Proposal for IEEE 802.16m Differential Encoding/Decoding for CL-MIMO Codebook Feedback

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

Re: IEEE 802.16m-08/016r1 – Call for Contributions on Project 802.16m System Description Document (SDD), on the topic of "Downlink MIMO schemes"

Purpose: Adopt the proposal into the IEEE 802.16m System Description Document

Scope

- This contribution presents a differential encoding/decoding method for CL-MIMO codebook feedback in IEEE 802.16m.
- The overall DL MIMO schemes are presented in a separate contribution (see C802.16m-08/342 "Proposal for IEEE 802.16m DL MIMO Schemes").

IEEE 802.16m System Requirements

- The TGm SRD (IEEE 802.16m-07/002r4) specifies the following requirements:
  - Section 6.10 System Overhead
    - “Overhead, including overhead for control signaling as well as overhead related to bearer data transfer, for all applications shall be reduced as far as feasible without compromising overall performance and ensuring proper support of systems features.”
- The proposed design targets the above requirement.

Introduction and Background (1/2)

- MIMO channel matrix information is feedback to the base station (BS) to improve the system performance.
  - Such a system is defined closed-loop (CL) MIMO.
- Closed-loop MIMO has gain in comparison to open-loop MIMO only when the channel variation is not too fast.
  - Channels variation is slow only for low mobile speed MS.
- Therefore, closed-loop MIMO is applied to low mobility scenario.

Introduction and Background (2/2)

- In closed-loop MIMO, channel state matrix is quantized to a codeword within a predefined codebook.
- The codeword index is feedback from MS to BS.
- The closed-loop MIMO provides performance gain only if the codebook has a reasonable number of codewords.
- However, for large codebook sizes, the overhead of the feedback channel may be very high.

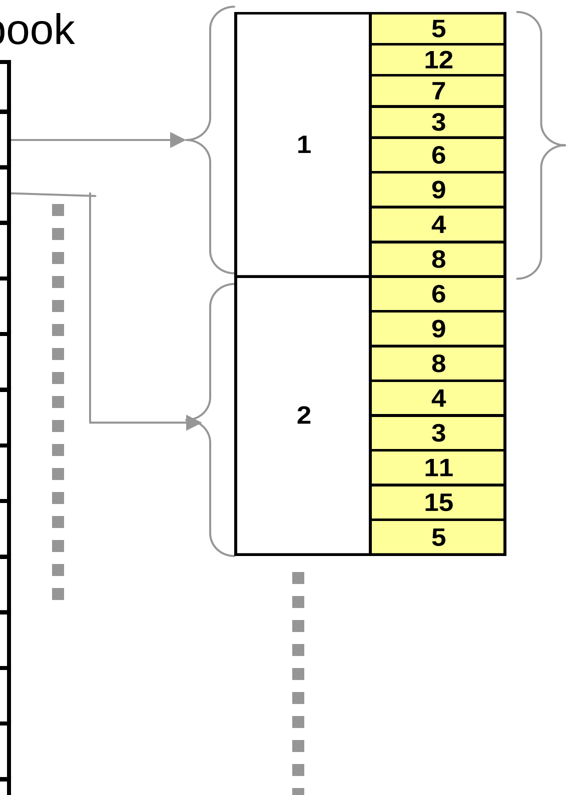
Differential Encoding/Decoding Design Overview

- Channel variation is slow in time and/or frequency domain.
- The sequence of the channel codewords is highly correlated.
- The codeword index offset is small due to the slow variation of the channel.
- The index offset can be represented by a small number of bits in comparison to the codeword index.
- Instead of the codeword index, we propose to transmit only the offset of the codeword index → differential encoding.
- Differential encoding reduces the feedback overhead.
- To prevent error propagation, a feedback of full codeword will be sent every X frames.

The Concept of Differential Coding
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* (=8) best ones which maximize

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

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

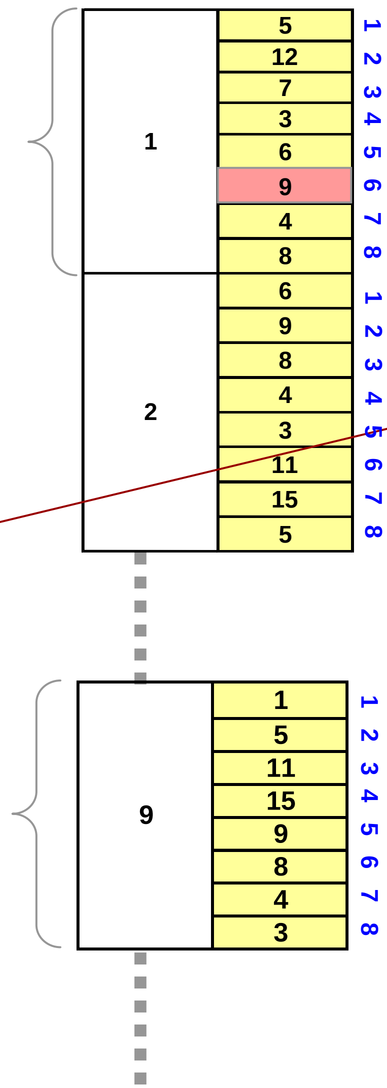
Besides the codebook, theses indexes subsets must be stored.

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

The Concept of Differential Coding
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 #?

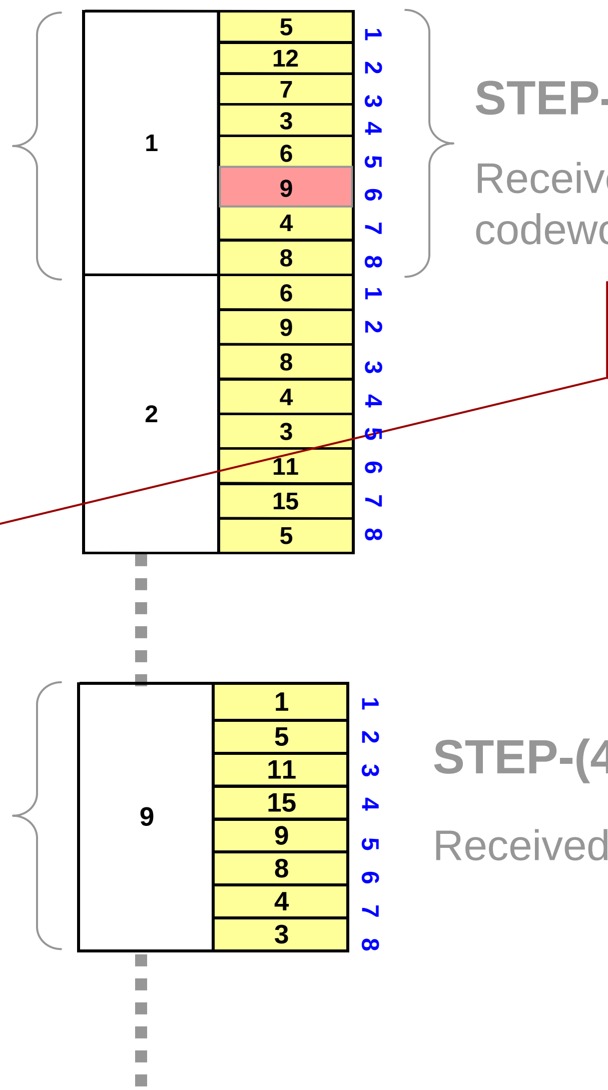
The Concept of Differential Encoding
Procedure III: *Differential Decoder*

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 #? …

Differential Encoding/Decoding Advantages

- We consider a subset of 8 (=*L)* codewords with highest correlations for the codebook expansion.
- In this case, for the 64 (=*M)* codewords, the codebook index requires 6 bits, whilst the differential-codebook index requires only 3 bits. This leads to a 3 bits saving per transmission, or a saving of 50% on PMI feedback overhead.
- The prices paid is the extra memory on both terminal and base station to store the differential-codebook index. Such an extra memory storage is $64 \times 8 \times \log_2(64)$, which is 3k bits or 384 bytes.
  - This extra memory is considered a very small size of memory in practice for both MS and BS.

Performance Evaluation
(3-bit differential PMI relative to 6-bit full PMI using the 6-bit codebook defined in 802.16e)

Differential PMI	4x2 CL-MIMO Rank1 Erasure 1%	4x2 CL-MIMO Rank1 Erasure 10%	4x2 CL-MIMO Rank2 Erasure 1%	4x2 CL-MIMO Rank2 Erasure 10%
Throughput Loss	1.22%	1.56%	2.85%	3.36%
Overhead* Saving Gain	32%	32%	32%	32%

* Overhead includes PMI, differential CQI(1bits), and CRC(9bits)
* Simulation assumptions are given in slides 14-17

Conclusions

- This contribution presents the concept of differential encoding/decoding.
- Differential encoding/decoding allows for significant reduction of feedback overhead.
- It can be applied to an arbitrary code book for closed-loop MIMO.

Proposed Text for SDD

- Section 11.x: MIMO schemes
- Section 11.x.1 DL MIMO schemes
- Section 11.x.1.1 DL MIMO Feedback
- Section 11.x.1.1.1 Differential Encoding/Decoding for Codebook Feedback
  - [*copy content of slides 6,7, 8, 9 here*]

Simulation Assumptions & Parameters (1/4)

Parameters	Value
Number of cells	19
Number of sectors per cell	3
Total number of sectors	57
BS-BS distance	1.5 km
Center frequency	2.5 GHz
Channel bandwidth	10 MHz
Frequency reuse	Reuse-1
Transmission power/sector	46 dBm
BS height	32 m
Tx antenna pattern	70^{o} (-3dB) with 20 dB front-to-back ratio
Tx antenna gain	17 dBi
MS height	1.5 m
Rx antenna pattern	Omni directional
Rx antenna gain	0 dBi
MS Noise Figure	7 dB
Penetration loss	10 dB
Hardware losses (Cable, implementation, etc.)	2 dB

Simulation Assumptions & Parameters (2/4)

Slow fading	
Path loss model	Loss (dB) = 130.62 + 37.6log10(R) (R in km)
Lognormal shadowing	μ=0 dB, σ_{SF} =8 dB
Shadowing correlation	100% inter-sector, 50% inter-BS
Fast fading	
Channel model	ITU PB3
Time correlation	Jakes spectrum
Spatial model (MIMO)	
Spatial correlation	specified as in 16m EMD (none correlation) with 4 wavelength antenna spacing

Simulation Assumptions & Parameters (3/4)

Parameters	**Value**
Frame duration	5 ms
DL OFDM data symbols	21
Control overhead per DL sub-frame	6 symbols DL, 3 symbols UL
DL channelization	AMC 2x3
Antenna modes	CL-MIMO 4X2
Close-loop codebook	802.16e v(4,1,6) or v(4,2,6)
Number of strong interferers	4
Initial PER	10%
HARQ type	Chase combining
Maximum number of HARQ retransmissions	4
PHY abstraction	QFACTOR

Simulation Assumptions & Parameters (4/4)

Parameters	**Value**
Number of active users per sector	10
Traffic type	Full buffer
Scheduling algorithm	Proportional Fair (alpha = 1.0)
CQI feedback delay	2 frames
CQI feedback error	0.0
CQI feedback period	1 frame
PMI feedback	Full PMI feedback or Differential PMI feedback
PMI feedback erasure rate	1% or 10%
Number of reported best bands	12 bands
Full PMI search interval (Reset interval)	6
Receiver structure	MRC or MMSE
Channel Estimation	Ideal