MIMO Strategies for the IEEE 802.16m Downlink

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Venue:
TGm – Call for contributions on Project 802.16m System Description Document – IEEE 802.16m-08/016r1 (Downlink MIMO Schemes)
Base Contribution:
IEEE C802.16m-08/273
Abstract:
Methodologies for supporting MIMO and Advanced Antenna Array Technology for the IEEE 802.16m downlink.
Purpose:
Discussion and adoption of recommended text into 802.16m System Description Document

DL MIMO Schemes for IEEE 802.16m: Contents

- Overall Theme:
  - Importance of optimizing the DL-MIMO schemes and the antenna array configuration to the deployment scenario
- SDD Functionality for DL-MIMO:
  - Required control signaling for enabling the adaptive choice of MIMO transmission mode
  - Transmission methods for Broadcast Control Channel (BCH)
  - Transmission methods for Unicast / Dedicated Control
  - Transmission methods for DL data transmissions
- Related Important Topics:
  - Importance of dedicated pilots in distributed allocations
  - Importance of block-based distributed allocations

DL MIMO Framework: Introduction

- IEEE 802.16m needs to have the flexibility to allow different deployment scenarios to operate with the MIMO transmission modes and antenna array configurations that are best for those scenarios

- The following must be specified:
  - The set of MIMO transmission methods (both data & control)
    - Closed-loop and open-loop methods; Beamforming, SU-MIMO, MU-MIMO, etc.
  - Feedback methodologies enabling those transmission methods
    - Codebook feedback, UL Sounding, Analog feedback, etc.
  - Control structures to enable link adaptation
    - MCS level, spatial rank, user grouping, etc.

Importance of Optimizing DL MIMO to the Deployment Scenario (1/3)

- Different deployment scenarios have different spatial channel characteristics that may call for different:
  - MIMO transmission schemes on DL Data Channels
  - MIMO transmission schemes for dedicated/unicast control
  - Antenna array types to be used (e.g., ULA, cross-pol array)
  - Transmission enablers (E.g., codebook feedback, analog feedback, etc.)

Importance of Optimizing DL MIMO to the Deployment Scenario (2/3)

- Low angular spread scenarios: (e.g., rural/suburban)
  - SU-MIMO will not provide significant TX diversity or spatial multiplexing gains (insufficient scattering)
  - Beamforming and MU-MIMO will provide significant system gains irrespective of the velocity with correlated antennas
- High angular spread scenarios: (e.g., urban)
  - Single-user MIMO will provide significant gains
  - Frequency-non-selective BF (or BF based on long-term statistics) will not provide significant gains
  - Low velocity:
    - Frequency-selective BF, SU-MIMO, and MU-MIMO will provide significant gains (must accurately track the channel response)
  - High velocity:
    - Closed-loop methods (BF, SU-MIMO, MU-MIMO) may have difficulty providing gains.
    - Open loop methods may be preferred.

Importance of Optimizing DL MIMO to the Deployment Scenario (3/3)

- Low angular spread channels may benefit from the use of closely spaced uniform linear arrays
  - High correlation improves the performance of beamforming & MU-MIMO based on long-term statistics
- High angular spread channels may benefit from the use of cross polarized or widely spaced antenna elements
  - Low correlation at transmitter improves performance of open-loop transmission schemes and the performance of closed-loop schemes in low velocity situations.
- Conclusion: The standard should allow BS manufacturer to optimize their antenna array configuration and choice of MIMO transmission modes to the deployment scenario

Required control signaling for enabling multiple MIMO transmission modes in a subframe

- Broadcast Control (BCH) must indicate the following characteristics of the dedicated/unicast control so that the MS can decode the dedicated/unicast control:
  - Transmission mode being used on the unicast control (e.g., CDD, SFBC)
  - Pilot type (broadcast or dedicated) used on the unicast control
  - Whether data portion of subframe also uses broadcast pilots or not
    - If both data and unicast control use broadcast pilots, then the MS can use all pilots in the subframe to decode unicast control.
- Dedicated/Unicast control indicates:
  - MIMO transmission mode used in each DL allocation
  - Pilot type (broadcast/dedicated) used in each DL allocation

Transmission Modes for Broadcast Control Channel (BCH)

- Single antenna transmission or multi-antenna with transparent aggregation
  - E.g., Low delay CDD or multi-tap CDD
- Justification:
  - Broadcast channel is heavily coded, exploits frequency diversity and needs to be reliable
  - Single source channel estimation provides lower complexity at mobile and better channel estimation performance
  - Similar performance to SFBC/STBC in low SNR scenarios with low code rate and abundant frequency diversity

Transmission Modes for Dedicated/Unicast Control channels

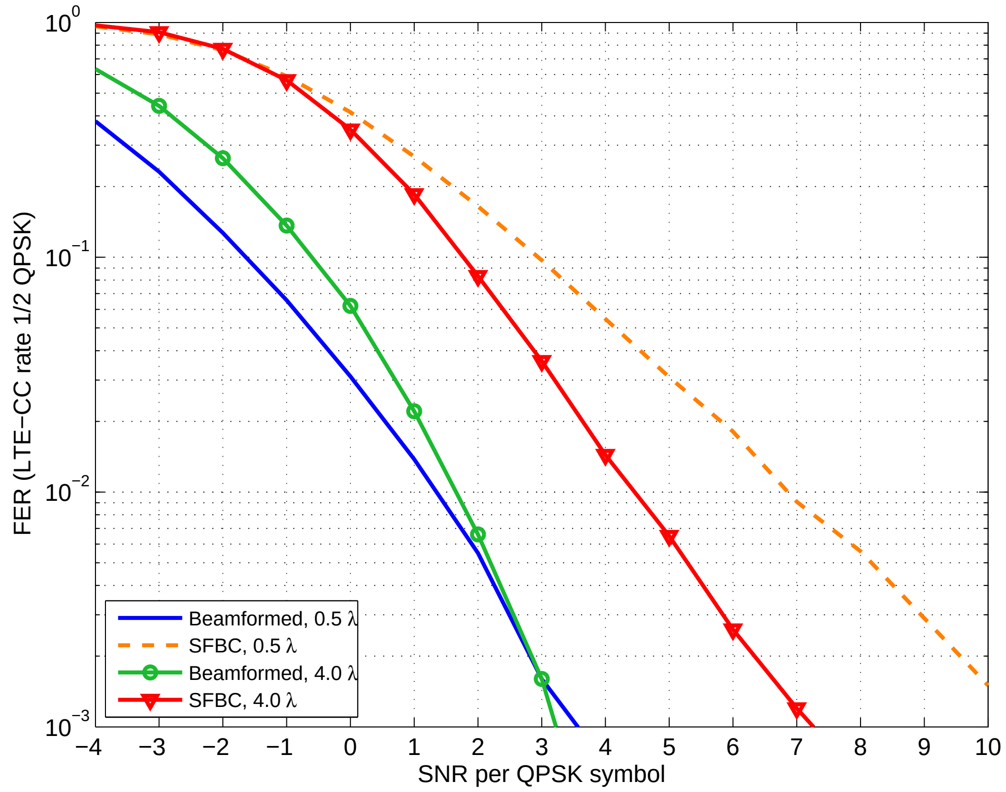
- BCH indicates the following characteristics of the dedicated / unicast control channels:
  - The Pilot type (dedicated or broadcast)
  - Transmission scheme used in the dedicated control
- Transmission methods:
  - Low delay CDD
    - Appropriate for low MCS, all velocities
  - SFBC
    - Appropriate for higher MCS on control
    - Can combine with antenna aggregation (eg. CDD) for BSs with > 2TX)
  - Beamforming
    - Important for expanding the coverage for a given transmit power
    - Different enablers depending on TDD vs FDD

Importance of Beamforming the Dedicated / Unicast Control

- A distinguishing feature of IEEE 802.16m should be the ability to employ beamforming to expand the cell radius beyond what would be possible for a given total transmit power.
- Broadcast Control Channel (BCH) would not be beamformed
  - Sent at a very low rate to reach the cell edge
  - Needs to be kept at a minimum information size and sent infrequently
- Optional beamforming on unicast control:
  - Improves the reliability and data rate of the unicast control
  - Methodologies exist for both TDD and FDD:
    - Can leverage TDD reciprocity with “long-term” UL statistics, ULCS, DOA-based methodologies, etc.

Importance of Beamforming the Dedicated / Unicast Control

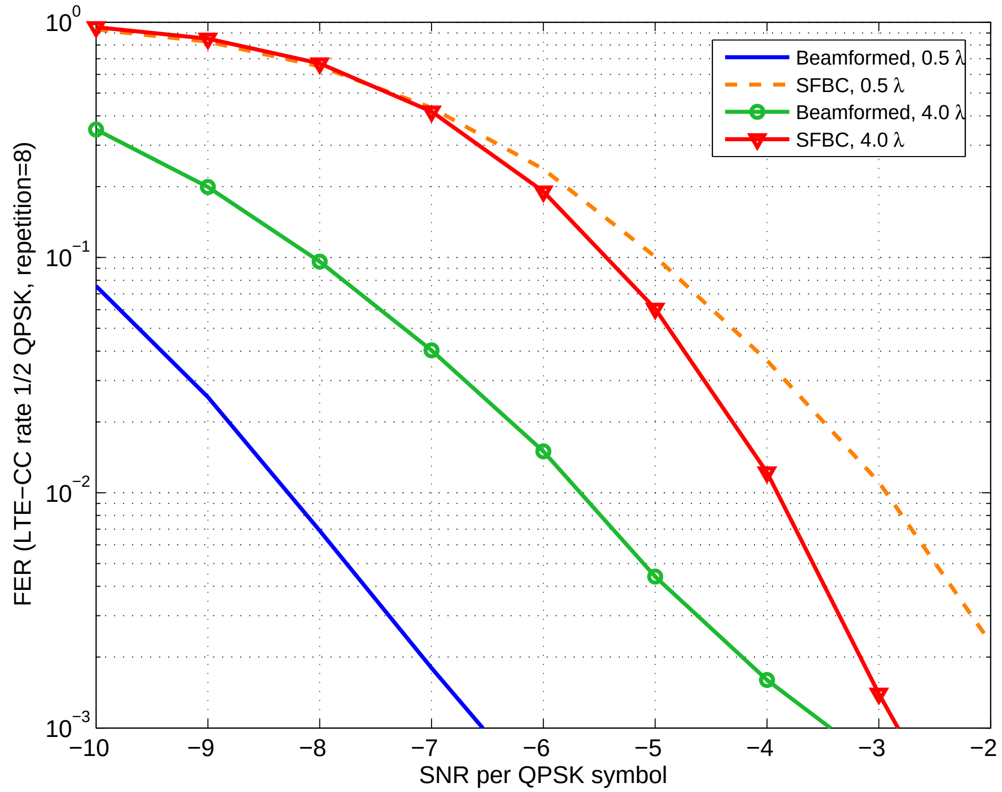
- 4 Tx, 2 Rx, modified pedB, 3° angular spread, 3 kph, 10 MHz BW
- **48 bit control message, 1/2 CC QPSK**
- SFBC:
  - Control channel consists of 6 groups of 8 subcarriers (groups spread across frequency)
  - Pair-wise Alamouti
  - Channel estimation uses all broadcast pilots in frequency (pilots spaced every 9 subcarriers)
- Beamforming:
  - Control channel consists of 3 groups of 18 subcarriers with a dedicated pilot on the 5th and 14th subcarriers in the group (groups spread across frequency)
  - For 0.5 λ: one weight on all groups w/broadband sounding
  - For 4.0 λ: sounding matches control allocation, different weight on each of the 3 groups
  - Sounding from only one antenna at the mobile (18 dB UL/DL imbalance)



- 5.5 dB gain for beamforming w/0.5 λ
- 3 dB gain for beamforming w/4.0 λ

Importance of Beamforming the Dedicated / Unicast Control

- 4 Tx, 2 Rx, modified pedB, 3° angular spread, 3 kph, 10 MHz BW
- **48 bit control message, 1/2 CC QPSK with repetition of 8**
- SFBC:
  - Control channel consists of 48 groups of 8 subcarriers (groups spread across frequency)
  - Pair-wise Alamouti
  - Channel estimation uses all broadcast pilots in frequency (pilots spaced every 9 subcarriers)
- Beamforming:
  - Control channel consists of one entire OFDM symbol with dedicated pilots on every 9th subcarrier (starting at 5th)
  - One beamforming weight over entire band
  - Sounding from only one antenna at the mobile (18 dB UL/DL imbalance), decimation of 64



- 5.3 dB gain for beamforming w/0.5 λ
- 1.8 dB gain for beamforming w/4.0 λ

MIMO for DL Unicast Data Channels: Transmission Methods

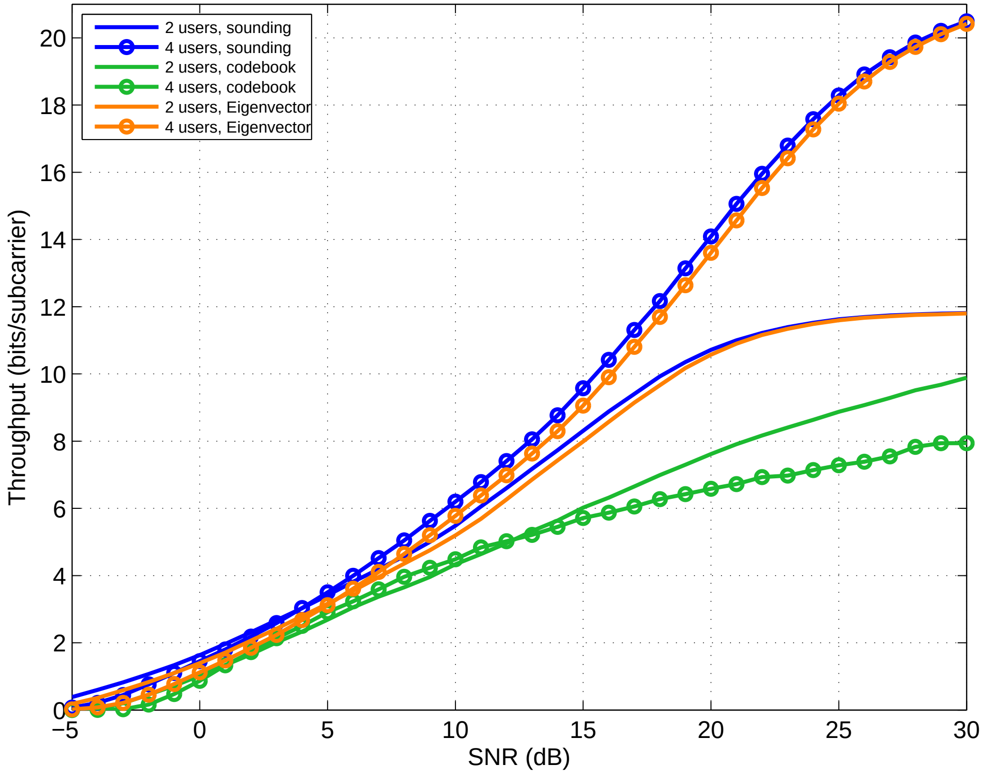
- Closed-loop (CSI-based) Transmission Methods (up to 4 streams)
  - Beamforming
  - SU-MIMO (multi-code-word)
  - MU-MIMO
- Open Loop (non-CSI-based) transmission methods
  - STBC/SFBC/MIMO (multi-code-word)

MIMO for DL Unicast Data Channels: Enablers for CSI/Feedback-based Transmission

- UL Channel Sounding
  - *Critical for enabling high performance MU-MIMO in TDD*
  - Lower channel measurement latencies in TDD than other feedback methods
  - More flexible Tx weight design at the BS
  - Enables arbitrary number of transmit antennas
  - Also useful for UL band selection in TDD/FDD
- Analog feedback
  - *Critical for enabling high performance MU-MIMO in FDD or TDD*
  - Useful when no reciprocity calibration at BS in TDD systems
  - Sounding channel can be designed to carry the analog feedback reliably at the cell edge
  - Useful for MS having >2RX: enables 1TX for feedback
- Codebook feedback
  - Reasonable for Beamforming & SU-MIMO in FDD scenarios

Importance of ULCS & Analog Feedback for Enabling High Performance MU-MIMO

- 4 Tx, 2 Rx, modified pedB, 3° angular spread, 3 kph, 10 MHz BW
- Throughput determined with EESM
- Channel estimation (2D-MMSE) on DL:
  - Dedicated pilots used for ULCS and Eigenvector feedback
  - Broadcast pilots used for codebook
- Non-ideal ULCS used and non-ideal dominant Eigenvector feedback used
  - UL/DL imbalance of 18 dB
  - MU-MIMO weights designed using regularized zero forcing
- Ideal codebook feedback and feed-forward assumed
  - 4 bit codebook
  - Codebook chosen from DL channel estimates
  - MU-MIMO weights designed from subspace averaging technique
- Ideal user grouping
- Mobile uses interference suppression receiver (using channel estimates)
- See C802.16m-08/123 for full details



- Eigenvector feedback almost as good as sounding
- Codebook feedback competitive only up to SNRs around 7 dB

Importance of Dedicated Pilots in Diversity Allocations

- Beamforming can be used in velocity channels by leveraging long-term spatial channel statistics
  - Example: suburban/rural macro-cell scenarios with low multipath angular spread and a correlated antenna array
- In velocity channels, best-band selection (e.g., Band AMC of 16e) will not work, but reciprocity-based beamforming can still provide good coherent processing gains
  - When best-band selection doesn't work, the system must be able to exploit frequency diversity via a distributed subcarrier allocation strategy
- Therefore need to support beamforming with a distributed / "diversity"-style allocation.
- Therefore need dedicated pilots with a "diversity"-style allocation to enable beamforming in scenarios where best-band selection does not work.

Importance of Block-Based Distributed Allocations for Beamforming and SU/MU-MIMO

- TDD-reciprocity-based or analog feedback-based SU/MU-MIMO requires pilots that are beamformed along with the data
  - Pilots must be "tied" to the data intended for a particular user
- Consider a distributed subcarrier allocation based on a subcarrier-level distribution across multiple disjoint Resource Blocks (similar to PUSC)
  - Multiple users are allocated to the subcarriers within a cluster/resource block
  - The pilots in a resource block cannot be dedicated to a single user
    - Pilots belong to the resource block/cluster, not the user
  - Enabling TDD-reciprocity based beamforming in this type of allocation requires the following:
    - Pilots are dedicated (but belong to the resource block)
    - Beamforming vector must be the same for all users allocated to the subcarriers of the resource block
      - This is the "Major Group Restriction" for beamforming in PUSC
      - If entire major group is assigned to one user, then the scheduling granularity is too big
- Therefore beamforming needs a diversity allocation method in which a user's data is transmitted in several resource blocks that are scattered across the band (and no other user is allocated to the subcarriers of that user's resource blocks)

Proposed Table of Contents: DL MIMO Schemes (See C802.16m-08/273 for more details)