Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**Linear Dispersion Codes for Uplink MIMO Schemes in IEEE 802.16m**
Date Submitted	**July 7, 2008**
Source(s)	Thierry Lestable, Ming Jiang, Alain Mourad Samsung Electronics Research Institute, UK — Thierry.lestable@samsung.com David Mazzarese, Shuangfen Han, Hokyu Choi, Heewon Kang Samsung Electronics — d.mazzarese@samsung.com Ismael Guttierez CTTC, Spain
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	

Linear Dispersion Codes for Uplink MIMO Schemes in IEEE 802.16m

T. Lestable, M. Jiang, D.Mazzarese, et al.
Samsung Electronics

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 to form 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.

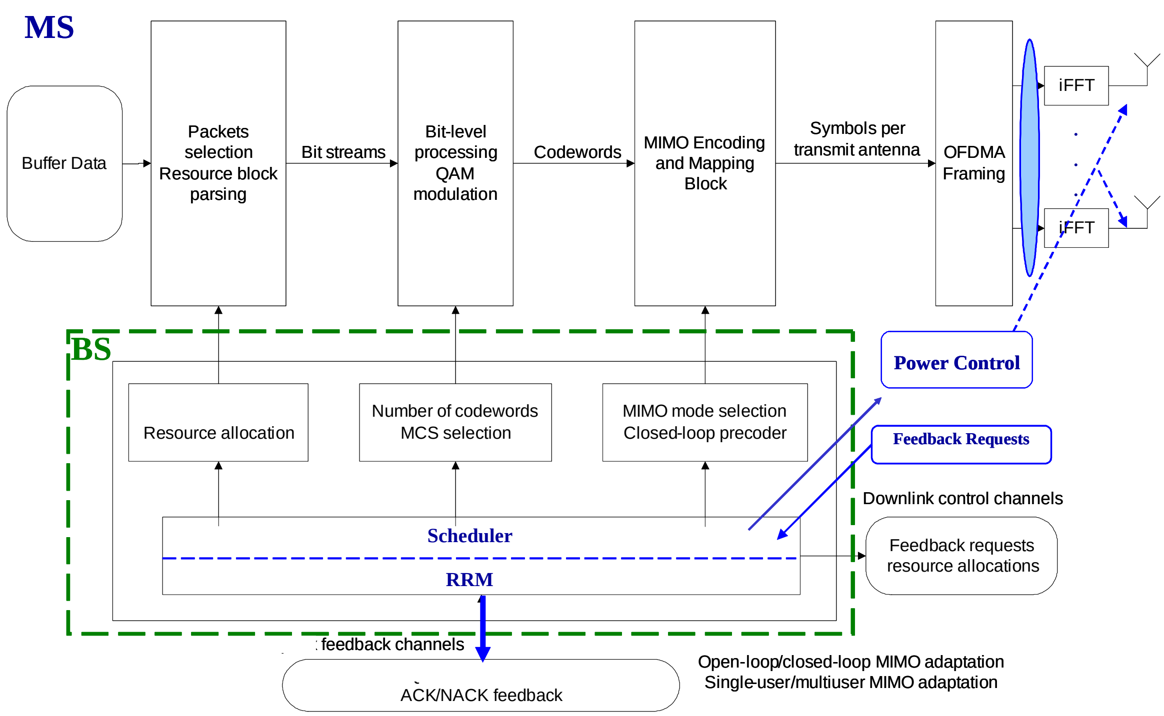


Figure 1 IEEE 802.16m MS transmitter structure

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.

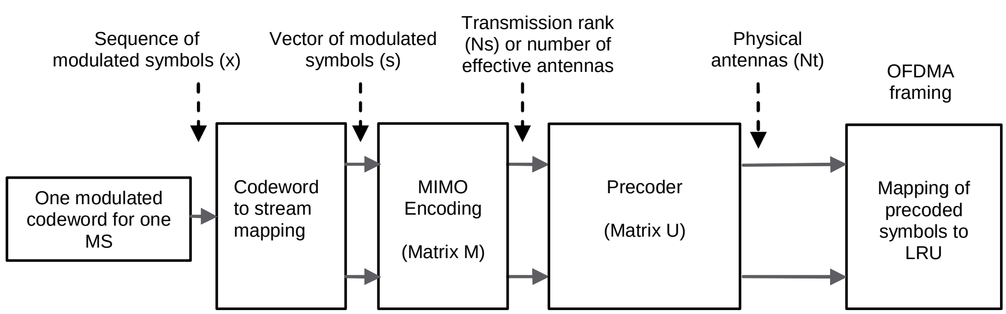


Figure 2 MIMO encoding and mapping block

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

The space-time modulation block performs the optional Linear Dispersion Codes (LDC) modulation.

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

5. Linear Dispersion Codes

5.1. Introduction

The concept of LDC [4] provides a space-time coding framework. Based on specific criteria, LDC disperses the transmission signal across space and time (frequency) dimensions, exploiting both spatial and time (frequency) diversity. By design, it subsumes a wide range of Space-Time Codes (STC), for example the Alamouti code [5], the Tarokh codes [6], and the Vertical Bell Labs Layered Space-Time (V-BLAST) scheme [7], also generally known as Spatial Multiplexing (SM).

The existing LDC designs mainly rely on one of the following methods:

- Conventional STC designs, e.g. the Alamouti code [5] and the Tarokh codes[6].
- Gradient-based search algorithms, e.g. Hassibi et al.[4], Gohary et al. [9], and Wang et al. [10];
- Frame theory, e.g. Heath et al.[8];
- Algebraic theory, e.g. the Diagonal Algebraic Space-Time (DAST) codes [11],[12], the Threaded Algebraic Space-Time (TAST) codes [13],[14], the Golden code [15], and the perfect codes [16].

5.2. Encoding

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

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

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 $\left[S_1, S_2, \ldots, S_Q\right] \in \Omega^Q$, with S_i is complex symbol from M-QAM constellation Ω.

The equivalent operation involving real and imaginary parts of QAM symbols is described in Equation (8):

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

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:

$$R_c = \frac{Q}{T} \quad (9)$$

5.3. Diversity Multiplexing Trade-Off

5.4. Unifying Framework w.r.t. legacy MIMO Schemes

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

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

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

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:

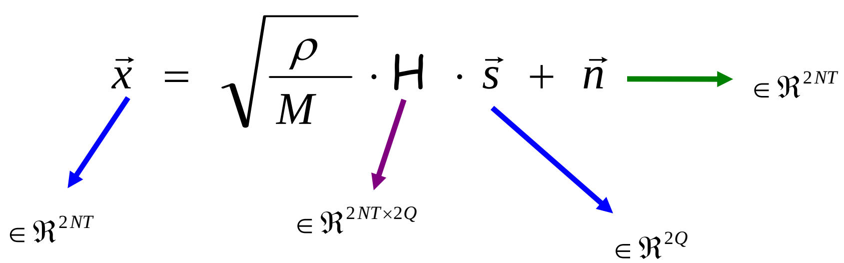
$$\mathbf{W}_{1,R} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \ \mathbf{W}_{1,I} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \ \mathbf{W}_{2,R} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \ \mathbf{W}_{2,I} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$

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

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

5.5. Detection

One key advantage of Linear Dispersion Codes (LDC) comes from their linear detection capability. Indeed, after few manipulations already extensively detailed in the literature ([4], [8]), together with the supporting presentation S802.16m-08/535, it can be shown that the received signal (transformed by splitting real and imaginary parts) is expressed as a linear equation of transmitted signal (split real and imaginary part):



Therefore any linear detection algorithm can be used to perform decoding of Linear Dispersion Codes.

Of course, performance results will greatly differ depending on the detection scheme used.

Whilst targeting best performance, LDC can be efficiently detected by means of Sphere Detection algorithms which greatly reduce the complexity of implementation compared with brute force ML, whilst maintaining a ML-like performance.

6. Performance Evaluation Results

6.1. 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 6-1, 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.

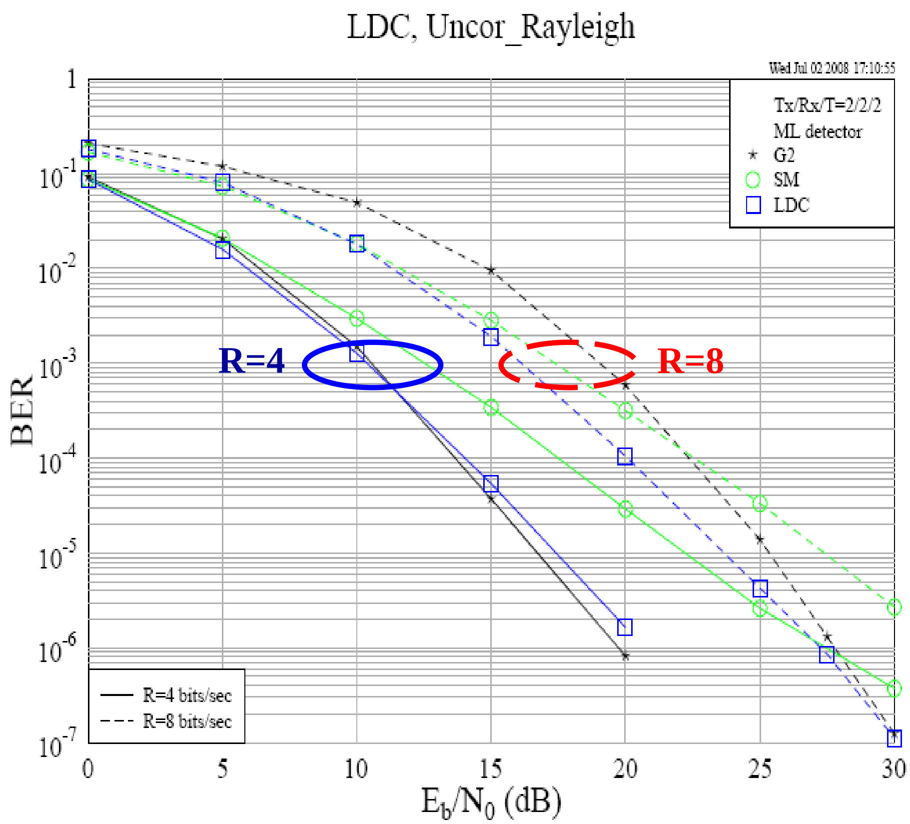


Figure 6-1 BER Performance of LDC compared with Matrix A and B

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 6-2:

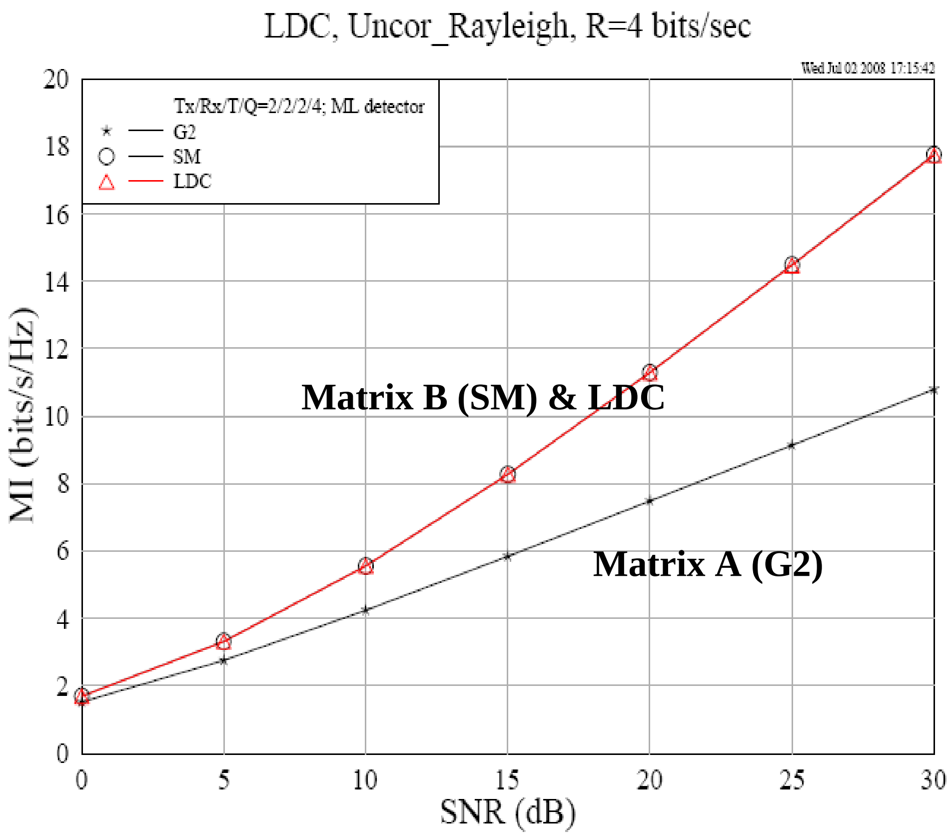


Figure 6-2 Capacity of LDC compared with Matrix A and B

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

6.2. 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 6-3 and Figure 6-4, are performed over ITU-R Ped.A channel, with 3km/h velocity, uncoded scenario, for 2 users with 2-transmit antennas MS each.

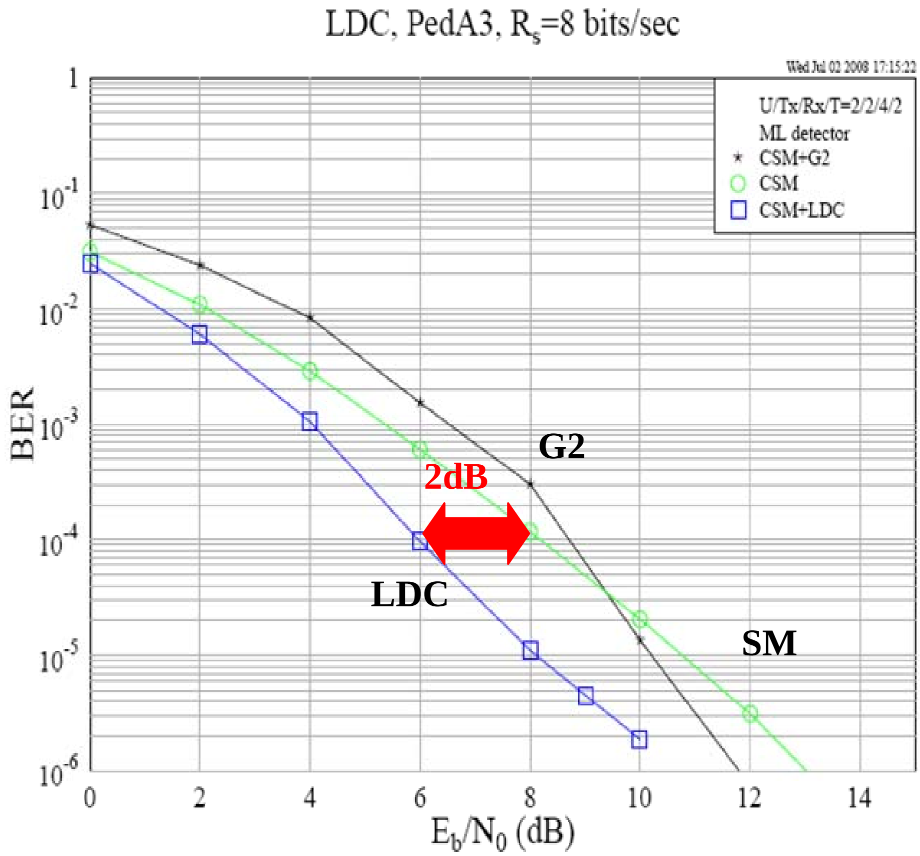


Figure 6-3 BER Performance of CSM-LDC compared with CSM-SM and CSM-STTD, for 2 users with 2-transmit antennas

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.

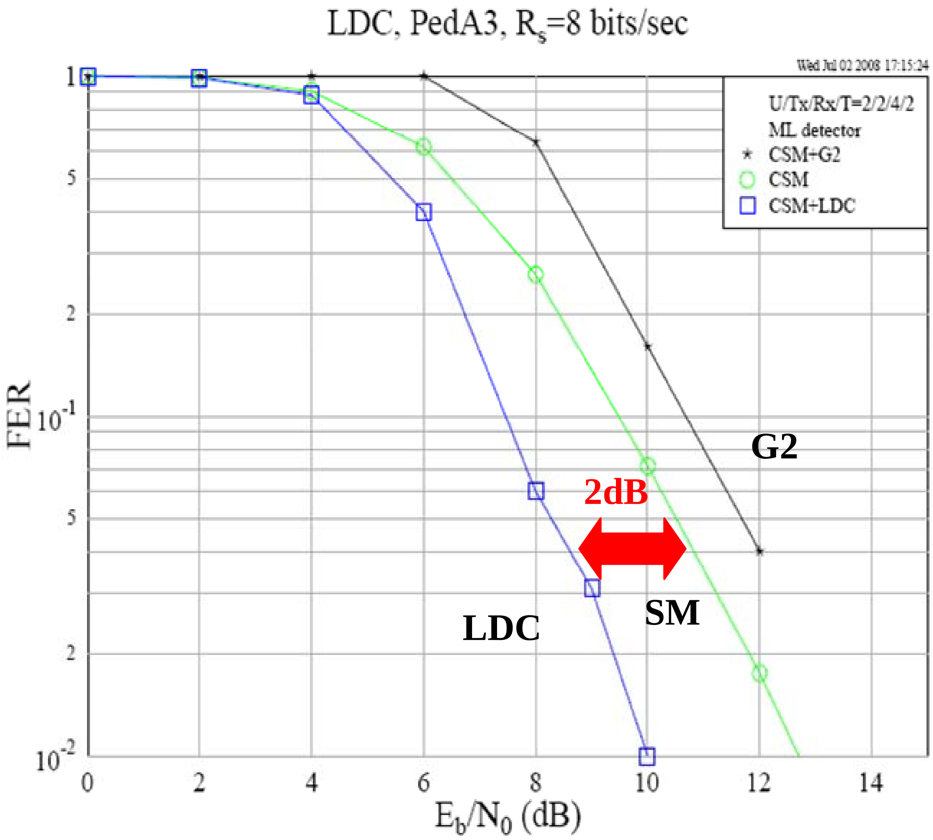


Figure 6-4 FER performance of CSM-LDC compared with CSM-SM and CSM-STTD, for 2 users with 2-transmit antennas

6.3. 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).

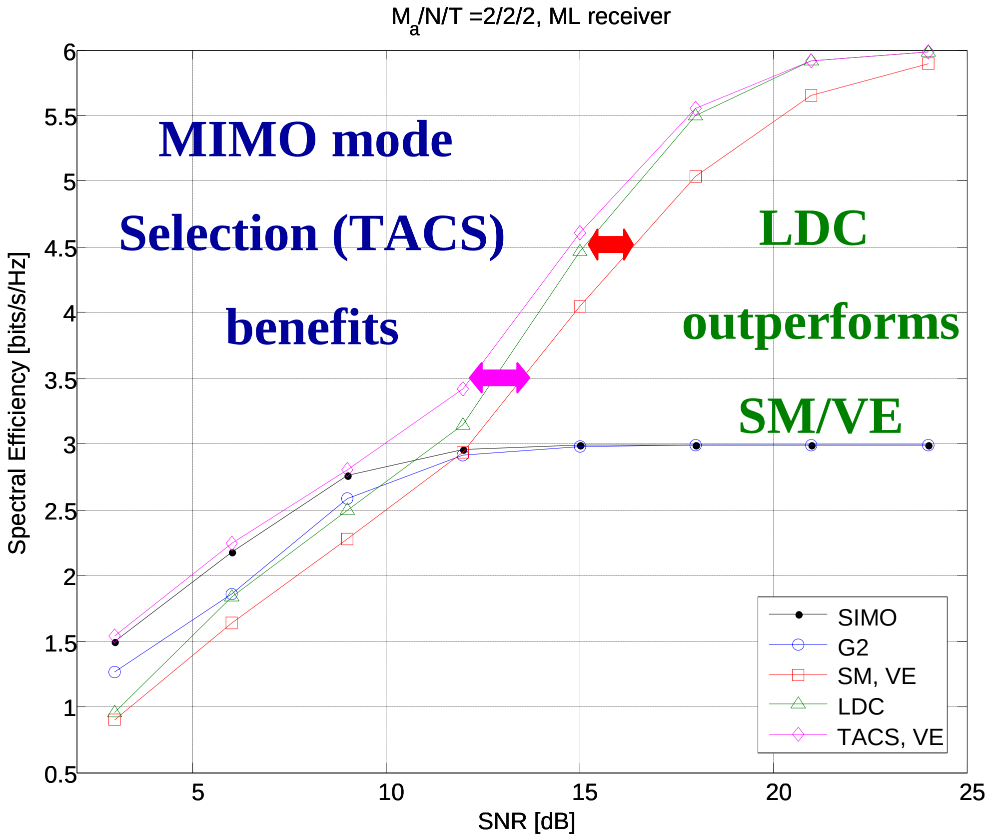


Figure 6-5 Spectral Efficiency comparison of full Spatial Adaptation with single MIMO modes

On the figure above (Figure 6-5), 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.

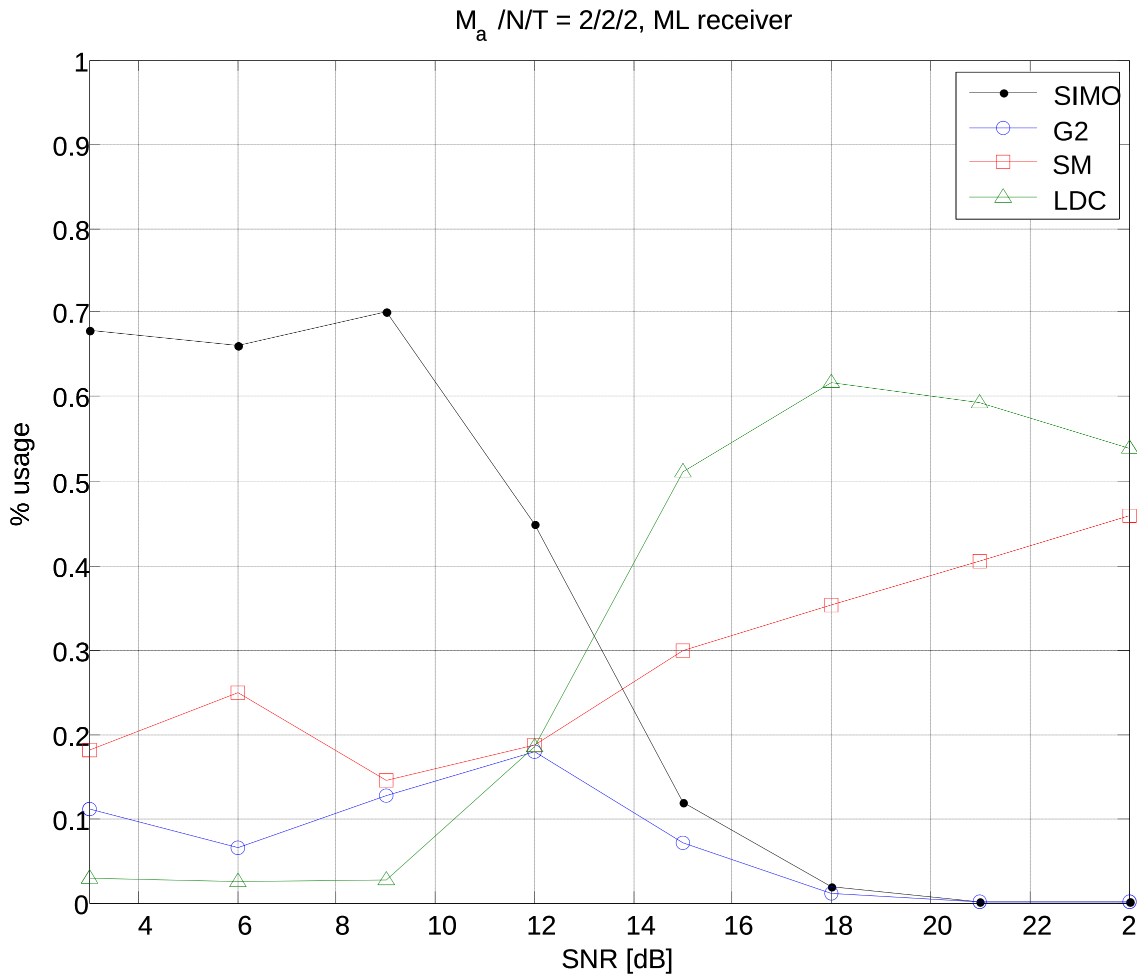


Figure 6-6 Percentage of usage for each MIMO scheme whilst using Spatial Adaptation

The figure above (Figure 6-6) illustrates the percentage of MIMO scheme selection whilst full Spatial Adaptation is triggered. It is quite interesting to notice that having such intermediate scheme between SM and STTD, providing an efficient way to reach the Diversity-Multiplexing trade-off, is definitely offering the overall system a reliable alternative MIMO scheme for boosting spectral efficiency.

7. Proposed Text for SDD

Insert the following text into Physical Layer sub-clause (i.e. Chapter 11 in [5]):

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

11.x. Uplink Transmission Schemes

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

11.x.1.3 MIMO Encoding

11.x.1.3.1 Transmit Diversity

11.x.1.3.2 Spatial Multiplexing

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):

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

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 $\left[S_1, S_2, ..., S_Q \right] \in \Omega^Q$, with S_i is complex symbol from M-QAM constellation Ω.

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

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

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:

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

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:

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

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

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:

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

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

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

11.x.1.4 Subcarrier data mapping for Uplink resource

11.x.1.4.1 Transmit Diversity

11.x.1.4.2 Spatial Multiplexing

11.x.1.4.3 Linear Dispersion Codes

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

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

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.y. Downlink Control Structures

11.y.3. Downlink MAP

The DL MAP shall include the LDC encoding matrix index in UL OL MIMO transmission mode.

8. 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-08/534, “Uplink MIMO Schemes for IEEE 802.16m”

[4] B. Hassibi and B. M. Hochwald, “High-rate codes that are linear in space and time,” IEEE Trans. Inf. Theory, vol. 48, no. 7, pp. 1804-1824, Jul. 2002.

[5] S. M. Alamouti, “A simple transmitter diversity scheme for wireless communications,” IEEE J. Select. Areas Commun., pp. 1451-1458, Oct. 1998.

[6] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, “Space–time block codes from orthogonal designs,” IEEE Trans. Inform. Theory, vol. 45, pp. 1456-1467, July 1999.

[7] G. J. Foschini, G. D. Golden, R. A. Valenzuela, and P. W. Wolniansky, “Simplified processing for high spectral efficiency wireless communication employing multi-element arrays,” IEEE J. Select. Areas

Commun., vol. 17, pp. 1841-1852, Nov. 1999.

[8] R. W. Heath and A. J. Paulraj, "Linear dispersion codes for MIMO systems based on frame theory," IEEE Trans. Signal Process., vol. 50, no. 10, pp. 2429-2441, Oct. 2002.

[9] R. H. Gohary and T. N. Davidson, "Design of linear dispersion codes: asymptotic guidelines and their implementation," IEEE Trans. Wireless Commun., vol. 4, no. 6, pp. 2892-2906, Nov. 2005.

[10] X. Wang, V. Krishnamurthy and J. Wang, "Stochastic gradient algorithms for design of minimum error-rate linear dispersion codes in MIMO wireless systems," IEEE Trans. Signal Process. vol. 54, no. 4, pp. 1242-1255, Apr. 2006.

[11] M. O. Damen, K. Abed-Meraim, and J.-C. Belfiore, "Diagonal algebraic space–time block codes," IEEE Trans. Inform. Theory, vol. 48, pp. 628-636, Mar. 2002.

[12] M. O. Damen and N. C. Beaulieu, "On diagonal algebraic space-time block codes," IEEE Trans. Commun., vol. 51, no. 6, pp. 911-919, Jun. 2003.

[13] H. El Gamal and A. R. Hammons Jr., "On the design of algebraic space-time codes for MIMO block-fading channels," IEEE Trans. Inform. Theory, vol. 49, no. 1, pp. 151-163, Jan. 2003.

[14] H. El Gamal, and M. O. Damen, "Universal space-time coding," IEEE Trans. Inform. Theory, vol. 49, no. 5, pp. 1097-1119, May 2003.

[15] J.-C. Belfiore, G. Rekaya and E. Viterbo, "The golden code: a 2x2 full-rate space-time code with nonvanishing determinants," IEEE Trans. Inform. Theory, vol. 51, no. 4, pp. 1432-1436, Apr. 2005.

[16] F. Oggier, G. Rekaya, J.-C. Belfiore and E. Viterbo, "Perfect Space-Time Block Codes," IEEE Trans. Inform. Theory, vol. 52, no. 9, pp. 3885-3902, Sep. 2006.