB 3 km/h
  - carrier frequency 2.5 GHz
  - Uncorrelated channel
  - Ideal channel estimation
- **Receiver**
  - Linear MMSE
- **Modulation and coding**
  - QPSK, 16-QAM, 64QAM
  - rate ½ duo-binary turbo code with decoding iterations
  - 1 or 2 MIMO layers
  - single codeword

Rank 1 with 2x2 antennas



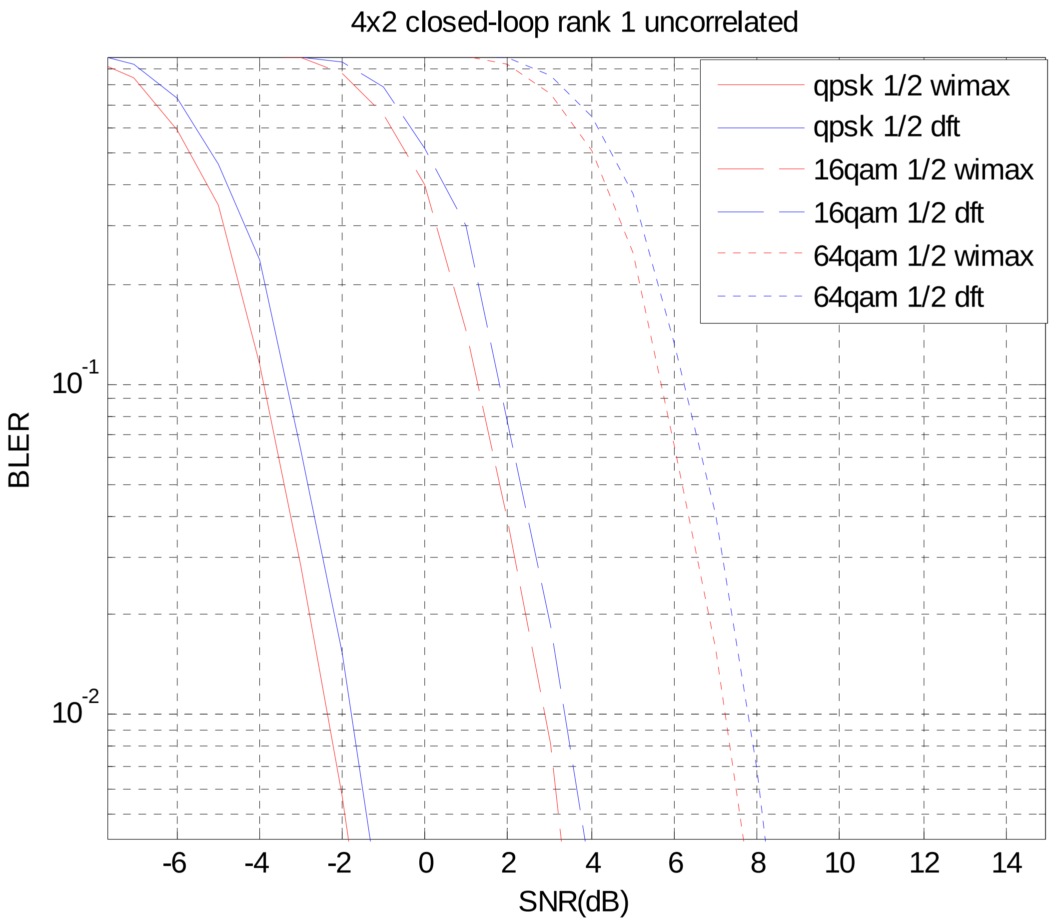
3-bit 16e codebook has 0.2 ~ 0.3 dB gain over 3-bit DFT codebook

Rank 2 with 2x2 antennas



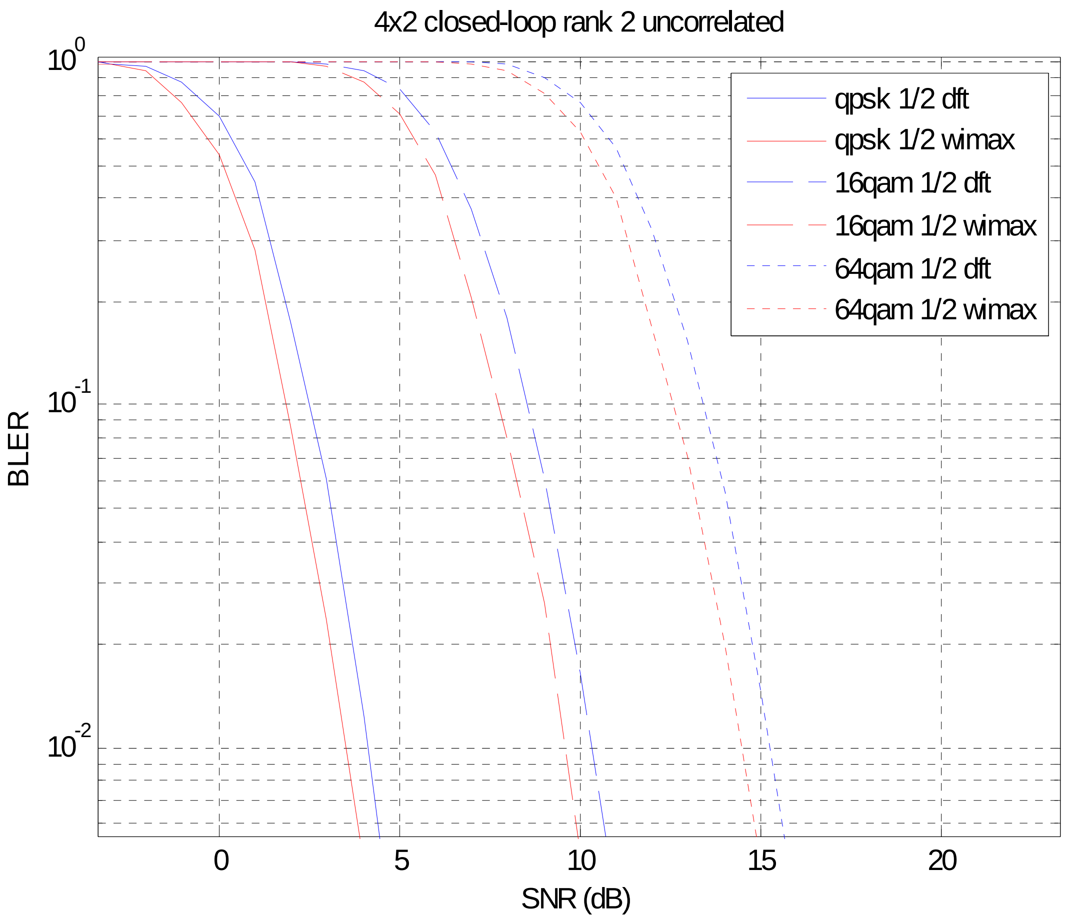
3-bit 16e codebook has similar performance as 3-bit DFT codebook

Rank1 with 4x2 antennas



6-bit 16e codebook has ~ 0.6 dB gain over 4-bit DFT codebook

Rank 2 with 4x2 antennas



6-bit 16e codebook has 0.6 ~ 0.8dB gain over 4-bit DFT codebook

Conclusions

- 16e codebook performs better in uncorrelated channels.
- DFT-based codebook performs better in correlated channels.
- Differential feedback can be applied to both 16e codebook and DFT-based codebook.
- Differential feedback saves uplink overhead without much throughput loss.

Reference

[1] P802.16Rev2/D6, Part 16: Air Interface for Broadband Wireless Access Systems

[2] IEEE C802.16m-08_013

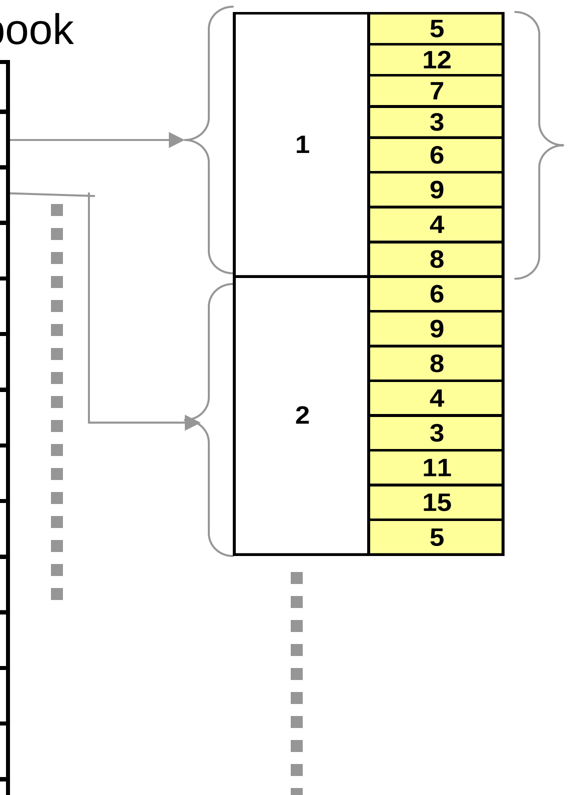
[3] IEEE C802.16m-08_347

Appendix: Differential Feedback (1/3)

Procedure I: *Codebook Construction*

Baseline arbitrary codebook

Codeword	Index
w_1	1
w_2	2
w_3	3
w_4	4
w_5	5
w_6	6
w_7	7
w_8	8
w_9	9
w_{10}	10
w_{11}	11
w_{12}	12
w_{13}	13
w_{14}	14
w_{15}	15
w_{16}	16



Search all the codewords to find *L* (e.g., 8) best ones which maximize

$$\left\langle \mathbf{w}_i, \mathbf{w}_j \right\rangle = \frac{\mathbf{w}_i^H . \mathbf{w}_j}{\left\| \mathbf{w}_i \right\| \left\| \mathbf{w}_j \right\|}$$

Theses L indexes are the highly correlated codewords associated to codeword 1.

Besides the codebook, theses indexes subsets must be stored.

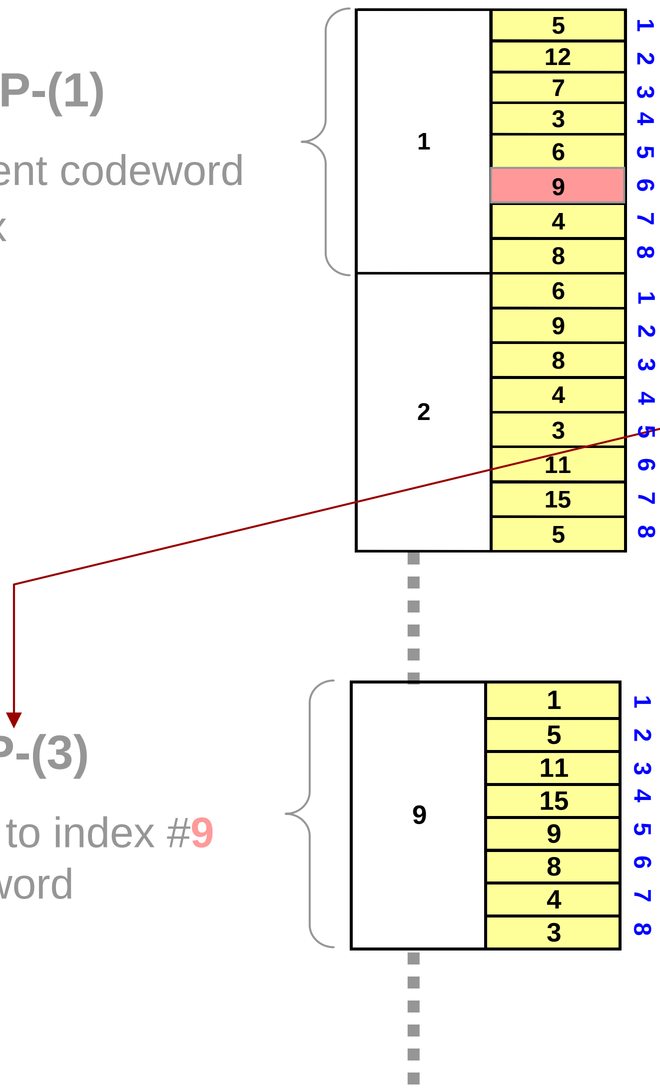
The volume of the extra memory is very low. It is only 3 kbits for *L*=8 and codebook size *M*=64.

Appendix: Differential Feedback (2/3)

Procedure II: *Differential Encoder*

STEP-(1)

Current codeword index



STEP-(2)

Search only *L* (=8) code words {5,12,7,3,6,9,4,8}
Find codeword #9 → Encoder output is differentials index **6**.

STEP-(3)

Jump to index #9 codeword

STEP-(4)

Search only *L* (=8) code words {1,5,11,15,9,8,4,3}

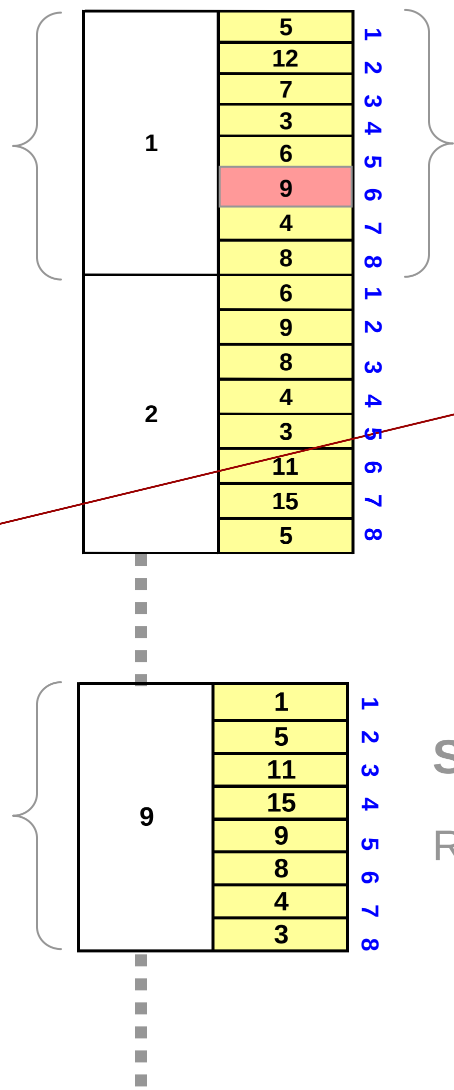
Find codeword #?

Appendix: Differential Feedback (3/3)

Procedure III: *Differential Decoder*

STEP-(1)

Previous decoded codeword index



STEP-(2)

Received differential index is **6** ➔ Decoded codeword is #**9**.

STEP-(3)

Jump to index #**9** codeword

STEP-(4)

Received differential index #? …