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Re:	Call for Contributions on IEEE 802.16m-08/003 System Description Document (SDD) Topic: Uplink MIMO schemes
Abstract	Proposal for IEEE 802.16m uplink MIMO schemes
Purpose	Discussion and approval
Notice	
Release	
Patent Policy	

Uplink MIMO Schemes for IEEE 802.16m

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1. Introduction

This contribution provides a proposal for uplink MIMO schemes, including Open-Loop and Close-Loop for both Single-User and Multi-User MIMO, specifically introducing Linear Dispersion Codes (LDC) not only as unifying framework (subsuming legacy MIMO schemes), but also as enabler for reaching SRD targets [1].

2. Definitions and List of Abbreviations

Open-loop MIMO (OL MIMO) is intended to refer to MIMO schemes for which the feedback information contains no more information than ESINR and selected MIMO scheme.

Closed-loop MIMO (CL MIMO) is intended to refer to MIMO schemes for which the feedback information contains information that allows forming at least one beam.

The transmission rank in single-user mode is defined as the number of columns in the precoding matrix. It depends on the MIMO scheme selected in OL MIMO, or on the number of beams formed in CL MIMO.

BS: base station

CL: closed-loop

CQI: channel quality information (i.e. CINR or ESINR)

LDC: linear dispersion codes

MS: mobile station

MU: multi-user

OL: open-loop

PCI: preferred codebook index (i.e. PVI or PMI)

PMI: preferred codebook matrix index

PVI: preferred codebook vector index

SU: single-user

SM: spatial multiplexing

STTD: space time transmit diversity

VE: vertical encoding

3. Scope of MIMO Schemes Supported in 802.16m

IEEE 802.16m is intended to become a global standard, and as such it should support a wide range of deployments including uncorrelated, correlated and cross-polarized antenna arrays at the base station.

Likewise, MIMO should be efficiently designed to support MS at low and high SNR, as well as fixed, nomadic and high speed MS.

MIMO offers flexibility to adapt the system operation to targeted performance measures, including high user throughput and high sector throughput. High user throughput is best supported by SU MIMO schemes, while high sector throughput is best supported by MU-MIMO schemes.

Closed-loop MIMO schemes shall be optimized for fixed and nomadic users as stated in the System Requirements Document [1], for both TDD and FDD deployments.

For the sake of simplicity and optimality of the standard, an effort has been made to limit the number of MIMO schemes and their structure to support all the above mentioned scenarios

4. Transmitter Architecture for MIMO Processing at the Mobile Station

The IEEE 802.16m MS transmitter structure is illustrated in Figure 1.

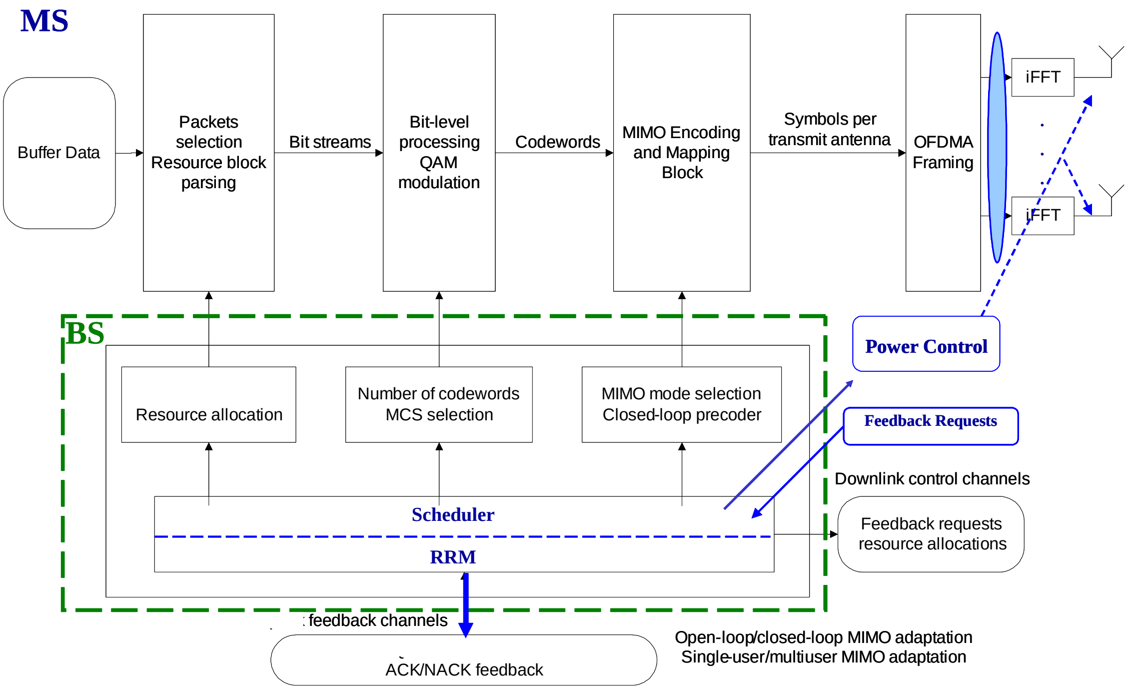

Figure 1 IEEE 802.16m MS transmitter structure

The MS MIMO encoding and mapping block is illustrated in Figure 2. The number of arrows at inputs and outputs of processing blocks is illustrative of one particular configuration with transmission rank 2 using 2 transmit antennas.

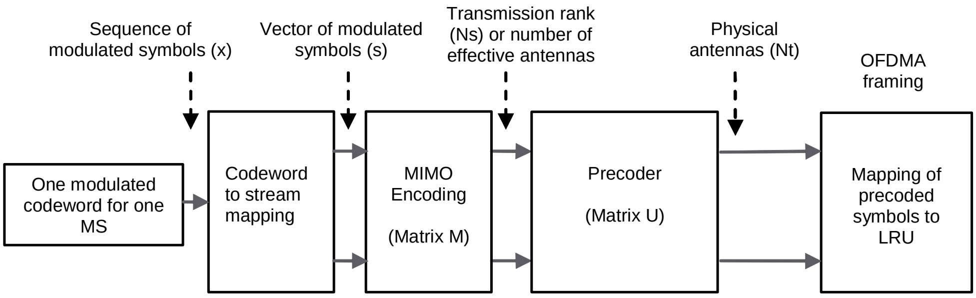

Figure 2 MIMO encoding and mapping block

The number streams per MS served in one resource unit is flexibly adapted at the Base Station (BS) thanks to overall scheduling algorithm (implementation dependent).

The MIMO encoding block shall perform one of three operations:

- Optional space-time or space-frequency block coding (negation, conjugation)
- Optional Linear Dispersion Codes (LDC) modulation
- No operation on the input streams

The precoding block shall perform one of two operations:

- Precoding by a fixed (pre-determined) matrix in OL MIMO for transmission rank adaptation
- Precoding by an adaptive matrix in CL MIMO to form one or more beams according to the feedback of channel conditions from BS

The fixed and adaptive precoders, for OL MIMO and CL MIMO respectively, shall not be concatenated.

The proposed transmitter processing of uplink pilots is the following:

- The uplink pilots shall be processed by the same precoding matrix as applied to the data.

The mapping of precoded symbols within a resource unit will be specified at a later stage than the SDD.

5. Open-Loop Single-User Uplink MIMO Schemes

5.1. MIMO Encoding

IEEE 802.16m shall support STTD, SM and Linear Dispersion Codes.

5.2. Fixed Precoding

The fixed (pre-determined) precoder is used in OL MIMO for adapting the transmission rank according to MIMO scheme selected for transmission to the BS, while ensuring transmit power balance among the power amplifier for each transmit antenna at the base station.

With N transmit antennas at the mobile station, a pre-determined N×N fixed precoding matrix is used for transmissions with rank 1 to N. For transmission rank r, the first r columns of the precoding matrix are used to process the input layers, and to produce symbols for each of the N transmit antennas.

The fixed precoder may be set to the identity matrix when the MS has 2 transmit antennas with SM and STTD transmissions of rank 2. The fixed precoder shall be used for rank 1 transmissions with 2 transmit antennas at the MS, and for transmissions with 4 transmit antennas at the MS.

The desired properties of the fixed precoder are:

- It is a unitary matrix whose elements have a constant modulus
- It is fixed in time
- Pre-determined: it shall be known at the BS and MS.
- Frequency-dependent: it shall vary according to the transmission subband, in a way compatible with FFR groups, localized and diversity resource groups. This is to exploit the full spatial diversity in diversity subchannels and enhance the BER of MS that experiences a frequency-flat channel.

The fixed precoder shall always be applied to the data and pilots with all OL MIMO schemes, including transmit diversity and spatial multiplexing.

5.3. Codeword to Stream Mapping

In the case of SU OL MIMO with SCW and SU OL STTD, R consecutive QAM modulated symbols from the same codeword are mapped to R streams with the identity permutation:

$$\begin{bmatrix} s_1 \\ \vdots \\ s_R \end{bmatrix} = \begin{bmatrix} x_1 \\ \vdots \\ x_R \end{bmatrix} \qquad (2)$$

s_i is sent over stream i.

The transmission rank R can take the following values:

- STTD: R=2
- SM: R=2 to 4
- One effective antenna scheme: R=1

6. Open-Loop Multi-User (CSM) Uplink MIMO Schemes

6.1. Transmission schemes for 1-antenna MS in UL

Two single Tx antenna MSs can perform collaborative spatial multiplexing onto the same subchannel. In this case, one MS should use the UL tile with pilot pattern A, and the other MS should use the UL tile with pilot pattern B.

Four single Tx antenna MSs can perform collaborative spatial multiplexing onto the same subchannel. In this case, one MS should use the UL tile with pilot pattern A, another MS should use the UL tile with pilot pattern B, another MS should use the UL tile with pilot pattern C, and another MS should use the UL tile with pilot pattern D.

6.2. Transmission schemes for 2-antenna MS in UL

Two dual Tx antenna MS can perform collaborative spatial multiplexing onto the same subchannel. In this case, the one MS should use the UL tile with pilot pattern A, B; and the other MS should use the UL tile with pilot pattern C, D. Each MS can use either STTD, SM, or LDC transmission mode with a specific data mapping.

7. Closed-Loop Single-User and Multi-user Uplink MIMO Schemes

The adaptive precoder is used for CL MIMO. It is adapted based on uplink channel state information available at the mobile station.

We propose that 802.16m supports two types of uplink channel estimation mechanisms:

- CSI estimation at BS based on uplink sounding
- CSI estimation at MS based on downlink reference signals (for TDD channels with channel reciprocity between downlink and uplink)

We propose that 802.16m supports downlink control information from the BS to support UL precoding:

- Precoding matrix index (reusing the DL codebook) with uplink sounding channel estimation
- MIMO scheme switching/selection

The DL codebook is robust in correlated and uncorrelated channels, and it has constant modulus elements that guarantee the balance of transmit power among power amplifiers at the terminal. A subset of the DL codebook may be selected rather than the whole codebook.

In case of CSI estimation at MS based on downlink reference signals, the uplink precoder used at the MS may not be known at the BS, and it shall be applied to the uplink pilots.

Switching among predefined MIMO transmission schemes/formats is done by BS indicating to the MS the index of the corresponding uplink MIMO mode to be used.

8. Downlink Reference Signals for CQI Measurements

IEEE 802.16m supports downlink reference signals with a regular pattern in frequency and time. These reference signals (e.g. common pilots or midamble) support measurements of the signals at 2 physical antennas at the mobile station. The reference signals appear in one subframe every frame (5 ms).

In TDD system, thanks to channel reciprocity this enables the MS to obtain Uplink Channel Estimate.

9. Feedback Information (MS to BS)

The MS may feedback information to support power control with CL MIMO schemes and vendor-dependent precoding, in case the precoding vector is unknown at the base station.

10. Uplink Sounding Channel

An uplink sounding symbol shall be specified in the standard, either as 802.16e uplink sounding symbol, or an enhanced version of it, in order to allow BS to have full access to refined CSI, and thus be able to take overall decision involving scheduling w.r.t. MCS level, precoder index and MIMO scheme to be used by MS.

11. Downlink Control Channel

For OL UL MIMO, the MIMO mode and the LDC encoding matrix index shall be signaled in the DL MAP.

For CL UL MIMO based on uplink sounding, the MIMO mode and the PMI shall be signaled in the DL MAP.

12. Performance Evaluation Results

12.1. Linear Dispersion Codes Advantages w.r.t. Legacy MIMO Schemes

For sake of simplicity, the i.i.d Rayleigh channel, and uncoded scenario have been used for the current simulation. This facilitates to demonstrate the inherent property from Linear Dispersion Codes (LDC), namely the achieving Diversity-Multiplexing Trade-Off.

Hereafter on Figure 12-1, the BER results are compared between legacy MIMO schemes, namely Matrix A (STTD/G2/Alamouti), Matrix B (SM) and one specifically designed Linear Dispersion Code.

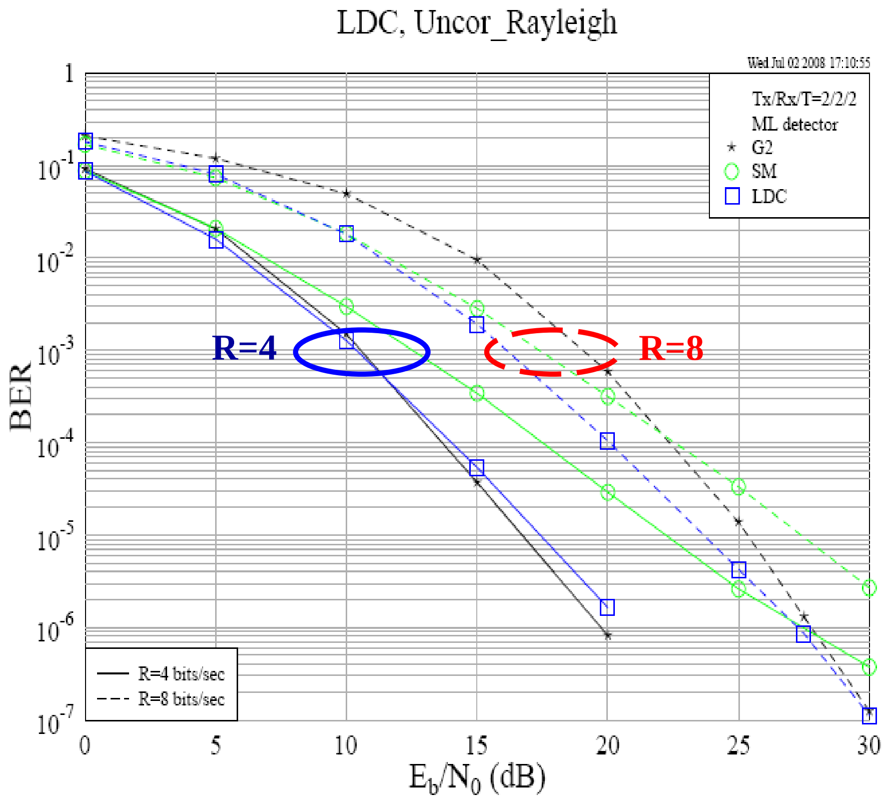

Figure 12-1 BER Performance of LDC compared with Matrix A and B

In the case of a rate of 4bps, LDC achieves same robustness than STTD, whilst for higher rates (here 8bps), it outperforms both SM and STTD.

Whilst being capable of reaching compelling diversity performance, LDC still achieves impressive capacity since offering same capacity as SM, as demonstrated hereafter on Figure 12-2:

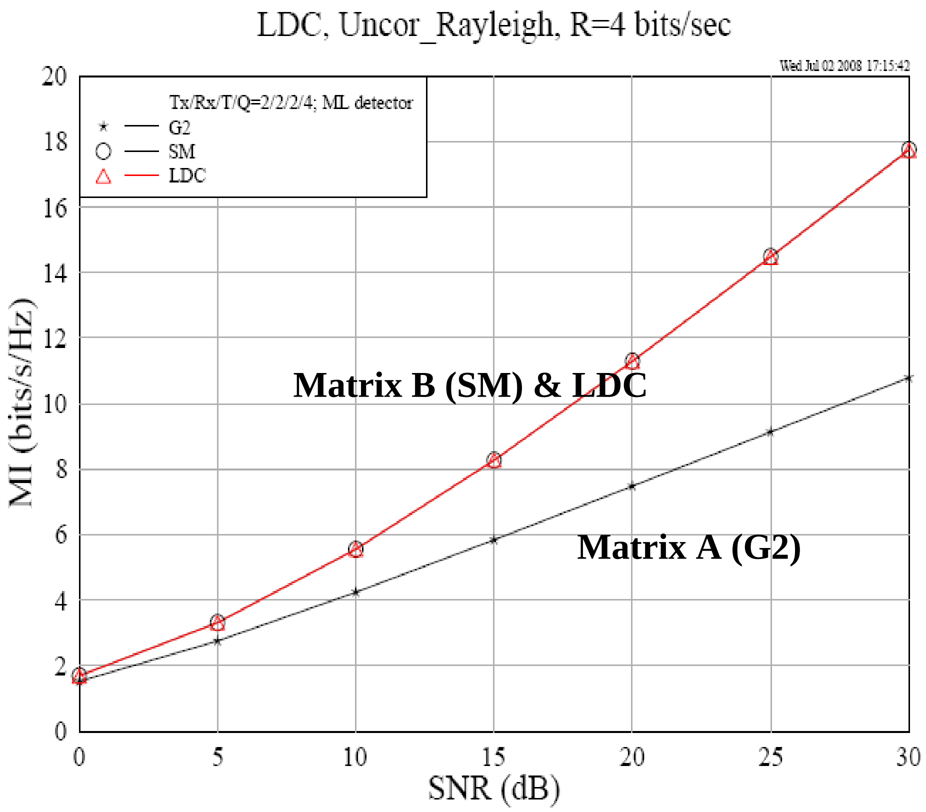

Figure 12-2 Capacity of LDC compared with Matrix A and B

As a consequence, the usage of LDC offers both same diversity gain as STTD, and same capacity gain as SM.

12.2. Multi-User Linear Dispersion Codes with Collaborative Spatial Multiplexing (CSM)

Another important feature from Uplink MIMO is due to Multi-User scenario, namely Collaborative Spatial Multiplexing (CSM). It is thus of great interest to evaluate what could be the gain of such additional LDC scheme w.r.t. legacy MIMO Schemes, once used within CSM context.

The initial performance results given hereafter on Figure 12-3 and Figure 12-4, are performed over ITU-R Ped.A channel, with 3km/h velocity, uncoded scenario, for 2 users with 2-transmit antennas MS each.

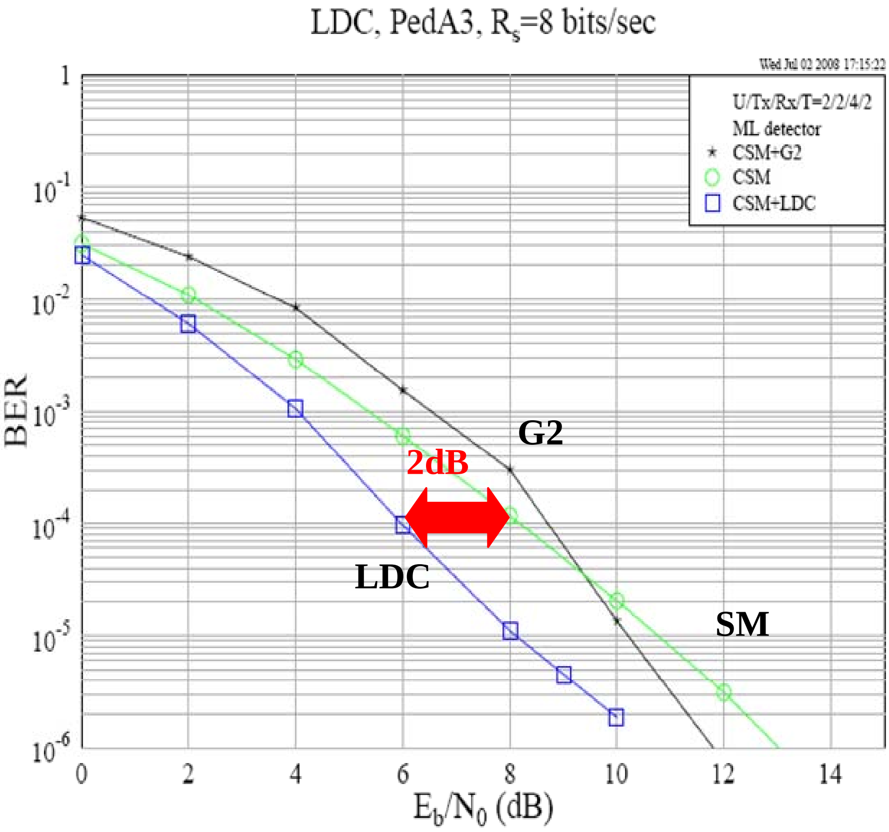

Figure 12-3 BER Performance of CSM-LDC compared with CSM-SM and CSM-STTD, for 2 users with 2-transmit antennas

The newly LDC scheme brings up to 2dB performance gain for both BER, and FER over legacy schemes, SM and STTD, whilst used within CSM context.

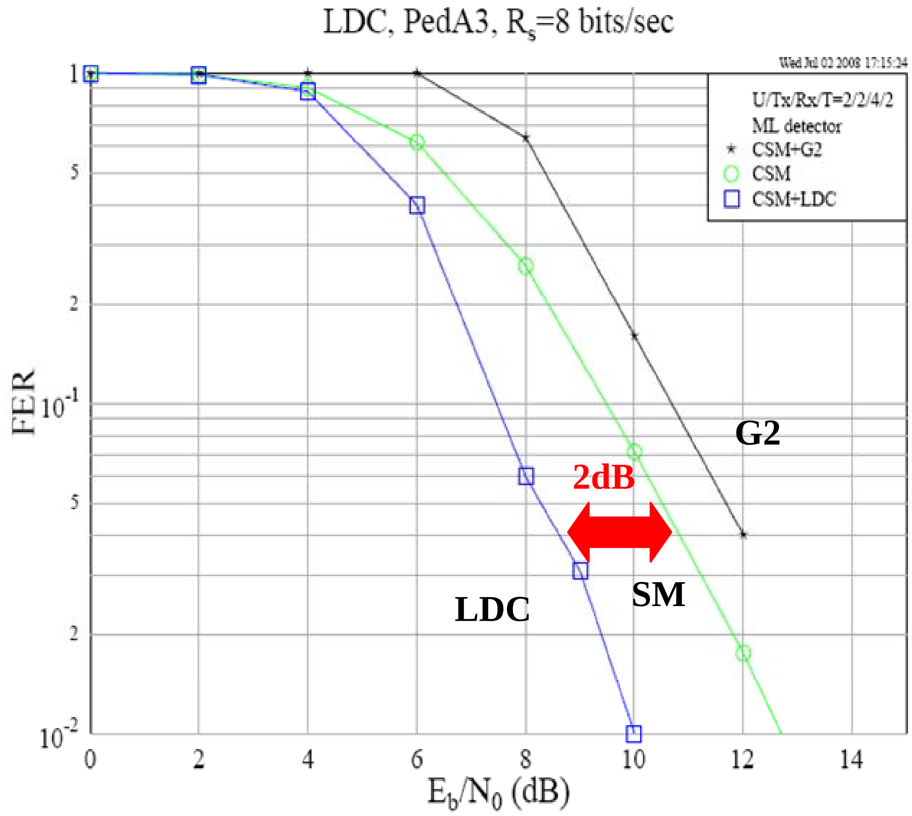

Figure 12-4 FER performance of CSM-LDC compared with CSM-SM and CSM-STTD, for 2 users with 2-transmit antennas

12.3. Linear Dispersion Codes with Spatial Adaptation

IEEE 802.16m shall support MIMO schemes switching also known as Spatial Adaptation, between not only legacy MIMO modes, represented by Matrix A and B, but also between specific MIMO schemes entirely described by Linear Dispersion Codes (LDC).

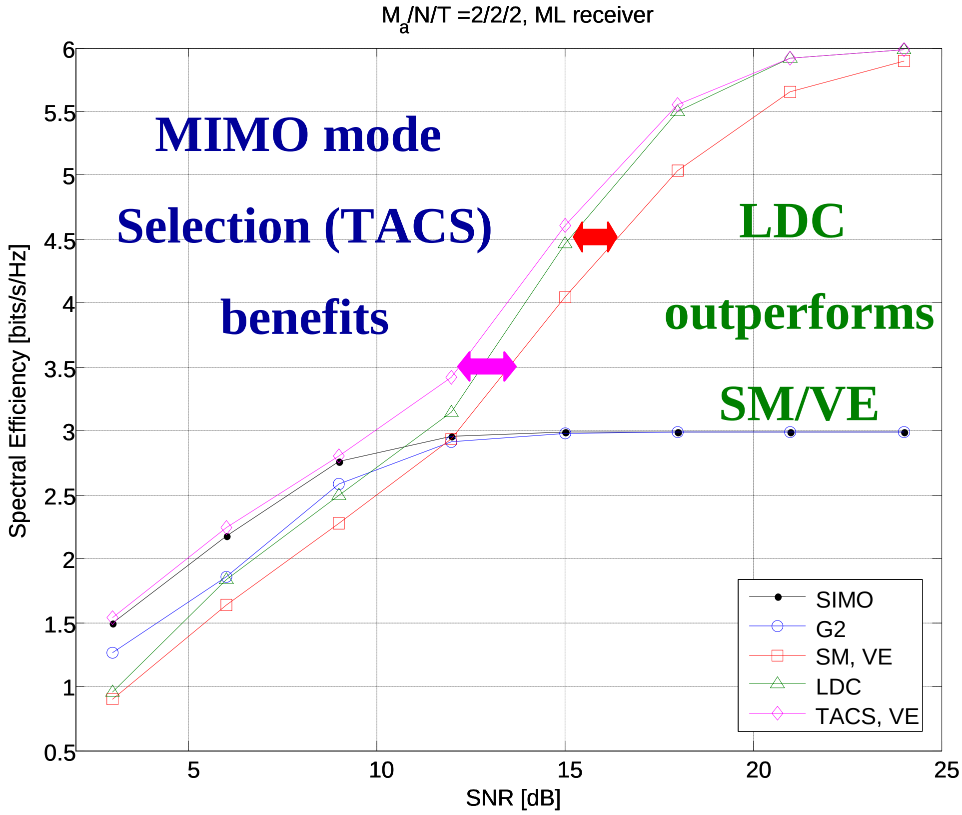

Figure 12-5 Spectral Efficiency comparison of full Spatial Adaptation with single MIMO modes

On the figure above (Figure 12-5), overall comparison is carried out between each MIMO scheme available, namely STTD (G2, Alamouti, Matrix A), Spatial Multiplexing (SM), SIMO, and finally Linear Dispersion Codes (LDC), with both Link Adaptation (MCS Level), and an overall Spatial Adaptation scheme allowing to switch among those mentioned MIMO modes, based on a given selection criteria. This final scheme is referred as TACS (Transmit Antenna and Code Selection).

The conclusion is that enabling Spatial Adaptation with an intermediate MIMO scheme, other than only Matrix A and B, will greatly benefit to overall spectral efficiency. Besides, the LDCs used alone are still outperforming SM and STTD with MCS level adaptation in Uplink. For sake of implementation simplicity we restricted SM to be vertically encoded.

13. Proposed Text for SDD

Insert the following text into Physical Layer sub-clause (i.e. Chapter 11 in [3]):

------------------------------- Text Start --

11.x. Uplink Transmission Schemes

11.x.1. Transmitter Blocks for MIMO Data Processing

The transmitter processing blocks for MIMO transmission shall be composed of the following steps to be applied to codewords of QAM modulated symbols:

1. codewords to streams mapping
   - multiple streams may be mapped to the same codeword
2. optional spatial modulation
   - STBC or SFBC modulation may be applied at this stage, which consists of conjugation and negation operations.
   - Linear Dispersion Codes (LDC) modulation may be applied at this stage, which consists of weighting, conjugation, addition and multiplication operations.
3. precoding
   - a pre-determined matrix (for open-loop MIMO) or an adaptive matrix (for closed-loop MIMO) shall be applied to map the streams to physical antennas.
   - The fixed and adaptive precoders shall not be concatenated.

The overall data processing operations on QAM modulated symbols is described by the following equation:

$$z = UM(s) \qquad (1)$$

Where U is a unitary precoding matrix of size Nt×Ns, M is an encoding matrix of size Ns×T, s is the input vector of QAM modulated symbols, and z is the output vector of symbols mapped to physical antennas.

The above parameters are defined as follows:

– Nt: number of physical transmit antennas at the MS
– Ns: Number of streams, or number of effective transmit antennas
– T: spatial codeword length at the MS transmitter

11.x.1. Single User Open Loop MIMO Schemes

11.x.1.1. Fixed Precoding

A pre-determined precoder fixed in time shall be applied to the streams of spatially modulated symbols, which produces the complex symbols that will be sent through the physical antennas. The size of that precoder shall be adapted to the rank r of transmission (number of streams), by selecting r columns of a pre-determined N×N matrix.

The fixed precoder may be set to the identity matrix when the MS has 2 transmit antennas with SM and STTD transmissions of rank 2. The fixed precoder shall be used for rank 1 transmissions with 2 transmit antennas at the MS, and for transmissions with 4 transmit antennas at the MS.

The fixed precoder shall always be applied to all open-loop uplink pilots and data transmissions. It shall not be applied with closed-loop MIMO pilots and data transmissions. In case of full rank transmission (where r = number of physical antennas), the fixed precoder may be chosen as the identity matrix.

The fixed precoder shall also be applied to open-loop uplink control transmissions to transform the channel into the baseline configuration with one effective transmit antenna at the mobile station.

The fixed precoder has the following properties:

- It is a unitary matrix whose elements have a constant modulus,
- fixed in time,
- pre-determined: it shall be known at the MS and BS,
- frequency-dependent: it shall vary according to the transmission subband, in a way compatible with FFR groups, localized and diversity resource groups. This is to exploit the full spatial diversity in diversity subchannels to enhance the BER of MS that experience a frequency-flat channel.

11.x.1.2. Codeword to Stream Mapping

In the case of SU OL MIMO with SCW and SU OL STTD, R consecutive QAM modulated symbols from the same codeword shall be mapped to R streams according to:

$$\begin{bmatrix} s_1 \\ \vdots \\ s_R \end{bmatrix} = \begin{bmatrix} x_1 \\ \vdots \\ x_R \end{bmatrix} \qquad (2)$$

si is sent over stream i.

The transmission rank R can take the following values:

- STTD: R=2
- SM: R=2 to 4
- One effective antenna: R=1

11.x.1.3 MIMO Encoding

11.x.1.3.1 Transmit Diversity

The UL transmit diversity scheme is analogous to DL transmit scheme. STTD Matrix A is used to transmit two complex symbols s1 and s2 over 2 effective antennas and 2 tones with space time coding rate 1 (R=T=2).

$$\mathbf{A} = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \quad (3)$$

11.x.1.3.2 Spatial Multiplexing

Spatial multiplexing scheme, enabled by matrix B transmits R complex symbols s_1 to s_R from effective antennas 0 to R-1, with space time coding rate R (T=1). Symbols s_1 to s_R represent the same subcarrier in the same OFDMA symbol. Note that when R = 1, this scheme is a rate-1 effective SIMO scheme, which may be used for uplink transmissions of control channels in the baseline mode with one effective antenna.

$$\mathbf{B} = \begin{bmatrix} s_1 \\ \vdots \\ s_R \end{bmatrix} \quad (6)$$

Table 1 – Maximum number of streams (rank R) supported for OL SU MIMO

TX	Localized channels	Diversity channels
2	2	2
4	4	4

11.x.1.3.3 Linear Dispersion Codes (LDC)

11.x.1.3.3.1 Encoding Process

The overall data processing for Linear dispersion codes (LDC) encoding of QAM constellation symbol shall follow either operations detailed in Equations (7) and (8):

$$\mathrm{X} = \sum_{q=1}^{Q} \left(S_q \cdot \tilde{\mathbf{W}}_{q,R} + S_q^* \cdot \tilde{\mathbf{W}}_{q,I} \right), \quad (7)$$

where $\left\{ \mathbf{W}_{q,R}, \tilde{\mathbf{W}}_{q,I} \right\}_{q \in [1,Q]}$ are complex spreading matrices of dimension T×M. And $\left[S_1, S_2, \ldots, S_Q \right] \in \Omega^Q$, where S_i is a complex symbol from M-QAM constellation Ω.

The equivalent operation involving real and imaginary parts of QAM symbols is described below:

$$\mathbf{X} = \sum_{q=1}^{Q} \left(\alpha_q \cdot \mathbf{W}_{q,R} + j \cdot \beta_q \cdot \mathbf{W}_{q,I} \right) \quad (8)$$

Where $S_q = \alpha_q + j \cdot \beta_q$, ($j = \sqrt{-1}$), $\mathbf{W}_{q,R} = \tilde{\mathbf{W}}_{q,R} + \tilde{\mathbf{W}}_{q,I}$ and $\mathbf{W}_{q,I} = \tilde{\mathbf{W}}_{q,R} - \tilde{\mathbf{W}}_{q,I}$.

The choice between both LDC data processing operations is implementation dependent.
Similarly to other MIMO scheme, we define the LDC coding rate (space time coding rate) as:

$$R_c = \frac{Q}{T} \tag{9}$$

11.x.1.3.3.2 Re-definition of Matrix A and B by Linear Dispersion Codes

The legacy transmission format A using Matrix A (space time coding rate = 1) can be defined with the following Space-Time spreading matrices:

$$\mathbf{W}_{1,R} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad \mathbf{W}_{1,I} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}, \quad \mathbf{W}_{2,R} = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}, \quad \mathbf{W}_{2,I} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$\mathbf{A} = \sum_{q=1}^{Q=2} \alpha_q \cdot \mathbf{W}_{q,R} + j \cdot \beta_q \cdot \mathbf{W}_{q,I} \tag{10}$$

Where $S_1 = \alpha_1 + j \cdot \beta_1$ and $S_2 = \alpha_2 + j \cdot \beta_2$.

The legacy transmission format B using Matrix B (space time coding rate = 2) is defined with the following Space-Time spreading matrices:

$$\mathbf{W}_{1,R} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \quad \mathbf{W}_{1,I} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \quad \mathbf{W}_{2,R} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \quad \mathbf{W}_{2,I} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$

$$\mathbf{B} = \sum_{q=1}^{Q=2} \alpha_q \cdot \mathbf{W}_{q,R} + j \cdot \beta_q \cdot \mathbf{W}_{q,I}, \tag{11}$$

Where $S_1 = \alpha_1 + j \cdot \beta_1$ and $S_2 = \alpha_2 + j \cdot \beta_2$.

11.x.1.3.3.3 Spreading Matrices for LDC

[TBD]

11.x.1.4 Subcarrier Data Mapping for Uplink Resource

11.x.1.4.1 Transmit Diversity

[TBD]

11.x.1.4.2 Spatial Multiplexing

[TBD]

11.x.1.4.3 Linear Dispersion Codes

[TBD]

11.x.2. Open Loop Multi-User MIMO (Collaborative Spatial Multiplexing)

11.x.2.1 Transmission Schemes for 1-antenna MS in Uplink

Two single Tx antenna MSs can perform collaborative spatial multiplexing onto the same subchannel. In this case, one MS should use the UL tile with pilot pattern A, and the other MS should use the UL tile with pilot pattern B.

Four single Tx antenna MSs can perform collaborative spatial multiplexing onto the same subchannel. In this case, one MS should use the UL tile with pilot pattern A, another MS should use the UL tile with pilot pattern B, another MS should use the UL tile with pilot pattern C, and another MS should use the UL tile with pilot pattern D.

11.x.2.2 Transmission Schemes for 2-antenna MS in Uplink

Two dual Tx antenna MS can perform collaborative spatial multiplexing onto the same subchannel. In this case, the one MS should use the UL tile with pilot pattern A, B; and the other MS should use the UL tile with pilot pattern C, D. Each MS can use either STTD, SM, or LDC transmission mode with the data mapping described in 11.x.1.4 for each of STTD, SM or LDC in CSM mode.

11.x.3. Single User and Multi-User Closed Loop MIMO Schemes

11.x.3.1 Transmission Schemes for 2-antenna MS in Uplink

11.x.3.1.1 Implementation-Dependent Adaptive Precoding

An implementation-dependent adaptive precoder may be applied at the mobile station by exploiting the channel information collected from the downlink reference signals in TDD with channel reciprocity. The uplink pilots shall be processed by the same adaptive precoding matrix as used on the data.

11.x.3.1.2 Unitary Adaptive Precoding

Codebook-based precoding may be used at the mobile station, following indication of PMI from the BS in a downlink control channel. The precoding codebook on the uplink shall be the same or a subset of the SU MIMO codebook for the downlink.

11.x.4 MIMO Scheme Selection

Switching among predefined MIMO transmission schemes/formats is done by BS indicating to MS index of the corresponding uplink MIMO mode to be used.

11.y. Downlink Control Structures

11.y.1. Downlink Reference Signals for MIMO Measurements

IEEE 802.16m supports downlink reference signals with a regular pattern in frequency and time. These reference signals (e.g. Common Pilots or midamble) shall support measurements of the signals at the physical antennas at the mobile station. The reference signals appear in one subframe every frame (5 ms). In TDD system, thanks to channel reciprocity this enables the MS to obtain uplink channel estimates.

11.y.1. Uplink CQI and PMI measurements at the BS

The BS shall compute the CQI and/or PMI based on uplink pilots in allocated resources, or based on uplink channel sounding.

11.y.3. Downlink MAP

This control channel will carry one or more of the following information:
- MIMO mode
- Precoder index (PMI),
- LDC Encoding matrix index,

- MCS Level

11.z. Uplink Control Structures
11.z.1. Uplink Sounding

An uplink sounding symbol is supported in 802.16m to obtain the channel information at the Base Station (BS) over Physical Resource Units (PRU).

14. References

[1] IEEE 802.16m-08/002r4, “IEEE 802.16m System Requirements Document”

[2] IEEE 802.16m-08/003r3, “The Draft IEEE 802.16m System Description Document”

[3] IEEE 802.16m-08/535, “Linear Dispersion Codes for Uplink MIMO Schemes in IEEE 802.16m”