Norm-Based Joint Transmit/Receive Antenna Selection (NBJTRAS) Aided and Two-Tier Channel Estimation (TTCE) Assisted STSK Systems

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Outline

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Background

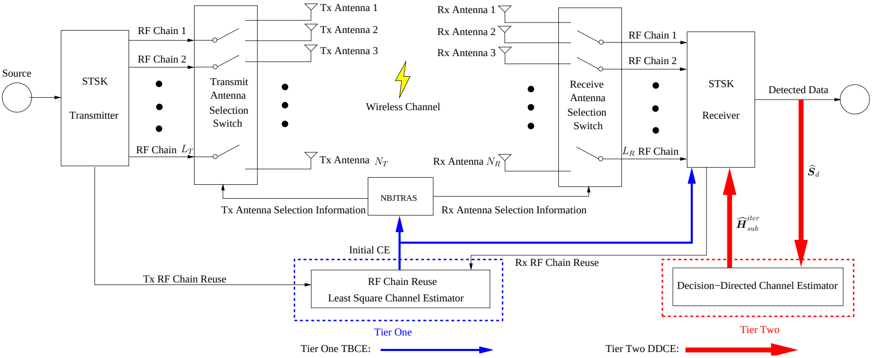
- MIMO systems' promise **wonderland** of **diversity** and/or **multiplexing** gains
  - requires **multiple** RF chains, which may lead to a **high power consumption** and **hardware costs**
- **Antenna Selection (AS)**:
  - Offers a low-cost technique of **reducing** the number of RF chains utilised at the transmitter and/or receiver, while **retaining** the significant advantages of MIMO systems
- **Challenges**:
  - **Low-complexity** AS is always desirable
  - **Efficient channel estimation (CE)** is needed

Our Contributions

- Existing joint transmit/receive AS and CE schemes
  1. Full-search based AS achieves optimal performance, while imposing a **high complexity**
  2. Sub-optimal AS leads to a certain **performance loss**
  3. Conventional training based CE (TBCE) imposes a **high overhead** required for acquiring accurate CSI, while pure blilnd CE imposes a **high complexity** and **estimation ambiguities**
- Our novel **NBJTRAS** and **TTCE**
  1. The new NBJTRAS relies on norm-based antenna selection **optimization** at a much **lower complexity**
  2. Simple yet efficient TTCE is capable of acquiring **accurate CSI**, while imposing a **low overhead**.

Outline

Structure of NBJTRAS aided STSK



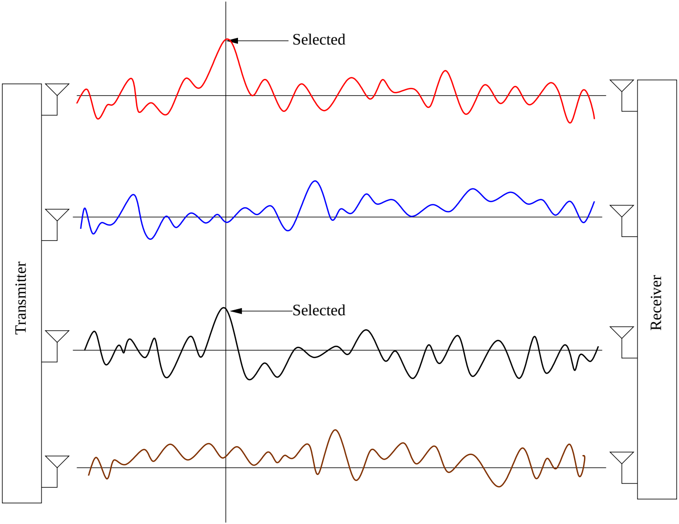
Norm-Based Selection (NBS) Criterion

- Let $\widehat{\boldsymbol{H}}_{sub} \in \mathbb{C}^{L_R \times L_T}$ be the subset candidates of the full channel matrix $\boldsymbol{H} \in \mathbb{C}^{N_R \times N_T}$, while the corresponding selected subset $\boldsymbol{H}_{sub}$ based on the NBS criterion may be formulated as:

$$\boldsymbol{H}_{sub} = \arg \max_{\widehat{\boldsymbol{H}}_{sub} \in \boldsymbol{H}} \left\{ \sum_{n_t=1}^{L_T} \sum_{n_r=1}^{L_R} ||\widehat{\boldsymbol{H}}_{sub}(n_r, n_t)|| \right\} \quad (1)$$

- Solving the above optimization problem by exhaustive search requires us to evaluate the norms of the $C_{N_R}^{L_R} \times C_{N_T}^{L_T}$ candidate subset matrices, where $C_{N_R}^{L_R}$ and $C_{N_T}^{L_T}$ are the row-dimension and column-dimension combinations of $\boldsymbol{H}_{sub}$, respectively.

Norm-Based Selection (NBS) Criterion



NBJTRAS Algorithm Description

- Given the full channel matrix $\boldsymbol{H} \in \mathbb{C}^{N_R \times N_T}$, without loss of generality, assume $\mathrm{C}_{N_R}^{L_R} < \mathrm{C}_{N_T}^{L_T}$. The NBJTRAS algorithm accomplishes the optimization in **two Steps**:
- **Step 1**: Row Based Operations

  Let $i_r \in \left\{1, 2, \cdots, \mathrm{C}_{N_R}^{L_R}\right\}$ be the row combination index, and get the sub-matrix $\boldsymbol{H}_{i_r} \in \mathbb{C}^{L_R \times N_T}$. Compute the magnitude of each column in $\boldsymbol{H}_{i_r}$, which yields the norm metric vector of

$$\boldsymbol{m}_{i_r}^{\mathrm{T}} = \left[m_{i_r}^1 \; m_{i_r}^2 \cdots m_{i_r}^{N_T} \right]. \tag{2}$$

  Applying (2) to all the $\mathrm{C}_{N_R}^{L_R}$ possible combinations leads to the norm metric matrix $\boldsymbol{M}^{\mathrm{T}} = [\boldsymbol{m}_1, \boldsymbol{m}_2, \cdots, \boldsymbol{m}_{\mathrm{C}_{N_R}^{L_R}}] \in \mathbb{C}^{N_T \times \mathrm{C}_{N_R}^{L_R}}$.

NBJTRAS Algorithm Description

- **Step 2**: Column Based Operations

  Find the largest L_T elements in the i_rth row of $\boldsymbol{M}$ and sum them up, which is denoted as $m_{\max}^{i_r}$, as well as record the column indices of these L_T elements in the index vector, producing the max-norm metric vector of

$$\boldsymbol{m}_{\max}^{\mathrm{T}} = \left[m_{\max}^{1} \; m_{\max}^{2} \cdots m_{\max}^{C_{N_R}^{L_R}} \right]. \quad (3)$$

  Then the optimal sub-set may be found by identifying the largest element in (3).

An Example of NBJTRAS with $L_T = L_R = 2$

Step 1: Row Based Operations

Full Channel Matrix with Norm Values ($N_T = 8$, $N_R = 4$)

0.5	1.2	1.2	1.2	1.0	0.9	0.7	0.5
1.1	2.5	0.2	0.8	1.4	1.1	0.9	0.5
0.7	2.1	0.4	0.2	1.5	0.5	1.6	1.5
0.6	1.2	1.1	1.5	0.5	1.1	0.7	1.2

Apply Eq. 2

Norm Metric Matrix ($N_T = 8$, $C_{N_R}^{L_R} = 6$)

1.6	3.7	1.4	2.0	2.4	2.0	1.6	1.0	Row(1 and 2)
1.2	3.3	1.6	1.4	2.5	1.4	2.3	2.0	Row(1 and 3)
1.1	2.4	2.3	2.7	1.5	2.0	1.4	1.7	Row(1 and 4)
1.8	4.6	0.6	1.0	2.9	1.6	2.5	2.0	Row(2 and 3)
1.7	3.7	1.3	2.3	1.9	2.2	1.6	1.7	Row(2 and 4)
1.3	3.3	1.5	1.7	2.0	1.6	2.3	2.7	Row(3 and 4)

Find $L_T = 2$ largest elements of each combination

3.7	2.4
3.3	2.5
2.4	2.7
4.6	2.9
3.7	2.3
3.3	2.7

Sum up elements in each combination

6.1
5.8
5.1
7.5
6.0
6.0

Wining combination → 7.5

Map wining combination back to full channel matrix

Step 2: Column Based Operations

Complexity Comparison

- Complexity of the **Exhaustive Search**:

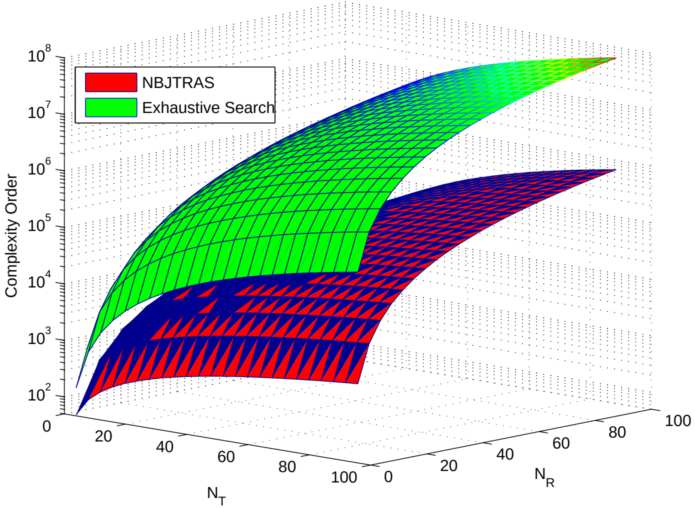
$$C_{\mathrm{ES}} \approx \mathcal{O}\left(\left(L_R \cdot L_T\right) \cdot \left(C_{N_T}^{L_T} \cdot C_{N_R}^{L_R}\right)\right)$$

- Complexity of the **NBJTRAS**:

$$C_{\mathrm{NBJTRAS}} \approx \mathcal{O}\left(\left(N_T \cdot L_R\right) \cdot C_{N_R}^{L_R}\right) \text{ (if } C_{N_R}^{L_R} \leq C_{N_T}^{L_T}\text{)}$$

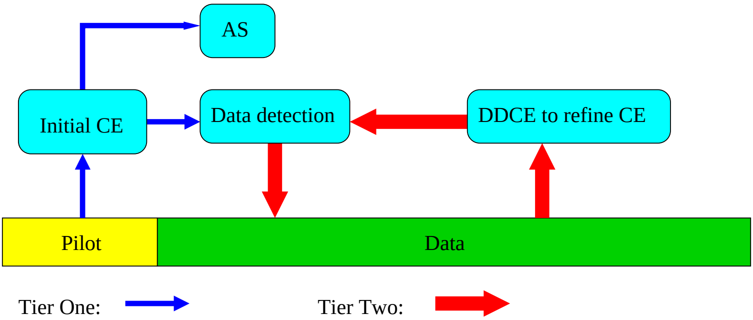
$$\text{or } C_{\mathrm{NBJTRAS}} \approx \mathcal{O}\left(\left(N_R \cdot L_T\right) \cdot C_{N_T}^{L_T}\right) \text{ (if } C_{N_R}^{L_R} > C_{N_T}^{L_T}\text{)}$$

Complexity Comparison Figure



Outline

Structure of Two-Tier Channel Estimation for NBJTRAS



Two-Tier Channel Estimation for NBJTRAS

- **Tier One**: Training Based CE (**TBCE**) for AS
  - We adopt the **low-complexity** TBCE relying on a low training overhead in **Tier One** to maintain a **high throughput** at the cost of a **poor CE**
  - AS is relatively **insensitive** to CE errors, therefore this inaccurate CE is adequate for the NBJTRAS scheme
  - The RF chains are **reused** during the estimation of the full channel matrix.
- **Tier Two**: Decision-Directed CE (**DDCE**) for data detection
  - Data detection requires **accurate** CE
  - Semi-blind DDCE employs detected data for further **refining** CE quality

Outline

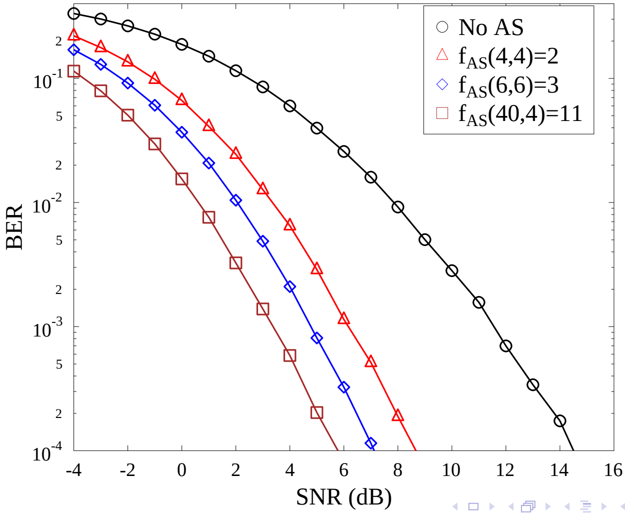
Simulation Settings

1. Quasi-static Rayleigh fading MIMO: STSK($L_T = 2, L_R = 2, T_n = 2, Q = 4, 4QAM$)
2. AS factor is defined as $f_{AS}\left(N_T, N_R\right) = \frac{N_T+N_R}{L_T+L_R}$
3. Transmitted signal power normalised to unity, SNR defined as $\frac{1}{N_\text{o}}$
4. Frame length set to 1,000 bits, yielding $\tau = 250$ STSK symbol blocks
5. Mean Channel Error (MCE): $J_{\text{MCE}}\left(\widehat{\boldsymbol{H}}_{sub}\right) = \left\|\boldsymbol{H}_{sub} - \widehat{\boldsymbol{H}}_{sub}\right\|^2 / \left\|\boldsymbol{H}_{sub}\right\|^2$
6. All the results were averaged over 10,000 channel realisations

Outline

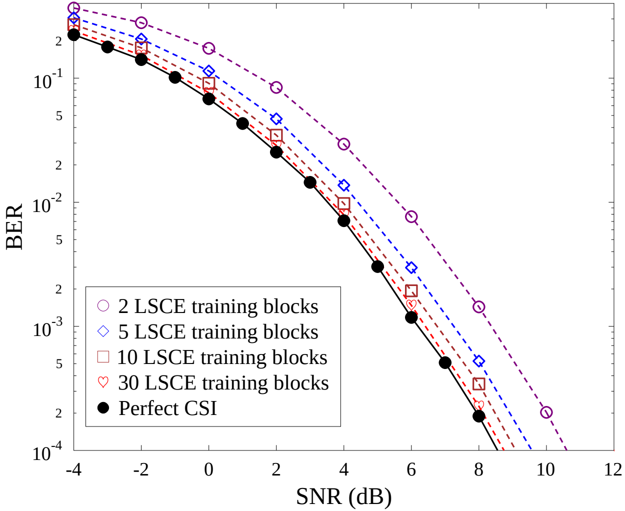
NBJTRAS Aided STSK with Perfect CSI

- **BER** performance of the proposed NBJTRAS aided STSK$(2, 2, 2, 4, 4QAM)$ given three AS factors $f_{AS}(N_T, N_R)$, in comparison to the performance of the conventional STSK$(2, 2, 2, 4, 4QAM)$ without AS



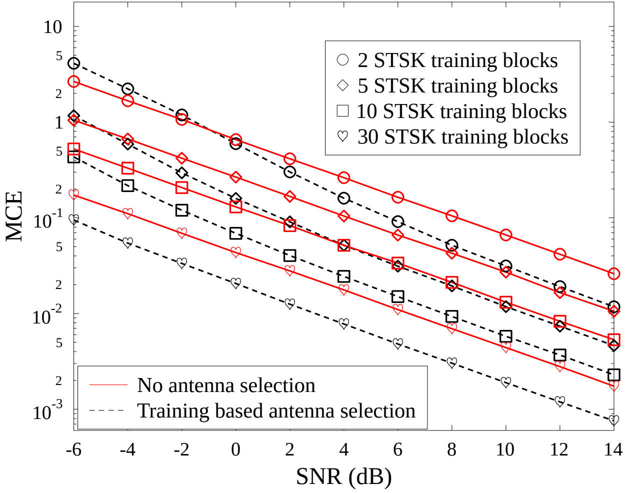
BER of TBCE for NBJTRAS Aided STSK

- **BER** performance of the NBJTRAS aided STSK(2, 2, 2, 4, 4QAM) with $f_{AS}(4,4) = 2$, assisted by the conventional TBCE scheme given the number of the STSK training blocks $M_T = 2, 5, 10$ and 30, in comparison to the perfect CSI case



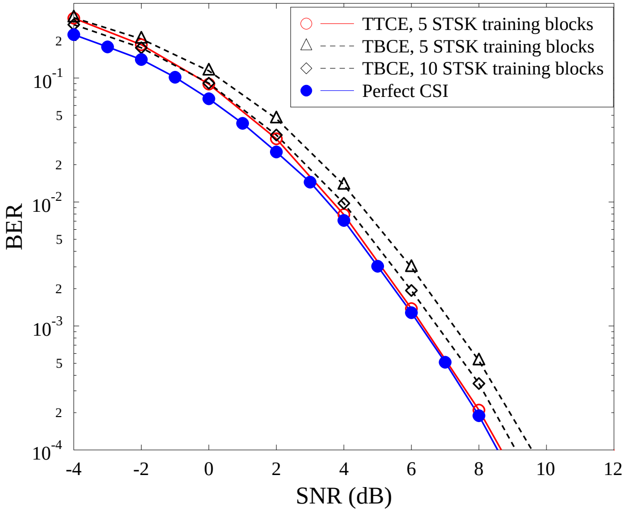
MCE of TBCE for NBJTRAS Aided STSK

- **MCE** performance of the NBJTRAS aided STSK$(2, 2, 2, 4, 4QAM)$ with $f_{AS}(4, 4) = 2$ and employing the conventional TBCE scheme, in comparison to the performance of the TBCE aided conventional STSK$(2, 2, 2, 4, 4QAM)$ without AS



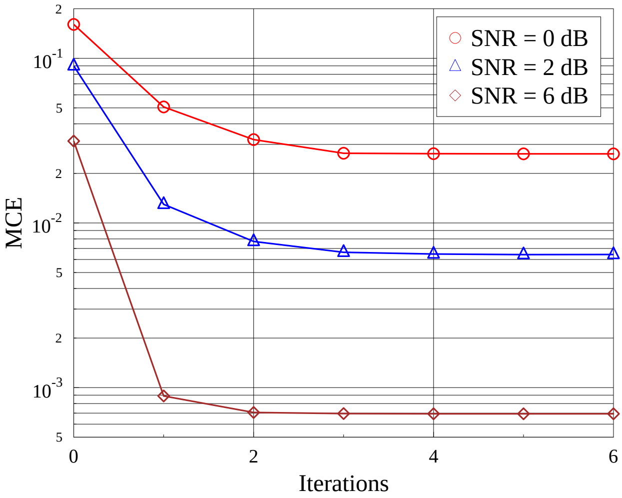
BER of TTCE for NBJTRAS Aided STSK

- **BER** performance of the proposed TTCE based NBJTRAS aided STSK$(2, 2, 2, 4, 4QAM)$ with $M_T = 5$ initial training blocks, in comparison to that of the conventional TBCE assisted NBJTRAS aided STSK$(2, 2, 2, 4, 4QAM)$ with $M_T = 5$ and 10. $f_{AS}(4, 4) = 2$ is adopted for both systems



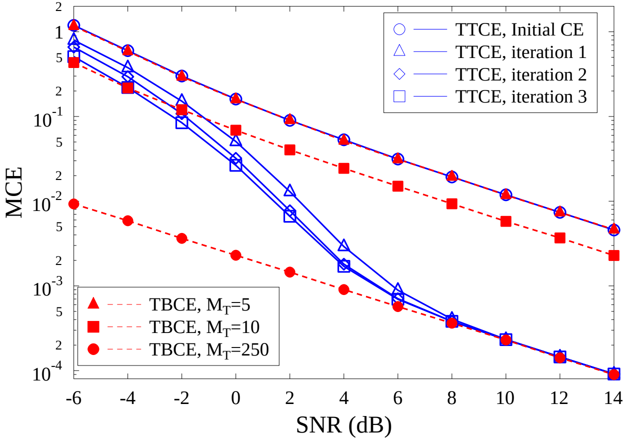
MCE Convergence Performance of TTCE

- **MCE convergence** performance of the proposed TTCE for the NBJTRAS aided STSK$(2, 2, 2, 4, 4QAM)$ with $f_{AS}(4, 4) = 2$ and $M_T = 5$ for three SNR values.



MCE Performance of TTCE

- **MCE** performance of the proposed TTCE for the NBJTRAS aided STSK(2, 2, 2, 4, 4QAM) with $M_T = 5$, in comparison to that of the conventional TBCE scheme for the NBJTRAS aided STSK(2, 2, 2, 4, 4QAM) with $M_T = 5$, 10 and 250. $f_{AS}(4, 4) = 2$ is adopted for both systems



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Summary

- We have proposed a simple yet efficient NBJTRAS aided STSK system
  1. Provides a low-complexity technique of reducing the number of RF chains required by MIMO systems, while retaining the MIMO advantages
  2. Our NBJTRAS is capable of solving the optimal NBS criterion at a lower complexity compared to the exhaustive search
- We have proposed a novel TTCE scheme for assisting the NBJTRAS aided STSK system
  1. Only requires a low training overhead in Tier One for AS
  2. Estimation of the selected sub-channel-matrix is further refined in Tier Two for data detection

Thank you.