10-1-2003

Combined Beamforming and Space-Time Block Coding with Sparse Array Antennas

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P222: Smart Antenna Design and Implementation

2003 Communication Design Conference

October 1, 2003
San Jose Convention Center
San Jose, CA

Outline

- Adaptive Beamforming and Angular Diversity
- Beamspace-Time Channel Estimation
- Array Antenna
- Channel Model: GBSBEM
- Peak detection and Adaptive Modulation
- Sparse Array Antennas and Beam Correlation
- Channel Estimation Errors
- Conclusions

Adaptive Beamforming and <u>Angular Diversity</u>

- First introduced in VTC Conference, Spring 2000
  - Macrocells with small angular spread
- Channel knowledge required
  - Reciprocity is assumed (channel same for downlink and uplink)
- Transmit power allocated to <u>peaks of channel response</u>
  - Space-Time Block Coding (STBC) applied to beams as (angular) diversity elements, as opposed to antennas
- Assumes flat fading channel (rich multipath environment)
  - Practical for moderate-rate indoor wireless communications

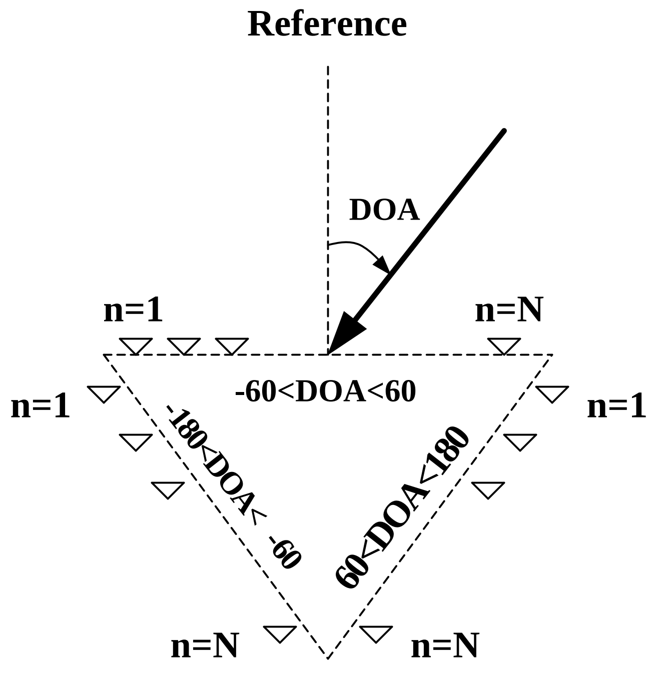
Beamspace-Time Channel Estimation

- Fixed Beamforming Network at base station (BS)

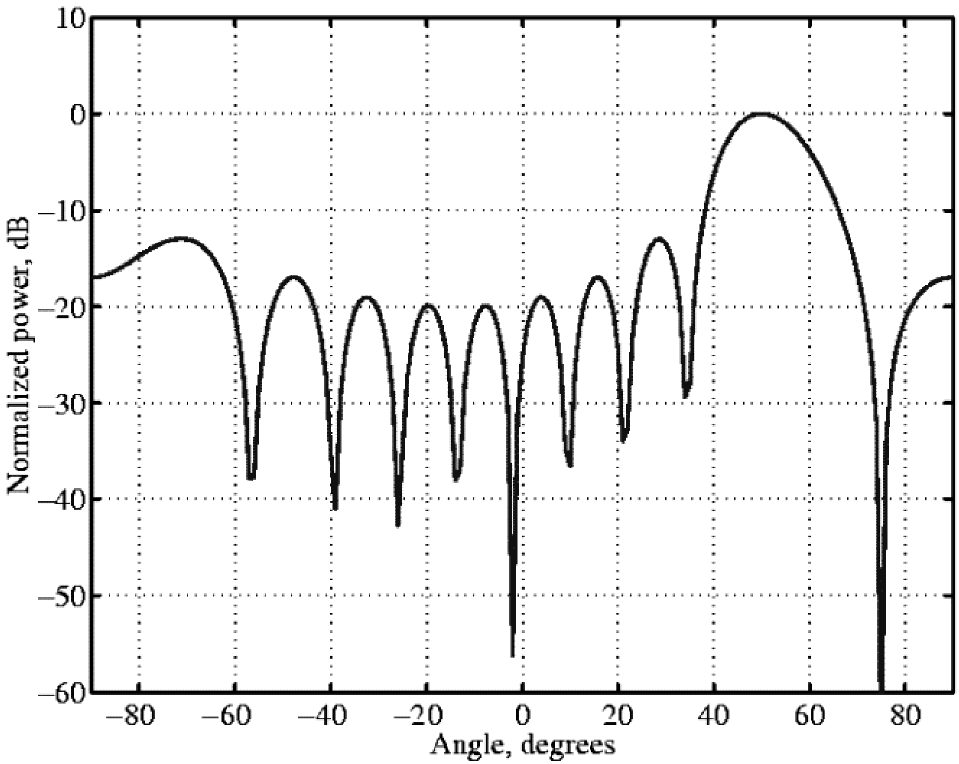
1. Mobile (MS) sends a pilot signal
2. BS does 360-degree beam scanning (switched beam)
3. BS estimates channel spatial gain pattern (CSGP)
4. BS determines beams and their angles, based on CSGP
5. Space-Time Block Coding (STBC) is applied and symbols transmitted
6. Upon reception, MS uses simple linear processing to estimate symbols

Array Antenna (360 degree coverage)

- Linear Equally Spaced Array. N elements per sector
- Three 120-degree sectors



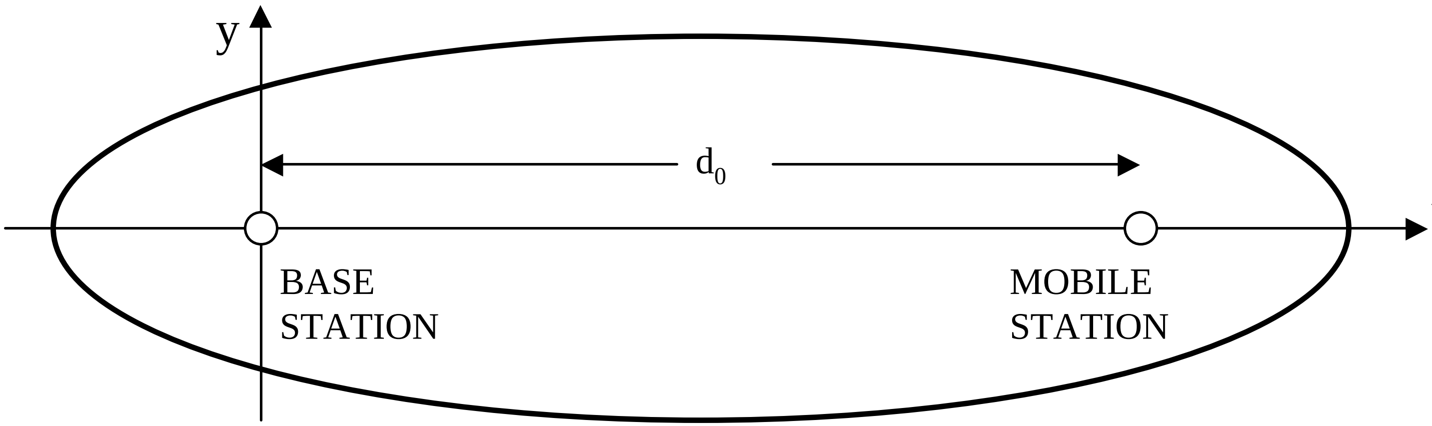
Example Pattern with 4-Antenna Array



The GBSB* Elliptical Model (GBSBEM)

* Geometrically-Based Single-Bounce

- Scatterers uniformly distributed within an ellipse
- Low antenna heights
- Applicable to picocell (indoor) environments



Main parameters

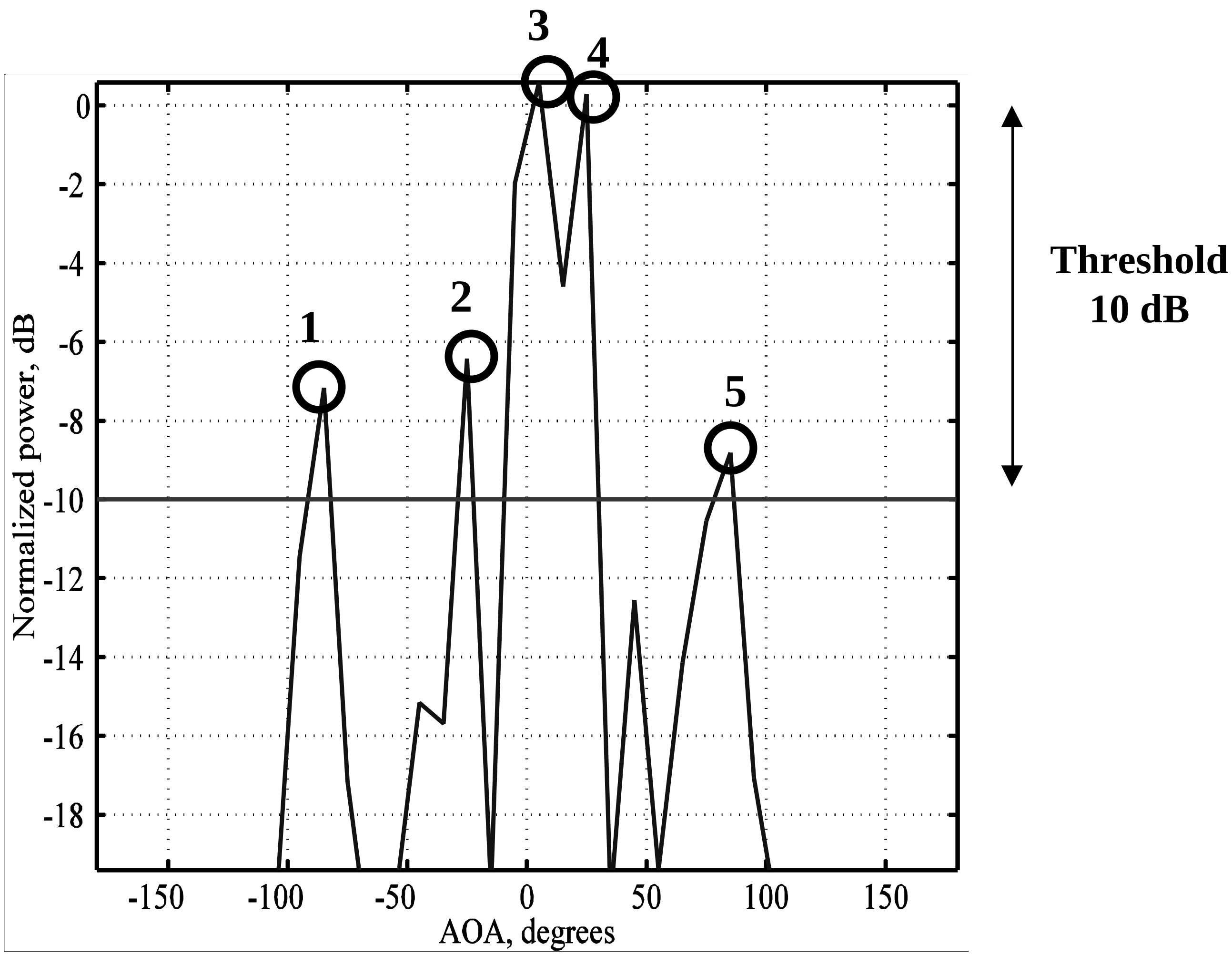
$n=4$ (Loss exponent)

d_0: Uniform [1,100] m

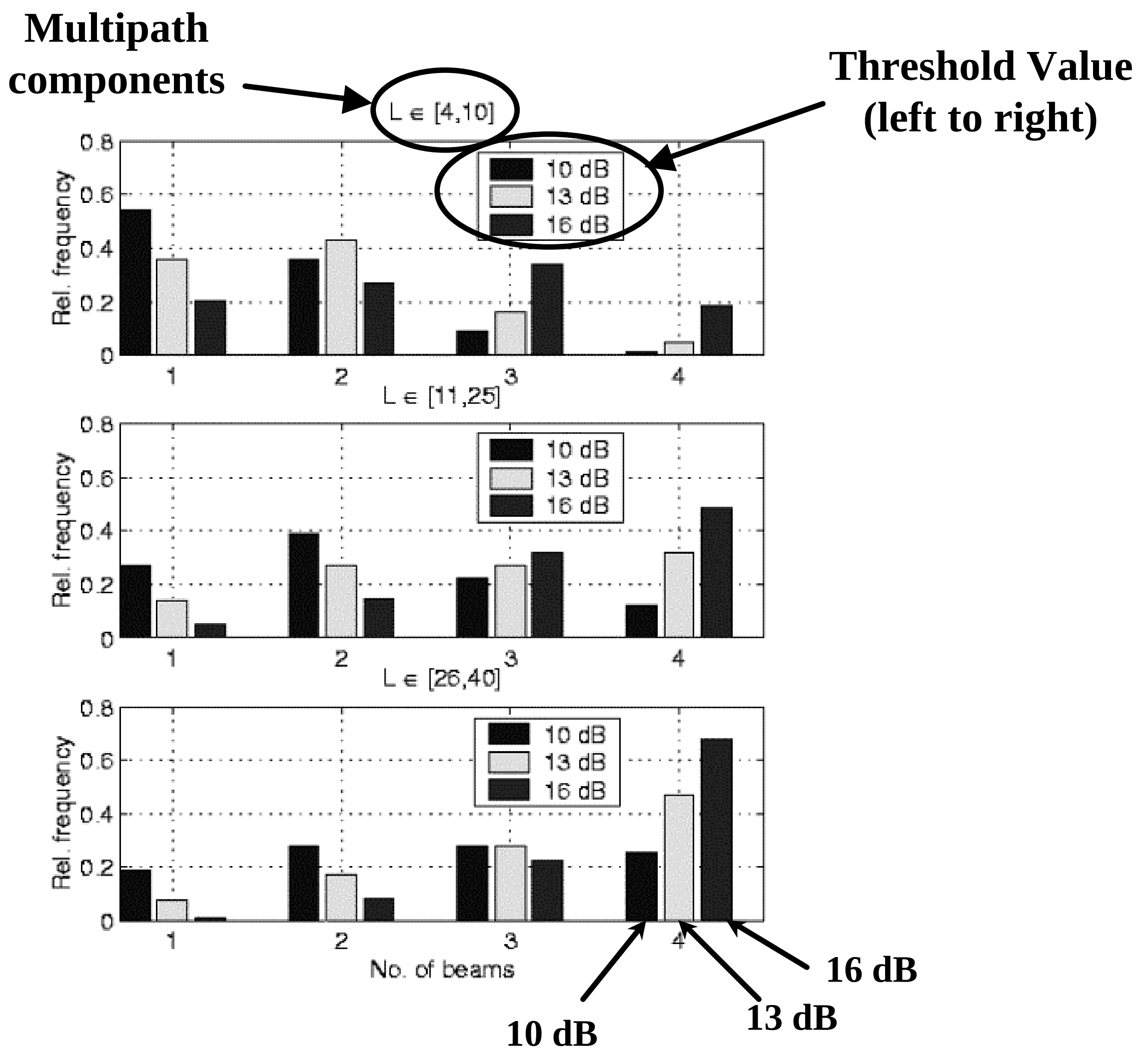
$\tau_m=2\tau_0$ (Maximum delay)

L: Number of multipath components, uniform in [10,50] and [26,50]

Peak Detection



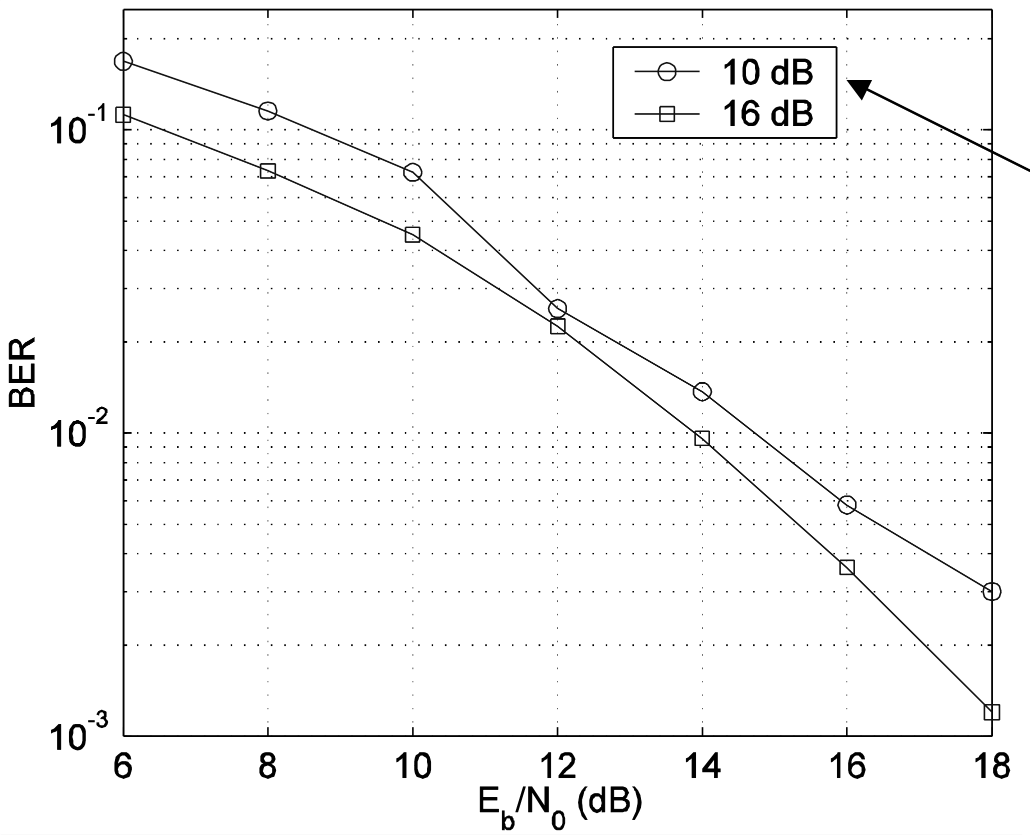
Distribution of Number of Beams



Adaptive Modulation

- In accordance to the number of transmit beams, the constellation is modified, to compensate for the rate loss of the STBC scheme:
  - n_t=2: K/T = 1 **QPSK modulation** (2 bps/Hz)
  - n_t=3 and n_t =4: K/T = ¾ **8-PSK modulation** (2.25 bps/Hz)

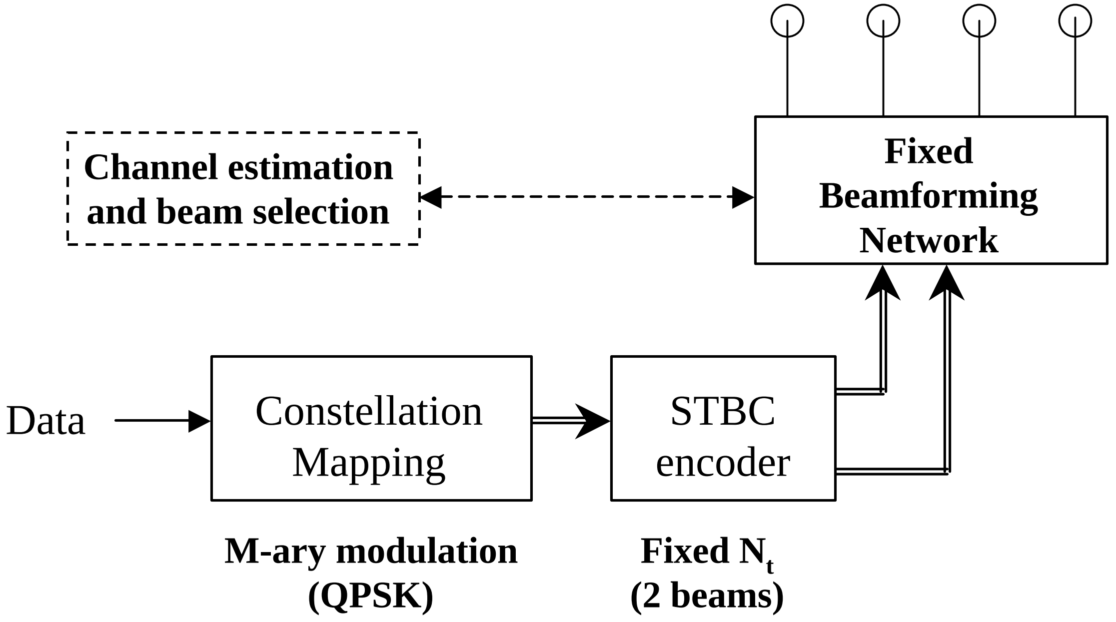
Error Performance of B-STBC: 10-Element Antenna Array



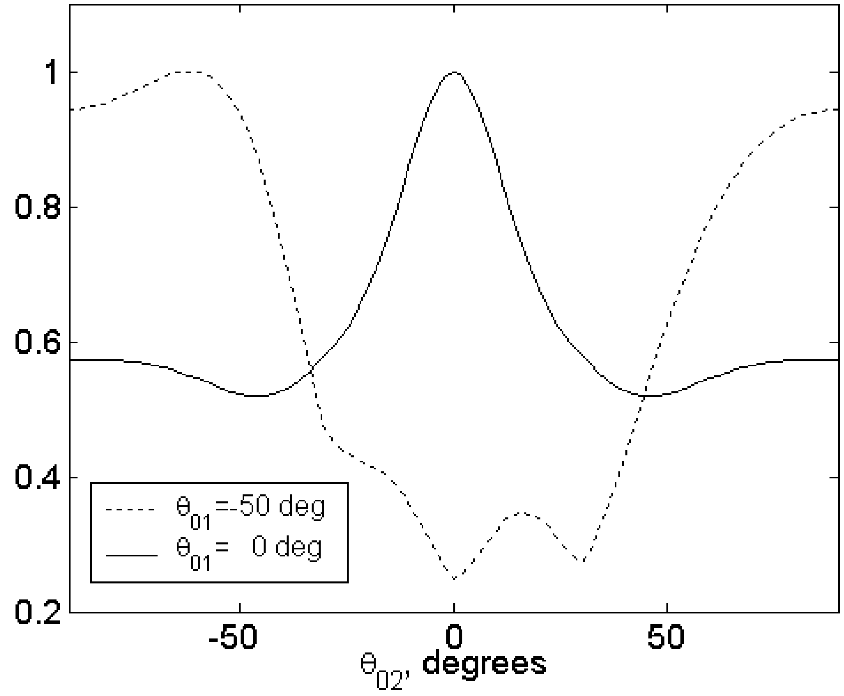
Threshold value

Transmit (Angular) Diversity with Sparse Array Antenna

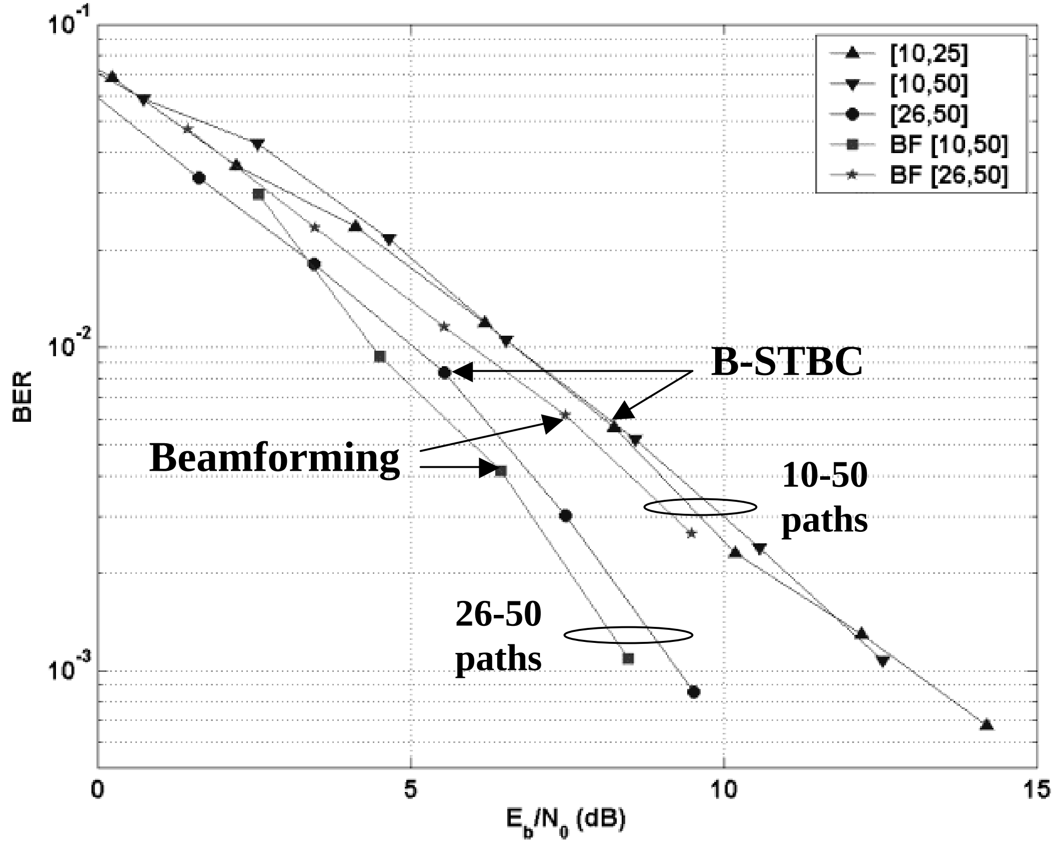
- Linear equally spaced array with N=4 elements
- Separation of half wavelength
- Switched-beam system
- Beams spaced by 6 degrees



Beam Correlation with 4 Antennas



Performance of B-STBC: Correlated Beams



Channel Estimation Errors

$$\mathrm{r} = \begin{bmatrix} r_0 \\ r_1^* \end{bmatrix}, \qquad \overline{\mathrm{H}} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}, \qquad \mathrm{n} = \begin{bmatrix} n_0 \\ n_1^* \end{bmatrix}, \qquad \mathrm{c} = \begin{bmatrix} c_0 \\ c_1 \end{bmatrix}$$

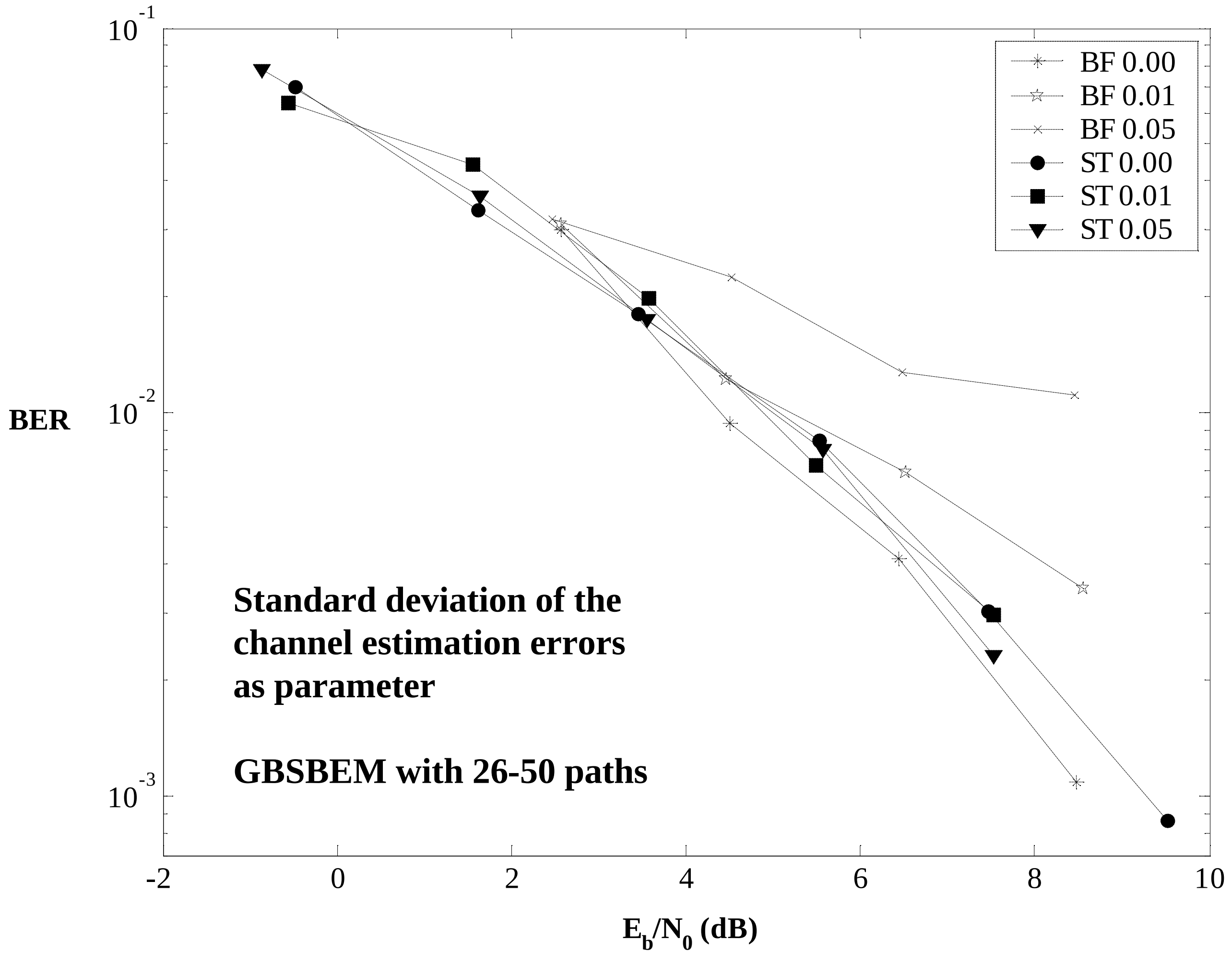
Received vector | **Equivalent channel** | **AWGN** | **Transmitted vector**

$$\hat{\mathrm{H}} = \overline{\mathrm{H}} + \overline{\mathrm{N}} = \overline{\mathrm{H}} + \begin{bmatrix} n_{e1} & n_{e2} \\ n_{e2}^* & -n_{e1}^* \end{bmatrix}.$$

Estimation errors

$$\begin{aligned} \tilde{\mathrm{r}} &= \hat{\mathrm{H}}^* \mathrm{r} \\ &= \hat{\mathrm{H}}^* \overline{\mathrm{H}} \mathrm{c} + \hat{\mathrm{H}}^* \mathrm{n} \\ &= \|\mathrm{H}\|_F^2 \, \mathrm{c} + (\overline{\mathrm{N}}\overline{\mathrm{H}}\mathrm{c} + \tilde{\mathrm{n}}) \\ &= \|\mathrm{H}\|_F^2 \, \mathrm{c} + \overline{\mathrm{N}}' \mathrm{c} + \tilde{\mathrm{n}} \end{aligned}$$

Performance of Adaptive B-STBC (Channel Estimation Errors)



Conclusions

- Beamforming (BF) outperforms B-STBC, under *perfect channel knowledge* conditions
- However, in the presence of *channel estimation errors*, the performance of BF degrades considerably, and it becomes worse than B-STBC, as the estimation error increases

- **The proposed adaptive B-STBC scheme is robust against channel estimation errors**

- We note that our work focuses on the use of *beams* as (angular) diversity elements, as opposed to the use of *antennas*