

Linear Dispersion Codes for Uplink MIMO Schemes in IEEE 802.16m

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Discussion and Approval

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Outline

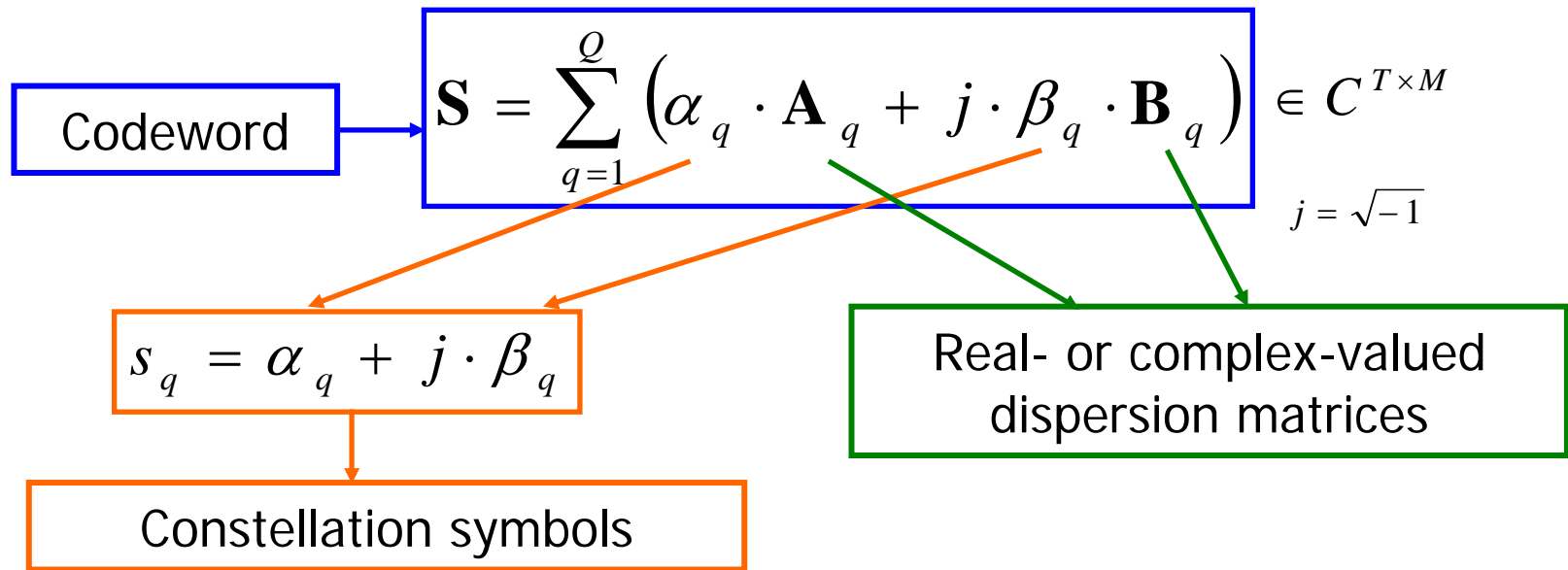
- **Introduction**
- **Code examples**
- **Pros/Cons**
- **Results**

Introduction (1/2)

- System model

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

- LDC definition



Introduction (2/2)

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

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

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

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



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

Transmit Power Constraint (1/3)

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

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

$$P_S = E\left(\|\mathbf{S}\|_F^2\right) = E\left(\text{Tr}(\mathbf{S} \cdot \mathbf{S}^H)\right) = E\left(\sum_i \sum_j |S_{i,j}|^2\right)$$
$$P_S = \sum_{i=1}^T \sum_{j=1}^M E\left(|S_{i,j}|^2\right) = T \times M$$

Transmit Power Constraint (2/3)

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

$$P_{s_q} = E\left(|s_q|^2\right) = 1 \left. \vphantom{P_{s_q}} \right\} E\left(\alpha_q^2\right) = E\left(\beta_q^2\right) = \frac{1}{2}$$

iid

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

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

Transmit Power Constraint (3/3)

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

Detection

- Decoding \rightarrow system model can be transformed to BLAST-like

$$\vec{x} = \sqrt{\frac{\rho}{M}} \cdot \mathbf{H} \cdot \vec{s} + \vec{n}$$

$\vec{x} \in \mathbb{R}^{2NT}$ $\mathbf{H} \in \mathbb{R}^{2NT \times 2Q}$ $\vec{s} \in \mathbb{R}^{2Q}$ $\vec{n} \in \mathbb{R}^{2NT}$

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

Codes Examples: Matrix A (G2), Alamouti

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

Tx#1 Tx#2

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

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

$$M = 2$$

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

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

r-QAM

Code examples: Matrix B, SM

$$\begin{array}{c} \boxed{\begin{bmatrix} s_1 & s_2 \\ s_3 & s_4 \end{bmatrix}} \\ \text{Tx\#1} \quad \text{Tx\#2} \end{array} \begin{array}{c} t \\ t+1 \end{array} \quad \rightarrow$$

$$\begin{array}{ll} \mathbf{A}_1 = \mathbf{B}_1 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} & \mathbf{A}_2 = \mathbf{B}_2 = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \\ \mathbf{A}_3 = \mathbf{B}_3 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} & \mathbf{A}_4 = \mathbf{B}_4 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \end{array}$$

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

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

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

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

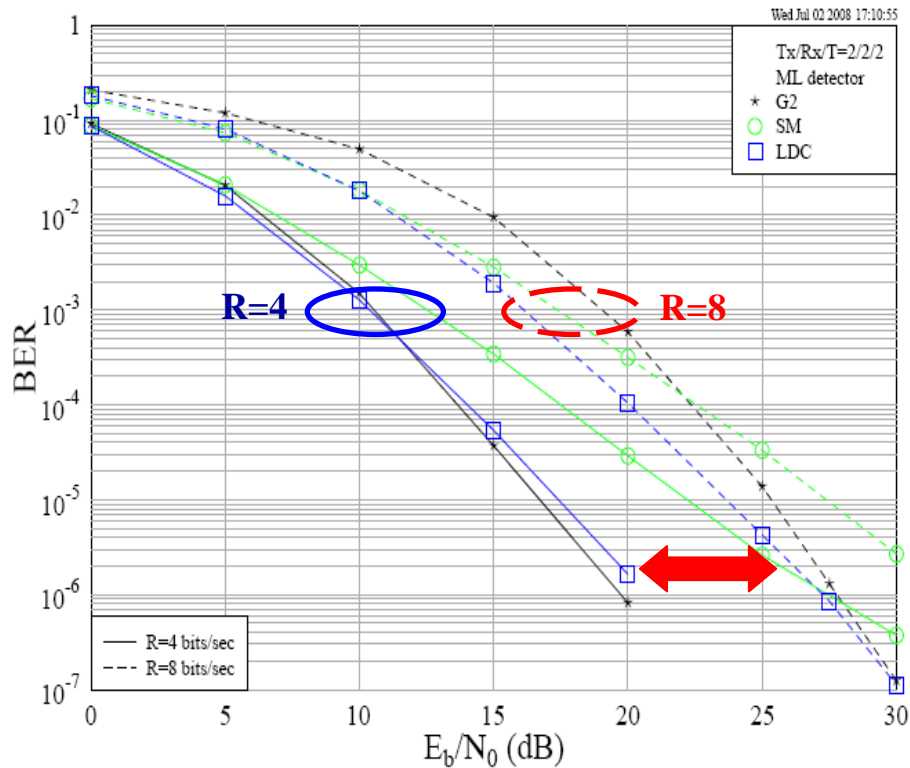
▪ Disadvantages

- Needs ML-like decoder (e.g. Sphere) → Higher decoding complexity than orthogonal STBCs and SM with similar dimensions
- **By choosing adequate structure of LDC, implementation feasibility is not obstacle, especially @ BS.**

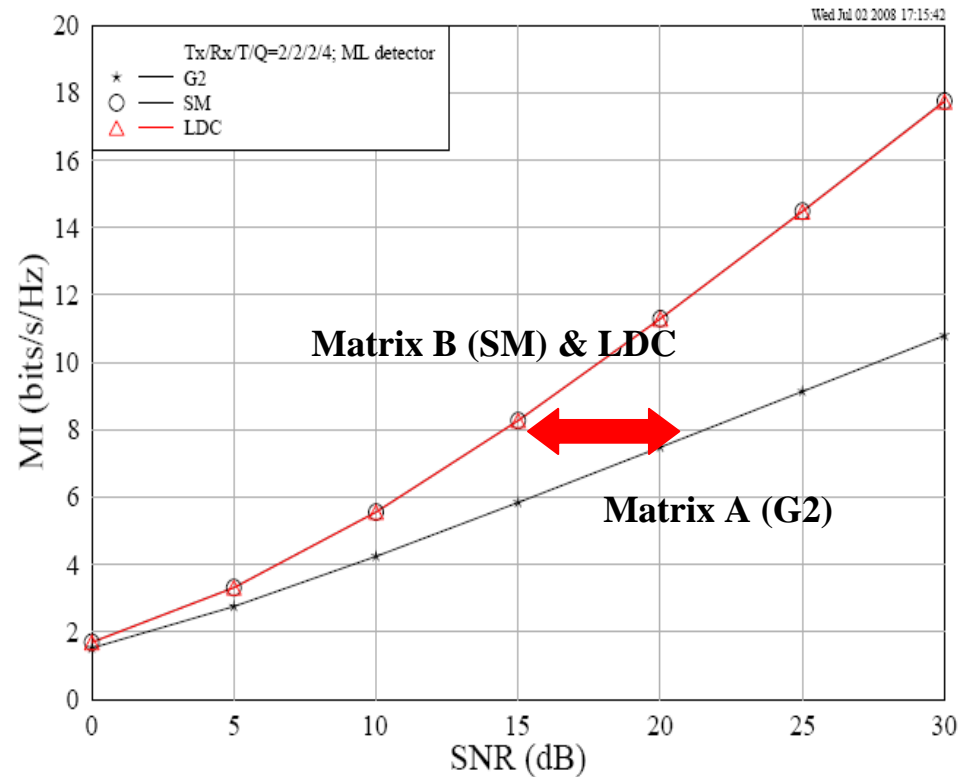
Simulations Results (1/3)

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

LDC, Uncor_Rayleigh



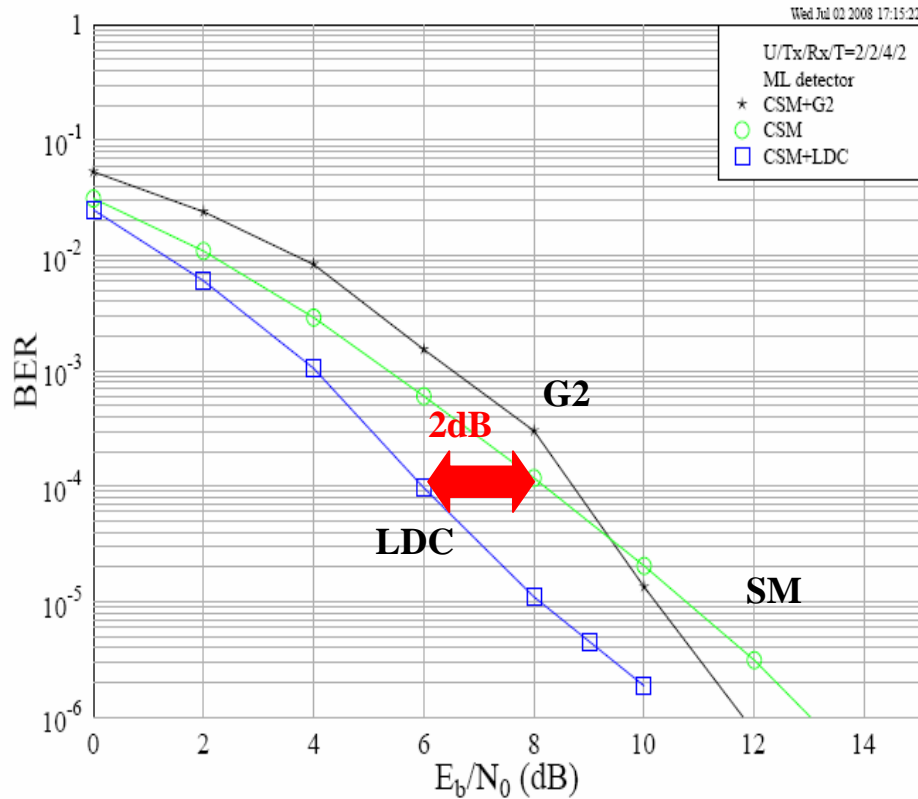
LDC, Uncor_Rayleigh, R=4 bits/sec



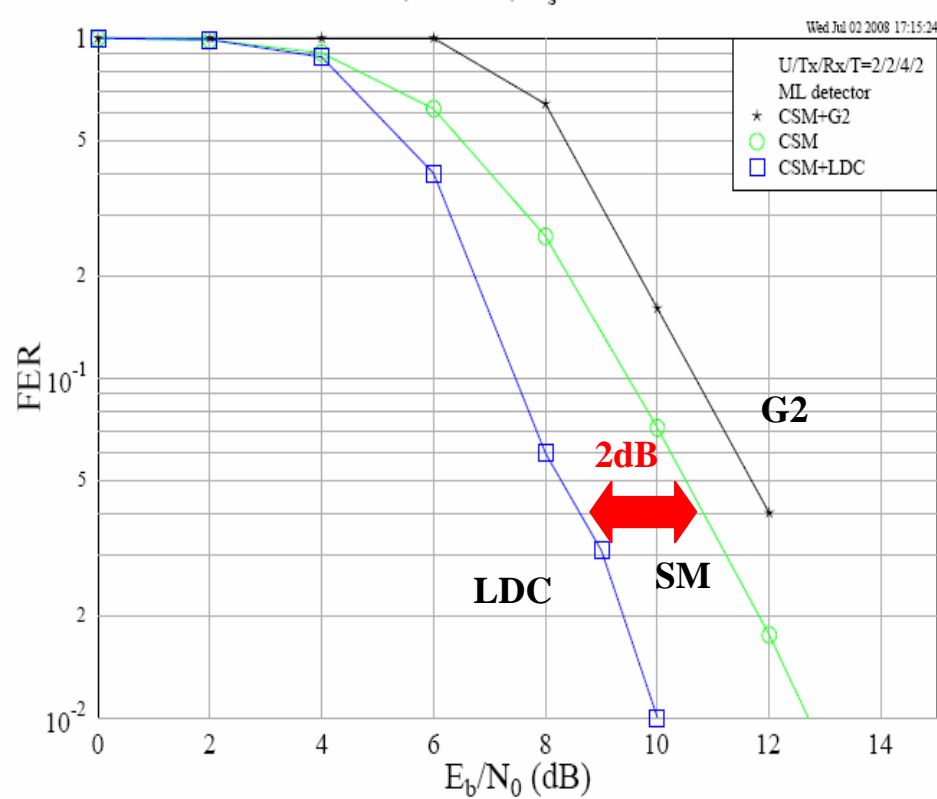
Simulations Results (2/3)

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

LDC, PedA3, $R_s=8$ bits/sec



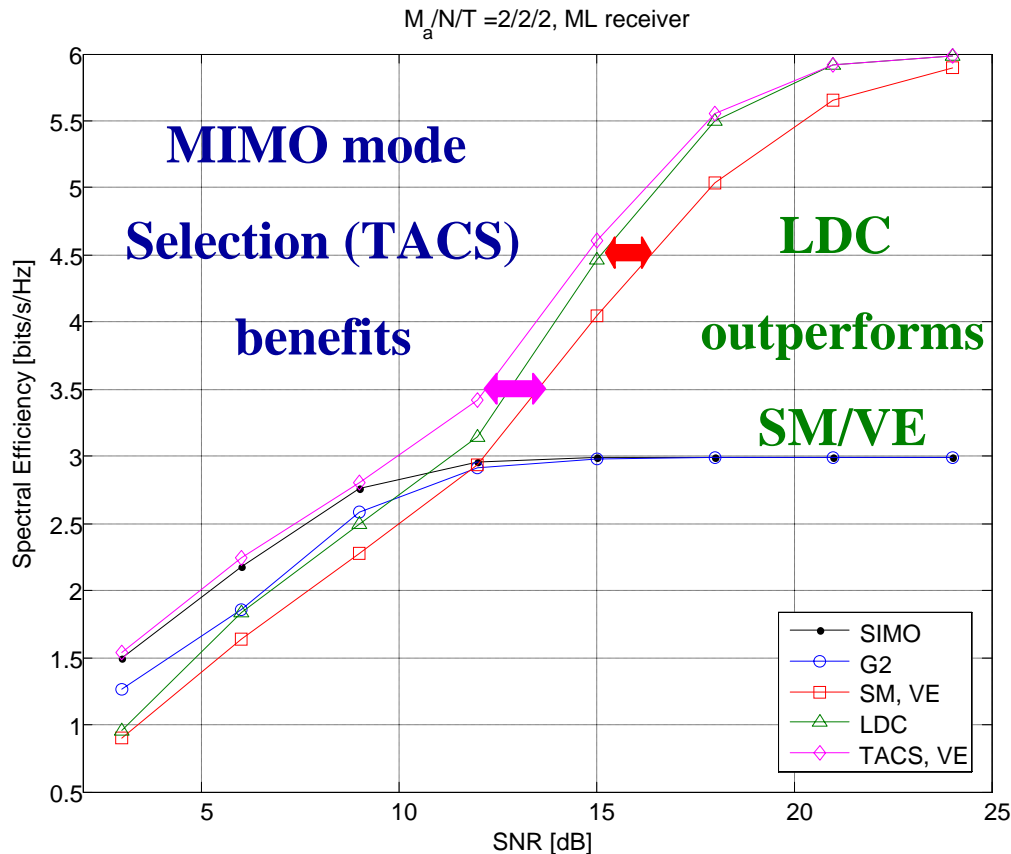
LDC, PedA3, $R_s=8$ bits/sec



Simulations Results (3/3)

▪ Spatial Adaptation

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



Back-Up

Detection

(1/6)

$$\begin{aligned}\mathbf{x} &\in \mathbb{C}^{T \times N} \\ \mathbf{S} &\in \mathbb{C}^{T \times M} \\ \mathbf{H} &\in \mathbb{C}^{M \times N} \\ \mathbf{v} &\in \mathbb{C}^{T \times N}\end{aligned}$$

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

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

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



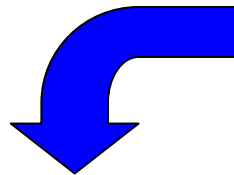
$$\mathbf{x} = \mathbf{x}_R + j \cdot \mathbf{x}_I$$

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

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

$$\mathbf{H} = \mathbf{H}_R + j \cdot \mathbf{H}_I$$

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



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

Detection

(2/6)

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

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

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

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

Detection

(3/6)

$$\left. \begin{aligned} \mathbf{x}_R &= [\vec{x}_1^R, \vec{x}_2^R, \dots, \vec{x}_N^R] \in \mathfrak{R}^{T \times N} \\ \vec{x}_i^R &\in \mathfrak{R}^T = i^{\text{th}} \text{ column of } \mathbf{x}_R \\ \mathbf{x}_I &= [\vec{x}_1^I, \vec{x}_2^I, \dots, \vec{x}_N^I] \in \mathfrak{R}^{T \times N} \\ \mathbf{H}_R &= [\vec{h}_1^R, \vec{h}_2^R, \dots, \vec{h}_N^R] \\ \mathbf{H}_I &= [\vec{h}_1^I, \vec{h}_2^I, \dots, \vec{h}_N^I] \\ \mathbf{v}_R &= [\vec{v}_1^R, \vec{v}_2^R, \dots, \vec{v}_N^R] \\ \mathbf{v}_I &= [\vec{v}_1^I, \vec{v}_2^I, \dots, \vec{v}_N^I] \end{aligned} \right\} \vec{s} = \begin{bmatrix} \alpha_1 \\ \beta_1 \\ \alpha_2 \\ \beta_2 \\ \dots \\ \dots \\ \alpha_Q \\ \beta_Q \end{bmatrix} \in \mathfrak{R}^{2Q} \quad \vec{x} = \begin{bmatrix} \vec{x}_1^R \\ \vec{x}_1^I \\ \vec{x}_2^R \\ \vec{x}_2^I \\ \dots \\ \dots \\ \vec{x}_N^R \\ \vec{x}_N^I \end{bmatrix} \in \mathfrak{R}^{2TN} \quad \vec{v} = \begin{bmatrix} \vec{v}_1^R \\ \vec{v}_1^I \\ \vec{v}_2^R \\ \vec{v}_2^I \\ \dots \\ \dots \\ \vec{v}_N^R \\ \vec{v}_N^I \end{bmatrix} \in \mathfrak{R}^{2TN}$$
$$\vec{h}_i = \begin{bmatrix} \vec{h}_i^R \\ \vec{h}_i^I \end{bmatrix} \in \mathfrak{R}^{2T}$$

Detection

(4/6)

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

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

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

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

$$\in \mathfrak{R}^{2NT \times 2Q}$$

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)

$$H = \begin{bmatrix} \mathbf{I}_N \otimes \mathbf{A}_1 & \mathbf{I}_N \otimes \mathbf{B}_1 & \dots & \mathbf{I}_N \otimes \mathbf{A}_Q & \mathbf{I}_N \otimes \mathbf{B}_Q \end{bmatrix} \cdot \begin{bmatrix} \vec{h}_1 & \vec{h}_1 & \vec{h}_1 & \vec{h}_1 & \dots & \dots & \vec{h}_1 & \vec{h}_1 \\ \vec{h}_2 & \vec{h}_2 & \vec{h}_2 & \vec{h}_2 & \dots & \dots & \vec{h}_2 & \vec{h}_2 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \vec{h}_N & \vec{h}_N & \vec{h}_N & \vec{h}_N & \dots & \dots & \vec{h}_N & \vec{h}_N \end{bmatrix}$$

$$H = \begin{bmatrix} \mathbf{I}_N \otimes \mathbf{A}_1 & \mathbf{I}_N \otimes \mathbf{B}_1 & \dots & \mathbf{I}_N \otimes \mathbf{A}_Q & \mathbf{I}_N \otimes \mathbf{B}_Q \end{bmatrix} \cdot \underbrace{\begin{bmatrix} \vec{h} & \vec{h} & \dots & \dots & \vec{h} & \vec{h} & \vec{h} & \vec{h} \end{bmatrix}}_{(\mathbf{I}_{2Q} \otimes \vec{h})^T}$$

$$H = \begin{bmatrix} \mathbf{I}_N \otimes \mathbf{A}_1 & \mathbf{I}_N \otimes \mathbf{B}_1 & \dots & \mathbf{I}_N \otimes \mathbf{A}_Q & \mathbf{I}_N \otimes \mathbf{B}_Q \end{bmatrix} \cdot \left[\mathbf{I}_{2Q} \otimes \vec{h}^T \right]$$

Spatial Adaptation

- MIMO scheme usage (%)

