Linear Dispersion Codes for Uplink MIMO Schemes in IEEE 802.16m

IEEE 802.16 Presentation Submission Template (Rev. 9)

Document Number:

IEEE S802.16m-08/535r2

Date Submitted:

2008-07-07

Source:

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Venue:

IEEE 802.16m Session#56, Denver, US

Call for contribution on IEEE 802.16m-08/003 System Description Document (SDD).

Topic: Uplink MIMO Schemes

Base Contribution:

IEEE C80216m-08_535

Purpose:

Discussion and Approval

Outline

- Introduction
- Code examples
- Pros/Cons
- Results

Introduction (1/2)

- **System model**

$$\mathbf{x} = \sqrt{\frac{\rho}{M}}\mathbf{H}\mathbf{s} + \mathbf{n} \qquad \mathbf{x} \in C^{N}, \mathbf{s} \in C^{M}, \mathbf{H} \in C^{N \times M}, \mathbf{n} \in C^{N}$$

- **LDC definition**

Codeword

$$\mathbf{S} = \sum_{q=1}^{Q} \left(\alpha_q \cdot \mathbf{A}_q + j \cdot \beta_q \cdot \mathbf{B}_q \right) \in C^{T \times M}$$

$$j = \sqrt{-1}$$

$$s_q = \alpha_q + j \cdot \beta_q$$

Real- or complex-valued dispersion matrices

Constellation symbols

Introduction (2/2)

$$\mathbf{S} = \sum_{q=1}^{Q} \left(s_q \cdot \mathbf{C}_q + s_q^* \cdot \mathbf{D}_q \right)$$

$$s_q = \alpha_q + j \cdot \beta_q$$

$$s_q^* = \alpha_q - j \cdot \beta_q$$

$$\mathbf{S} = \sum_{q=1}^{Q} \left[\left(\alpha_q + j \cdot \beta_q \right) \cdot \mathbf{C}_q + \left(\alpha_q - j \cdot \beta_q \right) \cdot \mathbf{D}_q \right]$$

$$\mathbf{S} = \sum_{q=1}^{Q} \left[\alpha_q \cdot \underbrace{\left(\mathbf{C}_q + \mathbf{D}_q \right)}_{\mathbf{A}_q} + j \cdot \beta_q \cdot \underbrace{\left(\mathbf{C}_q - \mathbf{D}_q \right)}_{\mathbf{B}_q} \right]$$

Transmit Power Constraint (1/3)

$$P_S = E\left(\|\mathbf{S}\|_F^2\right) = T \times M$$

$$\|\mathbf{S}\|_F = \sqrt{Tr\left(\mathbf{S} \cdot \mathbf{S}^{\mathbf{H}}\right)} = \sqrt{\sum_i \sum_j \left|S_{i,j}\right|^2}$$

$$P_S = E\left(\|\mathbf{S}\|_F^2\right) = E\left(Tr\left(\mathbf{S} \cdot \mathbf{S}^{\mathbf{H}}\right)\right) = E\left(\sum_i \sum_j \left|S_{i,j}\right|^2\right)$$

$$P_S = \sum_{i=1}^{T} \sum_{j=1}^{M} E\left(\left|S_{i,j}\right|^2\right) = T \times M$$

Transmit Power Constraint (2/3)

$$E\left(\|\mathbf{S}\|_F^2\right)=\sum_{q=1}^{Q} E\left(\alpha_q^2\right)\cdot Tr\left(\mathbf{A}_q\mathbf{A}_q^{\mathbf{H}}\right)+E\left(\beta_q^2\right)\cdot Tr\left(\mathbf{B}_q\mathbf{B}_q^{\mathbf{H}}\right)$$

$$\left.\begin{array}{l} P_{s_q}=E\left(\left|s_q\right|^2\right)=1 \\ \text{iid} \end{array}\right\} \quad E\left(\alpha_q^2\right)=E\left(\beta_q^2\right)=\frac{1}{2}$$

$$E\left(\|\mathbf{S}\|_F^2\right)=\frac{1}{2}\cdot\sum_{q=1}^{Q} Tr\left(\mathbf{A}_q\mathbf{A}_q^{\mathbf{H}}\right)+Tr\left(\mathbf{B}_q\mathbf{B}_q^{\mathbf{H}}\right)$$

$$\sum_{q=1}^{Q} Tr\left(\mathbf{A}_q\mathbf{A}_q^{\mathbf{H}}\right)+Tr\left(\mathbf{B}_q\mathbf{B}_q^{\mathbf{H}}\right)=2\cdot E\left(\|\mathbf{S}\|_F^2\right)=2\cdot T\cdot M$$

Transmit Power Constraint (3/3)

$$\sum_{q=1}^{Q} Tr\left(\mathbf{A}_q \mathbf{A}_q^{\mathbf{H}}\right) + Tr\left(\mathbf{B}_q \mathbf{B}_q^{\mathbf{H}}\right) = 2 \cdot T \cdot M$$

Detection

- **Decoding → system model can be transformed to BLAST-like**

$$\vec{x} = \sqrt{\frac{\rho}{M}} \cdot H \cdot \vec{s} + \vec{n} \in \Re^{2NT}$$

$$\in \Re^{2NT} \qquad \in \Re^{2NT \times 2Q} \qquad \in \Re^{2Q}$$

- **Existing BLAST-type detection algorithms are readily applicable**
  - LS/MMSE
  - PIC/SIC
  - ML
  - Sphere Decoders

Codes Examples: Matrix A (G2), Alamouti

$$G_2 = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad \begin{matrix} t \\ t+1 \end{matrix}$$

Tx#1 Tx#2

$$\mathbf{A}_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad \mathbf{B}_1 = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$\mathbf{A}_2 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \qquad \mathbf{B}_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$M = 2$$

$$R_c = \frac{Q}{T} = \frac{2}{2} = 1$$

$$R = R_c \cdot \log_2(r)$$

r-QAM

Code examples: Matrix B, SM

$$\begin{bmatrix} s_1 & s_2 \\ s_3 & s_4 \end{bmatrix}$$

t

t+1

Tx#1 Tx#2

$$\mathbf{A}_1 = \mathbf{B}_1 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \quad \mathbf{A}_2 = \mathbf{B}_2 = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$$

$$\mathbf{A}_3 = \mathbf{B}_3 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \quad \mathbf{A}_4 = \mathbf{B}_4 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$M = 2 \quad T = 2 \quad Q = 4$$

$$R_c = \frac{Q}{T} = 2$$

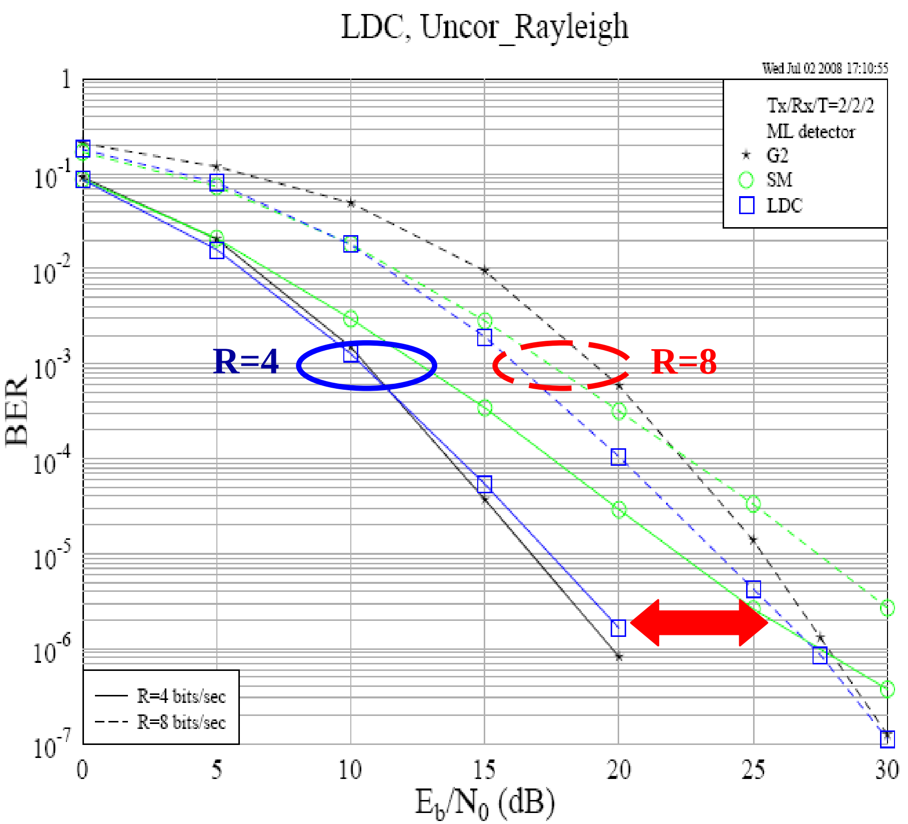
$$R = 2\log_2(r)$$

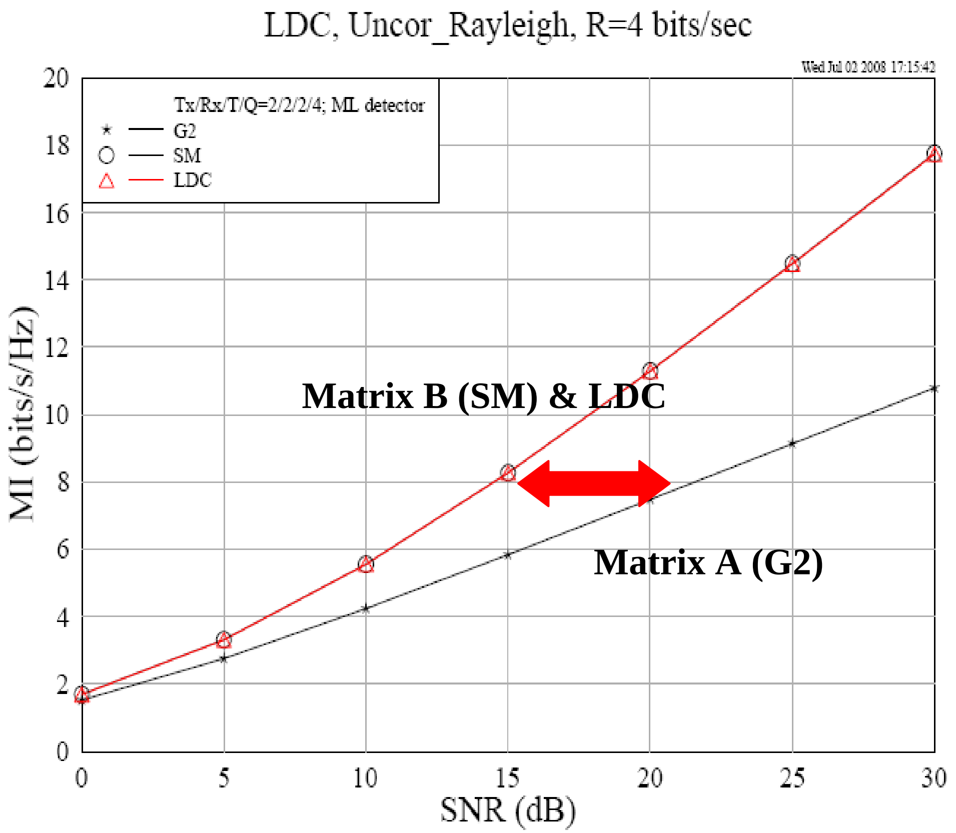
Pros/Cons

- **Advantages**
  - The linearity structure
    - ➢Linear encoding → Very simple
    - ➢General decoding → Existing linear/non-linear detection techniques can be readily employed/reused
  - Multiplexing/Diversity trade-off
    - ➢Cope with the loss in capacity experienced by conventional STBCs (e.g. Alamouti)
    - ➢But also provide satisfactory or better BER performance
  - A unified framework to subsume BLAST, SM, and most existing STBCs
    - ➢Great flexibility of accommodating different schemes into a single system
    - ➢Spatial adaptation → switch among different modes by adjusting encoding matrices
- **Disadvantages**
  - Needs ML-like decoder (e.q. Sphere) → Higher decoding complexity than ort hogonal STBCs and SM with similar dimensions
- **By choosing adequate structure of LDC, implementation feasibility is not obstacle, especially @ BS.**

Simulations Results (1/3)

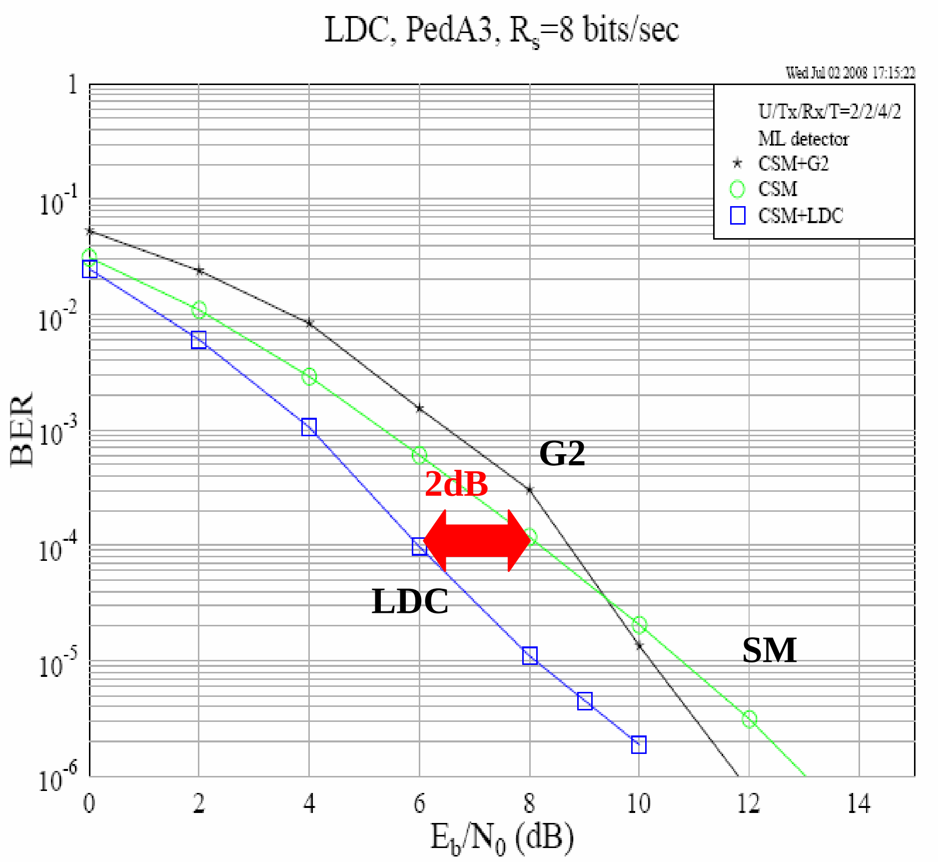
- **LDC advantages w.r.t. legacy UL MIMO (A,B)**
  - Unified Framework
  - Multiplexing-Diversity Trade-off

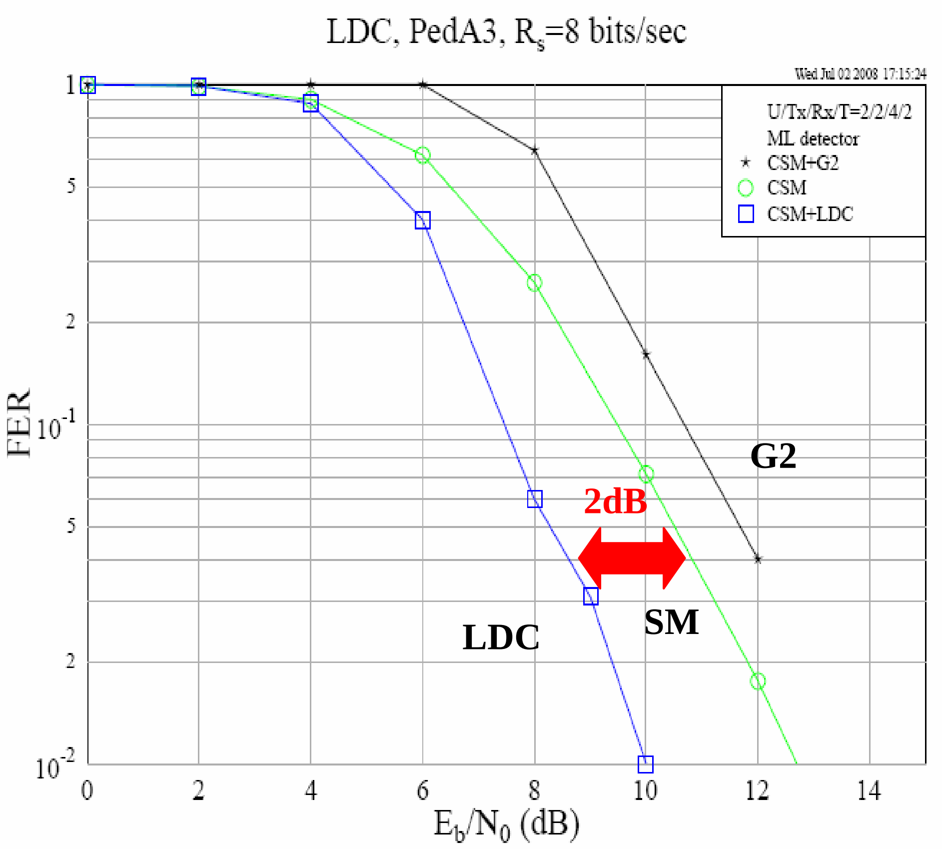




Simulations Results (2/3)

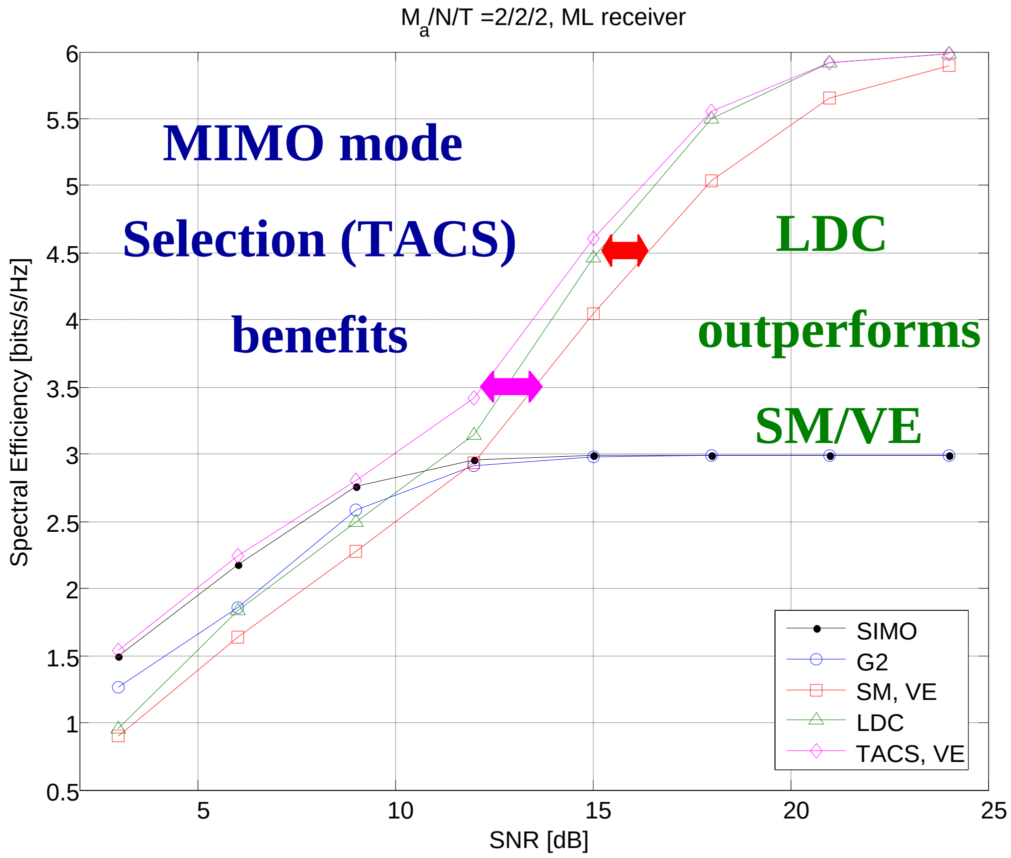
- **LDC within the Collaborative SM (Multi-user MIMO)**





Simulations Results (3/3)

- **Spatial Adaptation**
  - Switching between OL and CL MIMO
  - MIMO/LDC Selection
  - Link Adaptation



Back-Up

Detection (1/6)

$\mathbf{x} \in C^{T\times N}$

$\mathbf{S} \in C^{T\times M}$

$\mathbf{H} \in C^{M\times N}$

$\mathbf{v} \in C^{T\times N}$

$$\mathbf{x} = \sqrt{\frac{\rho}{M}} \cdot \mathbf{S} \cdot \mathbf{H} + \mathbf{v}$$

$$\mathbf{S} = \sum_{q=1}^{Q} \left(\alpha_q \cdot \mathbf{A}_q + j \cdot \beta_q \cdot \mathbf{B}_q \right)$$

$$\mathbf{x} = \sqrt{\frac{\rho}{M}} \cdot \left[\sum_{q=1}^{Q} \left(\alpha_q \cdot \mathbf{A}_q + j \cdot \beta_q \cdot \mathbf{B}_q \right) \right] \cdot \mathbf{H} + \mathbf{v}$$

$\mathbf{x} = \mathbf{x}_R + j \cdot \mathbf{x}_I$ $\quad$ $\mathbf{v} = \mathbf{v}_R + j \cdot \mathbf{v}_I$

$\mathbf{A}_q = \mathbf{A}_q^R + j \cdot \mathbf{A}_q^I$ $\quad$ $\mathbf{H} = \mathbf{H}_R + j \cdot \mathbf{H}_I$

$\mathbf{B}_q = \mathbf{B}_q^R + j \cdot \mathbf{B}_q^I$

$$\mathbf{x}_R + j \cdot \mathbf{x}_I = \sqrt{\frac{\rho}{M}} \cdot \left[\sum_{q=1}^{Q} \alpha_q \cdot \left(\mathbf{A}_q^R + j \cdot \mathbf{A}_q^I \right) + j \cdot \beta_q \cdot \left(\mathbf{B}_q^R + j \cdot \mathbf{B}_q^I \right) \right] \cdot \left(\mathbf{H}_R + j \cdot \mathbf{H}_I \right) + \left(\mathbf{v}_R + j \cdot \mathbf{v}_I \right)$$

Detection (2/6)

$$\mathbf{x}_R + j\cdot\mathbf{x}_I = \sqrt{\frac{\rho}{M}}\cdot\left[\sum_{q=1}^{Q}\alpha_q\cdot\left(\mathbf{A}_q^R + j\cdot\mathbf{A}_q^I\right) + j\cdot\beta_q\cdot\left(\mathbf{B}_q^R + j\cdot\mathbf{B}_q^I\right)\right]\cdot\left(\mathbf{H}_R + j\cdot\mathbf{H}_I\right) + \left(\mathbf{v}_R + j\cdot\mathbf{v}_I\right)$$

$$\mathbf{x}_R + j\cdot\mathbf{x}_I = \sqrt{\frac{\rho}{M}}\cdot\left[\sum_{q=1}^{Q}\left(\alpha_q\cdot\mathbf{A}_q^R - \beta_q\cdot\mathbf{B}_q^I\right) + j\cdot\left(\alpha_q\cdot\mathbf{A}_q^I + \beta_q\cdot\mathbf{B}_q^R\right)\right]\cdot\left(\mathbf{H}_R + j\cdot\mathbf{H}_I\right) + \left(\mathbf{v}_R + j\cdot\mathbf{v}_I\right)$$

$$\mathbf{x}_R = \sqrt{\frac{\rho}{M}}\cdot\left[\sum_{q=1}^{Q}\alpha_q\cdot\left(\mathbf{A}_q^R\cdot\mathbf{H}_R - \mathbf{A}_q^I\cdot\mathbf{H}_I\right) + \beta_q\cdot\left(-\mathbf{B}_q^I\cdot\mathbf{H}_R - \mathbf{B}_q^R\cdot\mathbf{H}_I\right)\right] + \mathbf{v}_R$$

$$\mathbf{x}_I = \sqrt{\frac{\rho}{M}}\cdot\left[\sum_{q=1}^{Q}\alpha_q\cdot\left(\mathbf{A}_q^I\cdot\mathbf{H}_R + \mathbf{A}_q^R\cdot\mathbf{H}_I\right) + \beta_q\cdot\left(\mathbf{B}_q^R\cdot\mathbf{H}_R - \mathbf{B}_q^I\cdot\mathbf{H}_I\right)\right] + \mathbf{v}_I$$

Detection (3/6)

$$\mathbf{x}_R = \left[\vec{x}_1^R, \vec{x}_2^R, \ldots, \vec{x}_N^R\right] \in \Re^{T\times N}$$

$\vec{x}_i^R \in \Re^T = i^{th}$ *column of* $\mathbf{x}_R$

$$\mathbf{x}_I = \left[\vec{x}_1^I, \vec{x}_2^I, \ldots, \vec{x}_N^I\right] \in \Re^{T\times N}$$

$$\mathbf{H}_R = \left[\vec{h}_1^R, \vec{h}_2^R, \ldots, \vec{h}_N^R\right]$$

$$\mathbf{H}_I = \left[\vec{h}_1^I, \vec{h}_2^I, \ldots, \vec{h}_N^I\right]$$

$$\mathbf{v}_R = \left[\vec{v}_1^R, \vec{v}_2^R, \ldots, \vec{v}_N^R\right]$$

$$\mathbf{v}_I = \left[\vec{v}_1^I, \vec{v}_2^I, \ldots, \vec{v}_N^I\right]$$

$$\vec{s} = \begin{bmatrix} \alpha_1 \\ \beta_1 \\ \alpha_2 \\ \beta_2 \\ \ldots \\ \ldots \\ \alpha_Q \\ \beta_Q \end{bmatrix} \in \Re^{2Q} \quad \vec{x} = \begin{bmatrix} \vec{x}_1^R \\ \vec{x}_1^I \\ \vec{x}_2^R \\ \vec{x}_2^I \\ \ldots \\ \ldots \\ \vec{x}_N^R \\ \vec{x}_N^I \end{bmatrix} \in \Re^{2TN} \quad \vec{v} = \begin{bmatrix} \vec{v}_1^R \\ \vec{v}_1^I \\ \vec{v}_2^R \\ \vec{v}_2^I \\ \ldots \\ \ldots \\ \vec{v}_N^R \\ \vec{v}_N^I \end{bmatrix} \in \Re^{2TN}$$

$$\vec{h}_i = \begin{bmatrix} \vec{h}_i^R \\ \vec{h}_i^I \end{bmatrix} \in \Re^{2T}$$

Detection (4/6)

$$\vec{h}_i = \begin{bmatrix} \vec{h}_i^R \\ \vec{h}_i^I \end{bmatrix} \in \Re^{2T}$$

$$\mathsf{A}_q = \begin{bmatrix} \mathbf{A}_q^R & -\mathbf{A}_q^I \\ \mathbf{A}_q^I & \mathbf{A}_q^R \end{bmatrix}$$

$$\mathsf{B}_q = \begin{bmatrix} -\mathbf{B}_q^I & -\mathbf{B}_q^R \\ \mathbf{B}_q^R & -\mathbf{B}_q^I \end{bmatrix}$$

$$\mathsf{H} = \begin{bmatrix} \mathsf{A}_1 \cdot \vec{h}_1 & \mathsf{B}_1 \cdot \vec{h}_1 & \mathsf{A}_2 \cdot \vec{h}_1 & \mathsf{B}_2 \cdot \vec{h}_1 & \cdots & \cdots & \mathsf{A}_Q \cdot \vec{h}_1 & \mathsf{B}_Q \cdot \vec{h}_1 \\ \mathsf{A}_1 \cdot \vec{h}_2 & \mathsf{B}_1 \cdot \vec{h}_2 & \mathsf{A}_2 \cdot \vec{h}_2 & \mathsf{B}_2 \cdot \vec{h}_2 & \cdots & \cdots & \mathsf{A}_Q \cdot \vec{h}_2 & \mathsf{B}_Q \cdot \vec{h}_2 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \mathsf{A}_1 \cdot \vec{h}_N & \mathsf{B}_1 \cdot \vec{h}_N & \mathsf{A}_2 \cdot \vec{h}_N & \mathsf{B}_2 \cdot \vec{h}_N & \cdots & \cdots & \mathsf{A}_Q \cdot \vec{h}_N & \mathsf{B}_Q \cdot \vec{h}_N \end{bmatrix}$$

$$\in \Re^{2NT \times 2Q}$$

Detection (5/6)

$$H = \begin{bmatrix} A_1 \cdot \vec{h}_1 & B_1 \cdot \vec{h}_1 & A_2 \cdot \vec{h}_1 & B_2 \cdot \vec{h}_1 & \dots & \dots & A_Q \cdot \vec{h}_1 & B_Q \cdot \vec{h}_1 \\ A_1 \cdot \vec{h}_2 & B_1 \cdot \vec{h}_2 & A_2 \cdot \vec{h}_2 & B_2 \cdot \vec{h}_2 & \dots & \dots & A_Q \cdot \vec{h}_2 & B_Q \cdot \vec{h}_2 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ A_1 \cdot \vec{h}_N & B_1 \cdot \vec{h}_N & A_2 \cdot \vec{h}_N & B_2 \cdot \vec{h}_N & \dots & \dots & A_Q \cdot \vec{h}_N & B_Q \cdot \vec{h}_N \end{bmatrix}$$

$$\vec{h} = \begin{bmatrix} \vec{h}_1 \\ \vec{h}_2 \\ \dots \\ \vec{h}_N \end{bmatrix}$$

$$\begin{bmatrix} A_Q & 0 & \dots & 0 \\ 0 & A_Q & 0 & \dots \\ \dots & 0 & \dots & 0 \\ 0 & \dots & 0 & A_Q \end{bmatrix} \cdot \begin{bmatrix} \vec{h}_1 \\ \vec{h}_2 \\ \dots \\ \vec{h}_N \end{bmatrix}$$

$$\begin{bmatrix} A_Q & 0 & \dots & 0 \\ 0 & A_Q & 0 & \dots \\ \dots & 0 & \dots & 0 \\ 0 & \dots & 0 & A_Q \end{bmatrix} = \mathbf{I}_N \otimes A_Q$$

Detection (6/6)

$$H = \left[\mathbf{I}_N \otimes A_1 \quad \mathbf{I}_N \otimes B_1 \quad \dots \quad \mathbf{I}_N \otimes A_Q \quad \mathbf{I}_N \otimes B_Q \right] \cdot \begin{bmatrix} \vec{h}_1 & \vec{h}_1 & \vec{h}_1 & \vec{h}_1 & \dots & \dots & \vec{h}_1 & \vec{h}_1 \\ \vec{h}_2 & \vec{h}_2 & \vec{h}_2 & \vec{h}_2 & \dots & \dots & \vec{h}_2 & \vec{h}_2 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \vec{h}_N & \vec{h}_N & \vec{h}_N & \vec{h}_N & \dots & \dots & \vec{h}_N & \vec{h}_N \end{bmatrix}$$

$$H = \left[\mathbf{I}_N \otimes A_1 \quad \mathbf{I}_N \otimes B_1 \quad \dots \quad \mathbf{I}_N \otimes A_Q \quad \mathbf{I}_N \otimes B_Q \right] \cdot \underbrace{\left[\vec{h} \quad \vec{h} \quad \dots \quad \dots \quad \vec{h} \quad \vec{h} \quad \vec{h} \quad \vec{h} \right]}_{\left(\mathbf{I}_{2Q} \otimes \vec{h} \right)^T}$$

$$H = \left[\mathbf{I}_N \otimes A_1 \quad \mathbf{I}_N \otimes B_1 \quad \dots \quad \mathbf{I}_N \otimes A_Q \quad \mathbf{I}_N \otimes B_Q \right] \cdot \left[\mathbf{I}_{2Q} \otimes \vec{h}^T \right]$$

Spatial Adaptation

- **MIMO scheme usage (%)**