Adaptive Transmit Antenna Selection with Pragmatic Space-Time Trellis Codes

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Presentation Outline

- Background
- Motivation
- System Model
- Performance Analysis
- Antenna Selection Criterion
- Pragmatic Space-Time Trellis Codes
- Performance Evaluation
- Conclusion

Background (1)

- Antenna selection is a promising technique providing a high potential diversity order with simple encoding and decoding algorithms and reduced complexity.
- Receive antenna selection (RAS) in a single-input multiple-output (SIMO)
  - Single RAS [Jakes]
  - Multiple RAS with maximal ratio combiner (H-RAS/MRC) [Eng et al'96] [Win et al'99]
- Transmit antenna selection (TAS) is more feasible for high rate downlink transmission.
  - Single TAS [Thoen et al'01]
  - Multiple TAS with space-time codes (TAS/STC) [Chen et al'02]

Background (2)—TAS

- TAS is a simple closed-loop approach.
- TAS is different from space-time precoding or water-filling strategies, which requires full feedback of channel state information (CSI) or singular value decomposition (SVD).
- TAS only requires partial CSI or limited feedback.
- Two types of selection criteria were studied in the literature.
  - Capacity based criteria [Gore et al'00] [Molisch et al'01] [Blum et al'02]
  - Performance based criteria [Heath et al'01] [Chen et al'02] [Shao et al'03]

Motivation

- Focus of previous work

1. uncoded space-time transmission
2. fixed number of selected antennas (not adaptive)

- Three general questions to be answered

1. What is the optimum antenna selection criterion?
2. How many antennas are appropriate?
3. What types of codes should be used? or, what is the code design criterion?

System Model (1)

- Consider an MIMO system with n_T transmit and n_R receive antennas.
- Assume that
  - partial channel state information is available at the transmitter;
  - a family of space-time codes with transmit antennas up to n_T is previously designed;
  - the feedback link is error-free and of zero delay.
- The system can adaptively select a variable number of transmit antennas and its corresponding space-time code for transmission.
- We only choose a subset with $n_s(t)$ $(n_s(t) \leq n_T)$ transmit antennas at time t. It is denoted by $(n_T, n_s; n_R)$.

System Model (2)

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$$\mathbf{r}_t = \mathbf{H}_s \mathbf{x}_t + \mathbf{n}_t \quad (1)$$

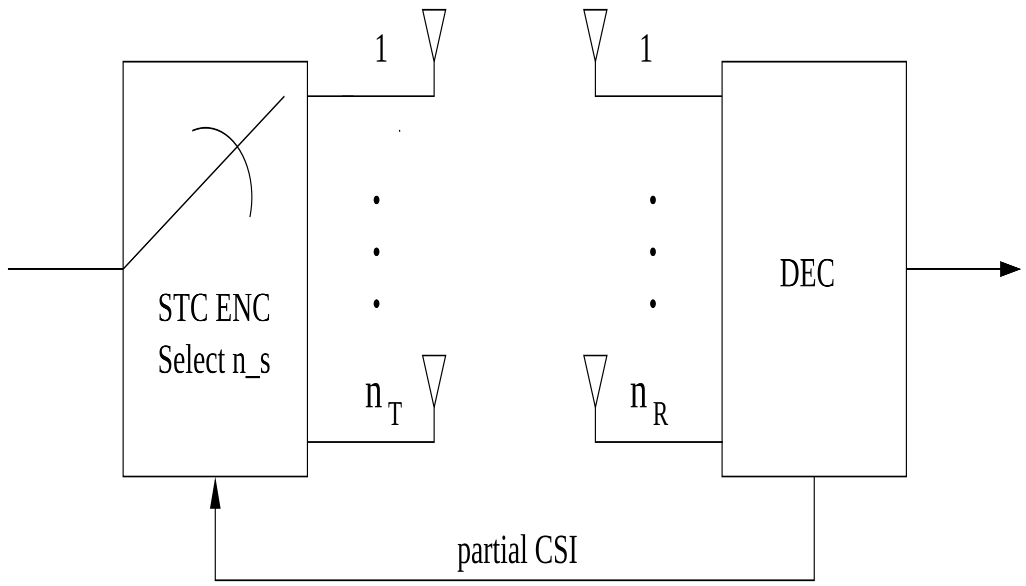

Figure 1: An $(n_T, n_s; n_R)$ TAS system

Performance Analysis

- $$P(\mathbf{x}, \hat{\mathbf{x}}|\mathbf{H}_s) \leq Q\left(\sqrt{\frac{SNR}{2n_s}\lambda^2_{\min}(\mathbf{H}_s)d^2_E(\mathbf{x}, \hat{\mathbf{x}})}\right) \quad (2)$$

  where $\lambda_{\min}(\mathbf{H}_s)$ denotes the minimum singular value of matrix $\mathbf{H}_s$, and $d^2_E(\mathbf{x}, \hat{\mathbf{x}})$ is the squared Euclidean distance between the pair of space-time coded sequences $\mathbf{x}$ and $\hat{\mathbf{x}}$.

- Effective selection gain

$$\min\{d^2_s(n_s)\} = \min\left\{\frac{\lambda^2_{\min}(\mathbf{H}_s)d^2_E(\mathbf{x}, \hat{\mathbf{x}})}{n_s}\right\} = \lambda^2_{\min}(\mathbf{H}_s)\frac{d^2_E(n_s)}{n_s} \quad (3)$$

Antenna Selection Criterion (1)

- Based on the performance analysis, we can formulate the criterion for TAS
  - select a subset of n_T transmit antennas such that $\lambda_{\min}^2(\mathbf{H}_s)\frac{d_E^2(n_s)}{n_s}$ is maximized.
- The term $\lambda_{\min}^2(\mathbf{H}_s)$ is determined by the selected subset channel matrix $\mathbf{H}_s$. We call it channel selection gain.
- $\frac{d_E^2(n_s)}{n_s}$ is only dependent on the code and we call it code selection gain.

Antenna Selection Criterion (2)

- The effective selection gain is actually the product of the gains provided by the channel selection and the corresponding code.
- In the adaptive antenna selection scheme, the channel characteristic and space-time codes are jointly considered to optimize the error performance.

Antenna Selection Criterion (3)

- **Proposition 1** For systems with n_T transmit and n_R receive antennas, the maximum value of n_s is equal to $\min(n_T, n_R)$.
- **Proposition 2** The code selection gain $\frac{d_E^2(n_s)}{n_s}$ shows that for the MIMO systems with n_s selected transmit antennas, the minimum Euclidean distance of the space-time code should be maximized in order to minimize the error probability.
- This indicates that the space-time codes for all possible transmit antennas should be designed based on the Euclidean distance criterion.

A Simplified Antenna Selection Criterion (1)

- Let us define C_{k_i} as the total channel power gain for the signal from the k_i-th transmit antenna.

$$C_{k_i} = \sum_{j=1}^{n_R} |h_{j,k_i}|^2, \quad C_{k_1} \geq C_{k_2} \geq \cdots \geq C_{k_{n_T}} \tag{4}$$

- We can further formulate a sub-optimal antenna selection criterion
  - select a subset of n_T transmit antennas to maximize $\frac{\sum_{i=1}^{n_s} C_{k_i} d_E^2(n_s)}{n_s^2}$.
- The parameter in the selection criterion can also be decomposed into two terms.

$$\frac{\sum_{i=1}^{n_s} C_{k_i} d_E^2(n_s)}{n_s^2} = \frac{\sum_{i=1}^{n_s} C_{k_i}}{n_s} \cdot \frac{d_E^2(n_s)}{n_s} \tag{5}$$

A Simplified Antenna Selection Criterion (2)

- The first term $\frac{\sum_{i=1}^{n_s} C_{k_i}}{n_s}$ denotes the average total received power per transmit antenna which can be regarded as the channel (antenna) selection gain.
- The second term $\frac{d_E^2(n_s)}{n_s}$ is the code selection gain.
- In contrast to the fixed number of antenna selection schemes, this adaptive selection scheme considers maximizing the average total received power per transmit antenna as the guideline to select antennas between the subsets with various numbers of transmit antennas.

Pragmatic Space-Time Trellis Codes (1)

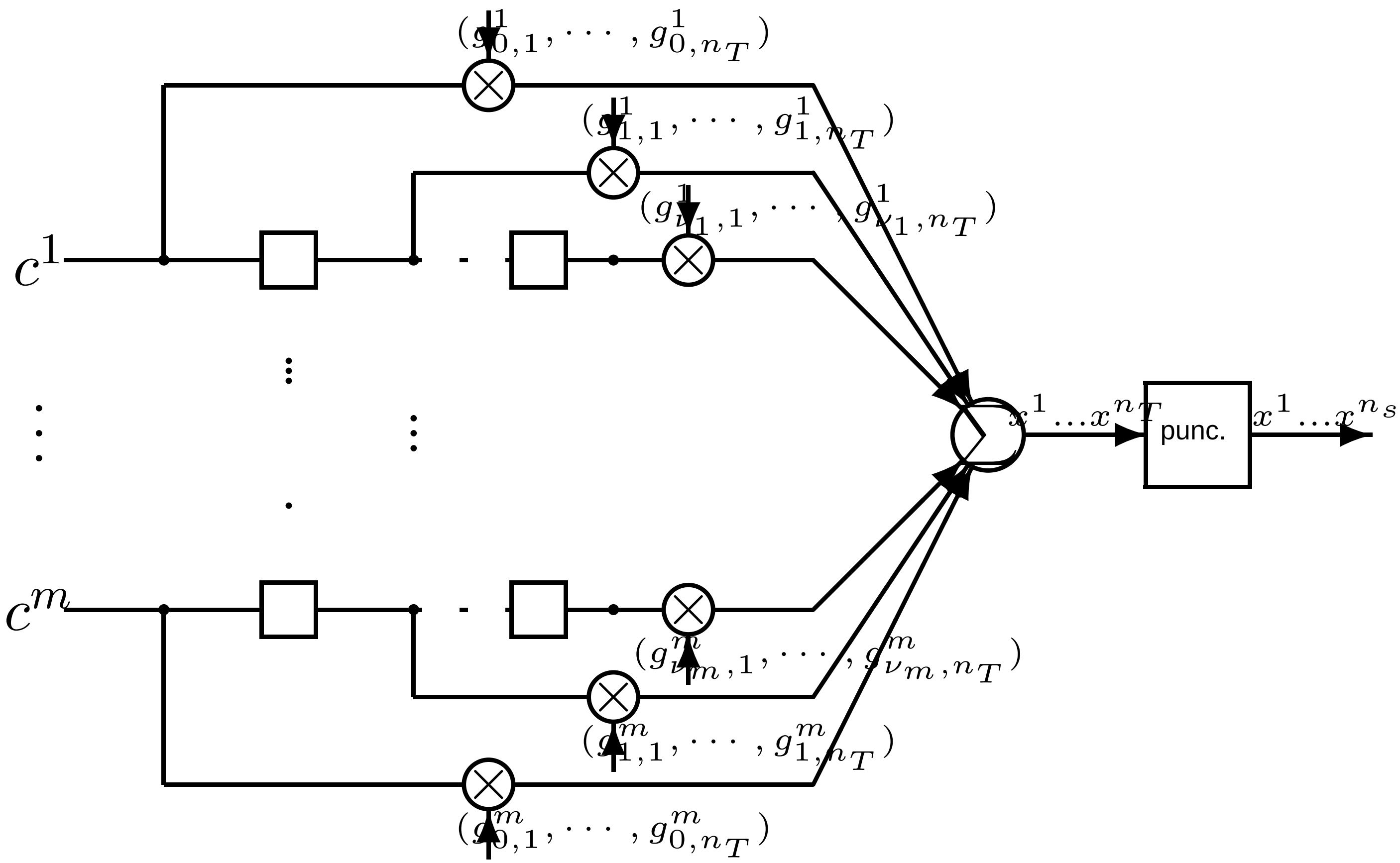

Figure 2: Encoder for pragmatic STTC

Pragmatic Space-Time Trellis Codes (2)

- **Proposition 3** If the optimal space-time codes with $n_T - 1$ and n_T antennas have the coefficients

$$g_{j,i}^k, k = 1, 2, \cdots, m, j = 1, 2, \cdots, v_k, i = 1, 2, \cdots, n_T - 1, \tag{6}$$

and

$$\tilde{g}_{j,i}^k, k = 1, 2, \cdots, m, j = 1, 2, \cdots, v_k, i = 1, 2, \cdots, n_T, \tag{7}$$

respectively, we have

$$g_{j,i}^k = \tilde{g}_{j,i}^k, \text{ for } \; i = 1, 2 \cdots, n_T - 1. \tag{8}$$

Pragmatic Space-Time Trellis Codes (3)

- This proposition implies that given an optimal space-time trellis code with n_T transmit antennas based on the Euclidean distance criterion, deleting the symbols for the n_T-th transmit antenna $x_t^{n_T}$ results in the optimal space-time trellis code for $n_T - 1$ transmit antennas.

- In general, to get the optimal code with n_s antennas from the code of n_T antennas, the puncture pattern is

$$P = [\underbrace{1 \cdots 1}_{n_s} \underbrace{0 \cdots 0}_{n_T - n_s}] \tag{9}$$

Pragmatic Space-Time Trellis Codes (4)

Table 1: Optimal pragmatic 4-PSK space-time trellis codes

ν	generator sequences	$d_E^2(n_s = 2)$	$d_E^2(n_s = 3)$	$d_E^2(n_s = 4)$
2	$\mathbf{g}^1 = [(0,2,2,0),(1,2,3,2)]$ $\mathbf{g}^2 = [(2,3,3,2),(2,0,2,1)]$	10	16	20.0
3	$\mathbf{g}^1 = [(2,2,2,2),(2,1,1,2)]$ $\mathbf{g}^2 = [(2,0,3,1),(1,2,0,3),(0,2,2,1)]$	12	20	26.0
4	$\mathbf{g}^1 = [(1,2,1,1),(1,3,2,2),(3,2,1,3)]$ $\mathbf{g}^2 = [(2,0,2,2),(2,2,0,0),(2,0,2,2)]$	16	24	32.0
5	$\mathbf{g}^1 = [(0,2,2,2),(2,3,3,2),(1,2,2,1)]$ $\mathbf{g}^2 = [(2,2,0,1),(1,2,2,0),(2,3,1,0),(2,0,0,2)]$	16	24	36.0
6	$\mathbf{g}^1 = [(0,2,2,1),(3,1,0,2),(3,3,2,2),(3,2,1,3)]$ $\mathbf{g}^2 = [(2,2,0,2),(2,2,2,0),(0,0,3,1),(2,0,1,2)]$	18	28	38.0

Pragmatic Space-Time Trellis Codes (4)

Table 2: Optimal pragmatic 8-PSK space-time trellis codes

ν	generator sequences	$d_E^2(n_s = 2)$	$d_E^2(n_s = 3)$	$d_E^2(n_s = 4)$
3	$\mathbf{g}^1 = [(2,1,3,7),(3,4,0,5)]$ $\mathbf{g}^2 = [(4,6,2,2),(2,0,4,4)]$ $\mathbf{g}^3 = [(0,4,4,4),(4,0,2,0)]$	7.172	12	16.586
4	$\mathbf{g}^1 = [(2,4,2,2),(3,7,2,4)]$ $\mathbf{g}^2 = [(4,0,4,4),(6,6,4,0)]$ $\mathbf{g}^3 = [(7,2,2,0),(0,7,6,3),(4,4,0,2)]$	8	14	20.0
5	$\mathbf{g}^1 = [(0,4,0,3),(4,4,4,3)]$ $\mathbf{g}^2 = [(0,2,4,2),(2,3,7,1),(2,2,7,5)]$ $\mathbf{g}^3 = [(4,2,6,5),(4,2,0,7),(3,7,2,6)]$	8.586	16	22.1

Performance Evaluation (1)

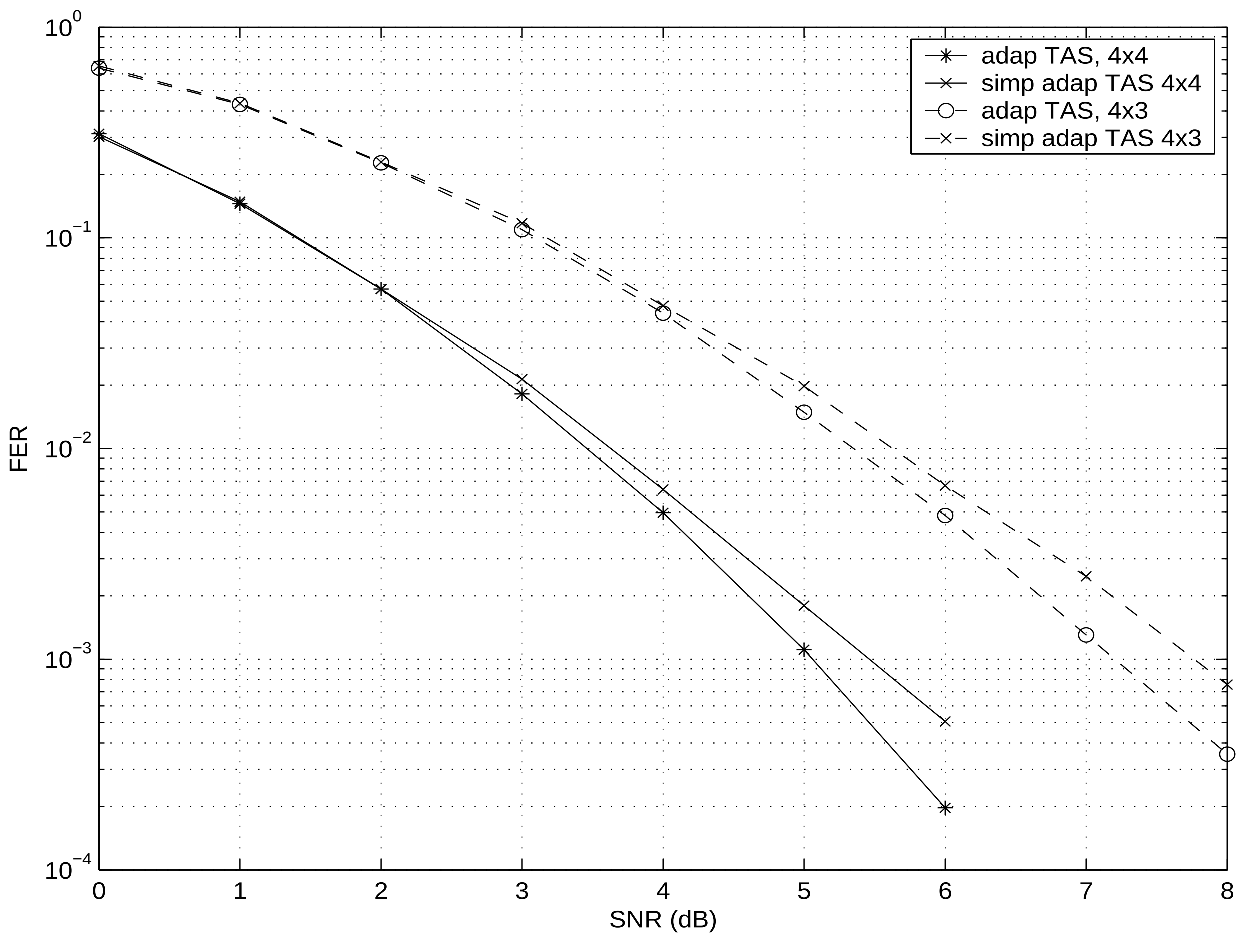

Figure 3: Comparison between two selection criteria

Performance Evaluation (2)

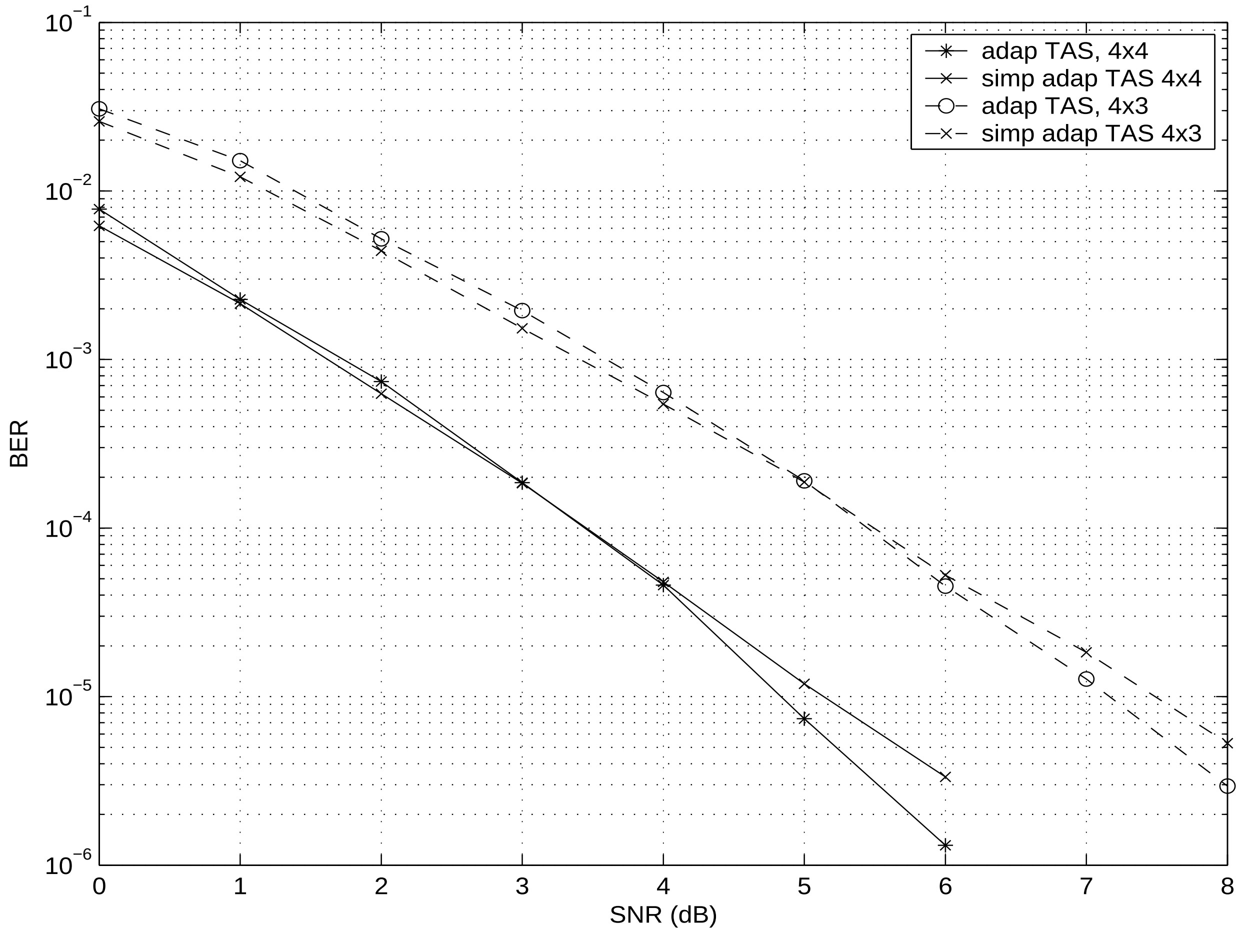

Figure 4: Comparison between two selection criteria

Performance Evaluation (3)

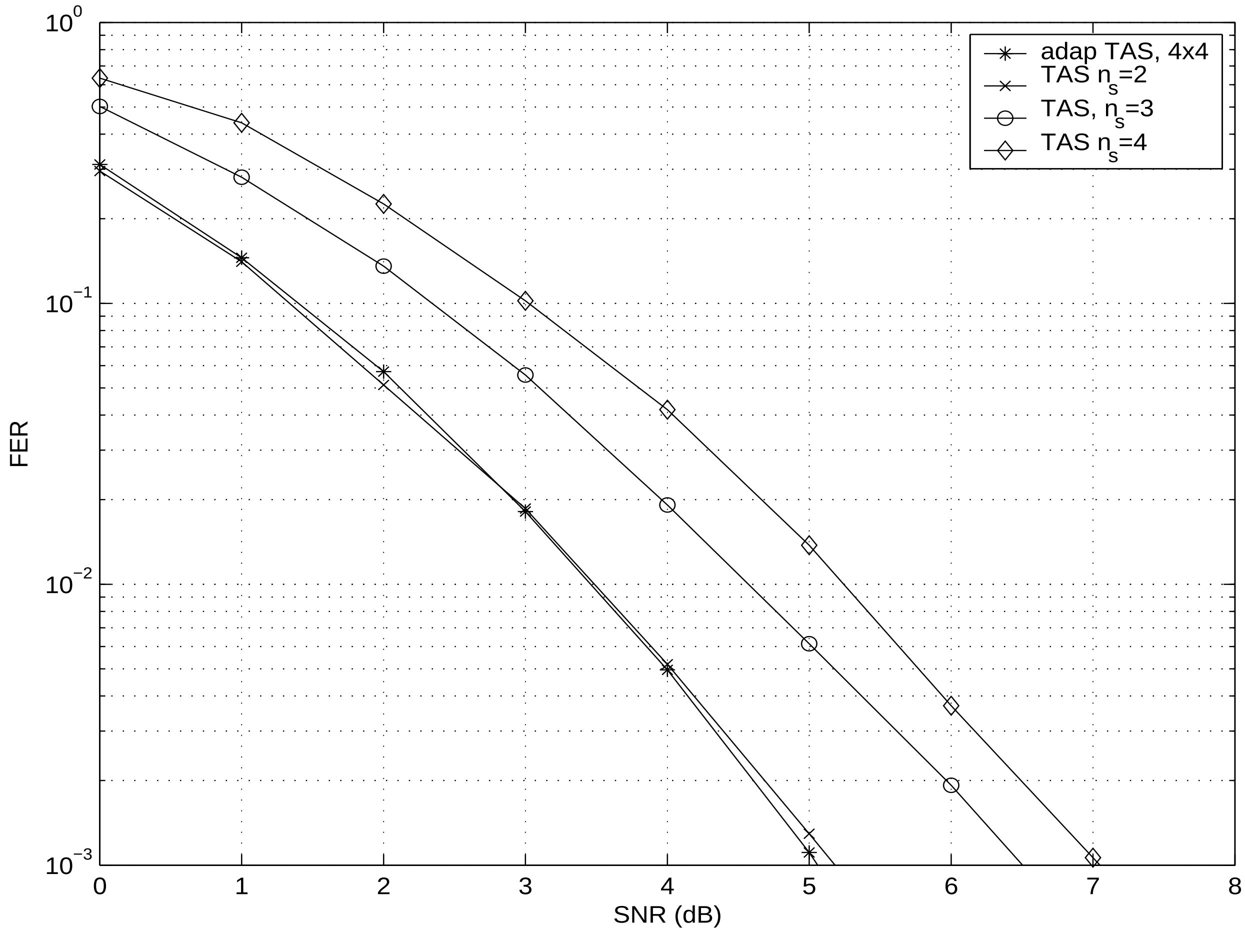

Figure 5: FER for adaptive TAS in (4,4) systems

Performance Evaluation (4)

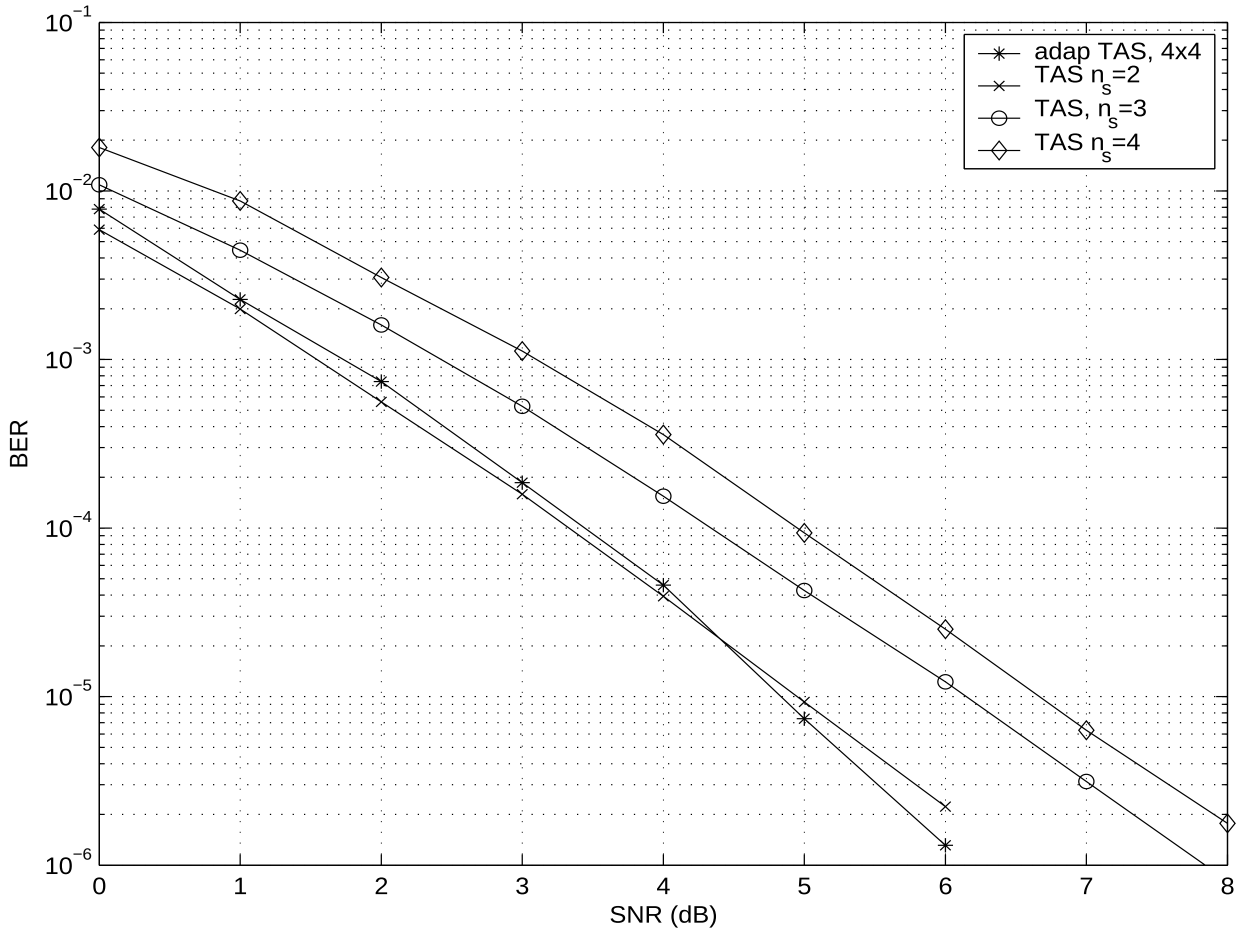

Figure 6: BER for adaptive TAS in (4,4) systems

Performance Evaluation (5)

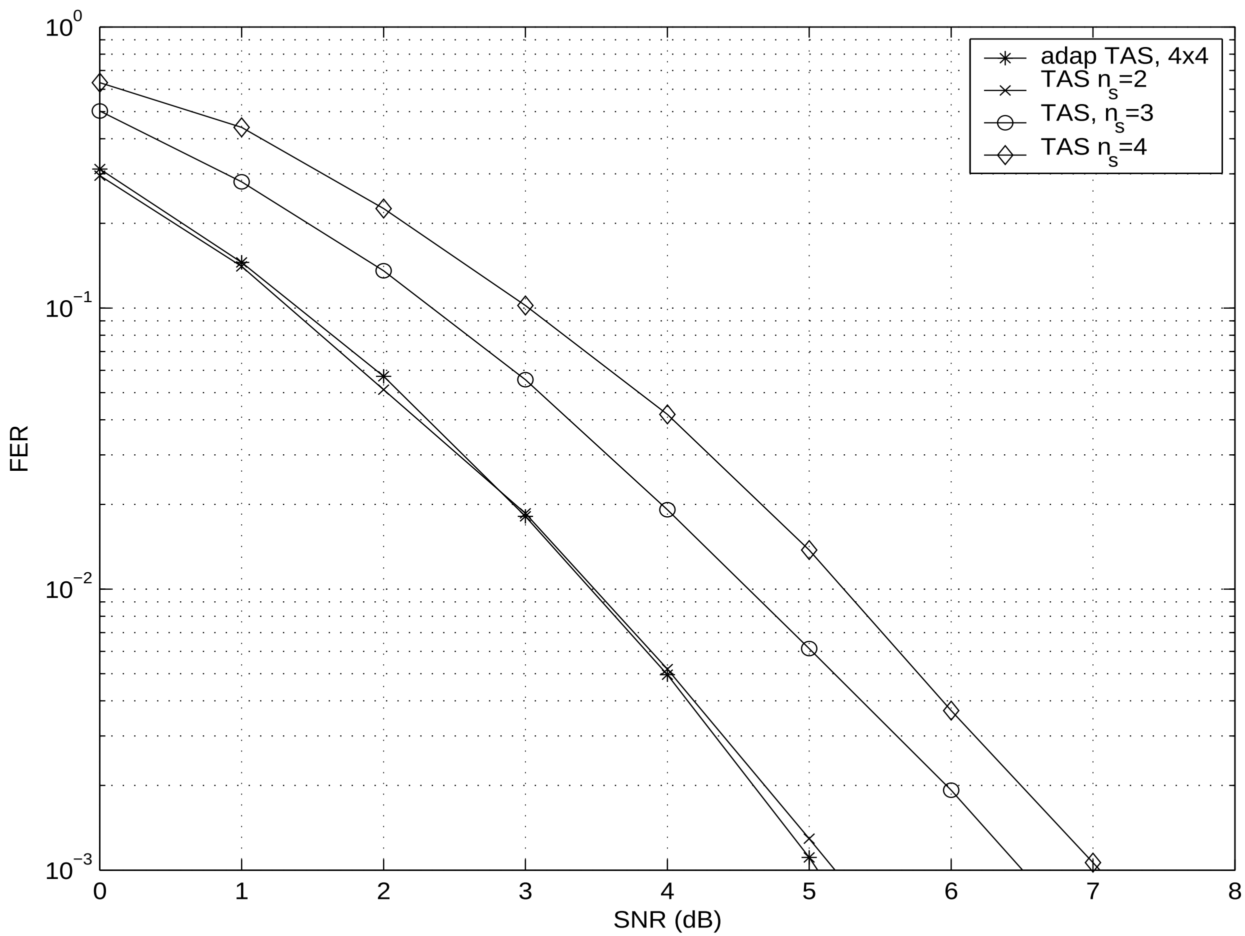

Figure 7: FER for adaptive TAS in (4,3) systems

Performance Evaluation (6)

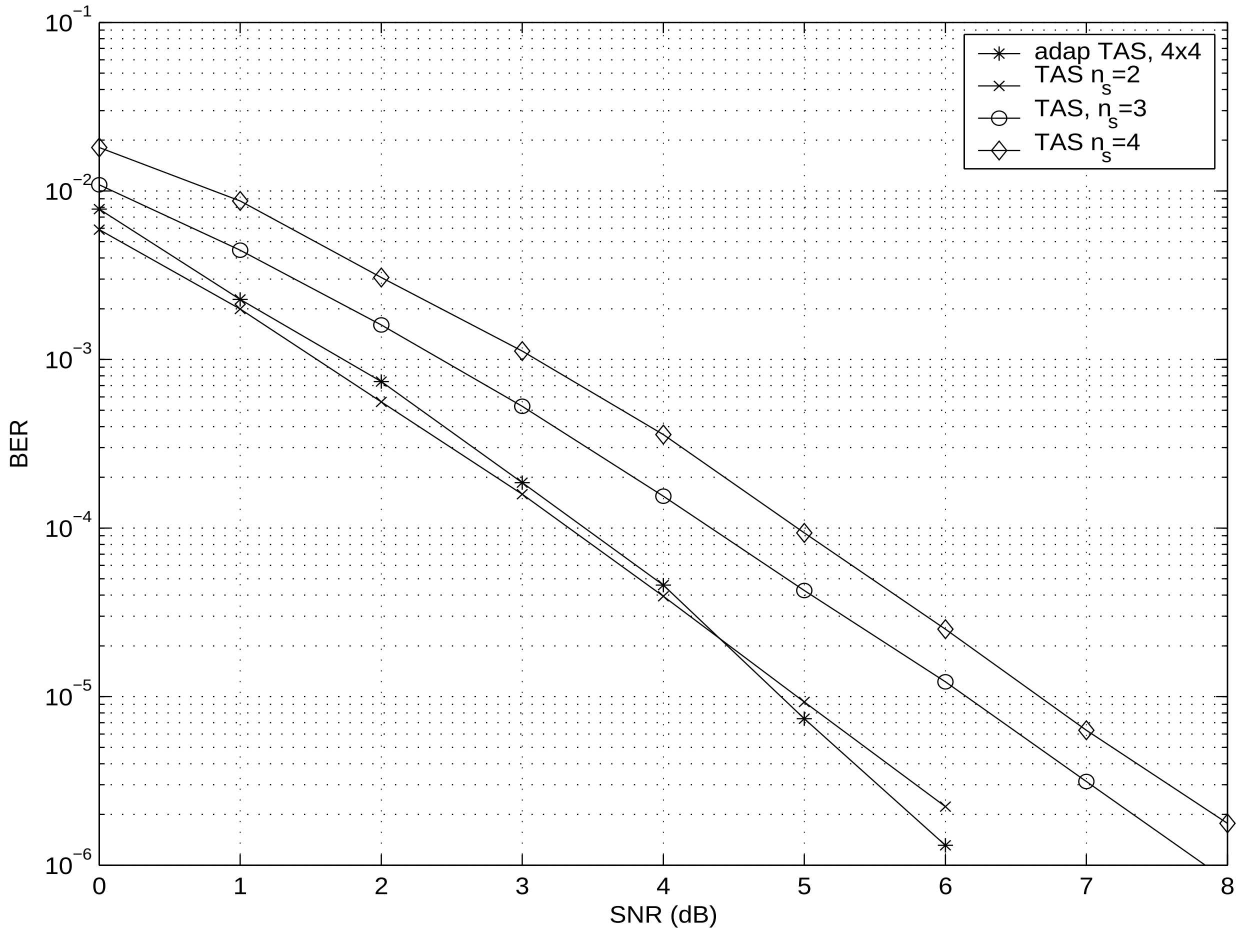

Figure 8: BER for adaptive TAS in (4,3) systems

Performance Evaluation (7)

Table 3: Percentage of n_s in a (4,4) TAS scheme

SNR	0	1	2	3	4	5	6
$n_s = 2$	0.841	0.831	0.835	0.827	0.835	0.834	0.833
$n_s = 3$	0.159	0.169	0.165	0.173	0.165	0.166	0.167
$n_s = 4$	0	0	0	0	0	0	0

- **Proposition 4** If the family of space-time codes satisfies

$$\frac{d_E^2(n)}{n} \geq \frac{d_E^2(m)}{m} \tag{10}$$

for any m, where $m > n$, based on the simplified selection criterion, choosing $n_s = n$ can achieve a larger code selection gain.

Conclusions

- We present an analytical error probability upper bound for space-time codes with adaptive antenna selection.
- Two sets of criteria of selecting a subset of available transmit antennas to minimize the space-time code error probability are proposed.
- We present pragmatic space-time trellis coding schemes for slow Rayleigh fading channels.
- We show that a single encoder and decoder can be used for systems with a variable number of transmit antennas.
- It is shown the adaptive selection offers considerable performance gain relative to the system with a fixed selection.

Questions?

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