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

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

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P222: Smart Antenna Design and Implementation

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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 Angular Diversity

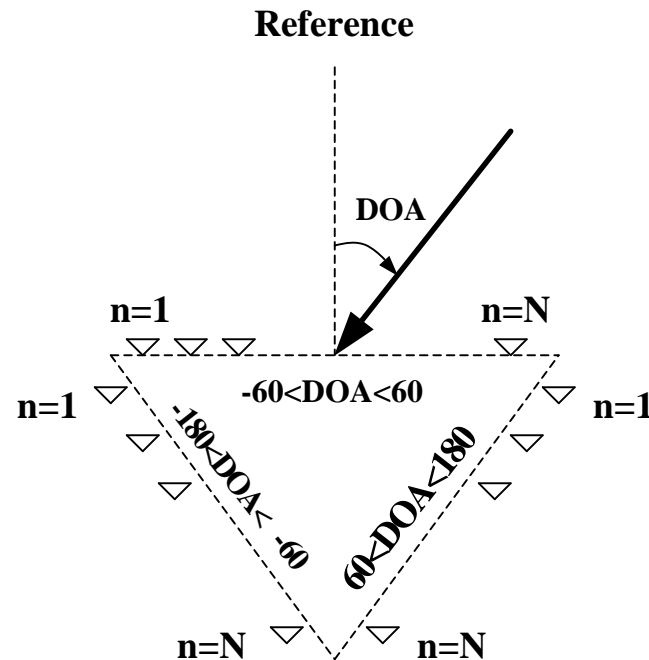
- First introduced in VTC Conference, Spring 2000
 - Macrocells with small angular spread
- Channel knowledge required
 - Reciprocity is assumed (channel same for downlink and uplink)
- Transmit power allocated to peaks of channel response
 - Space-Time Block Coding (STBC) applied to beams as (angular)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

Beamspace-Time Channel Estimation

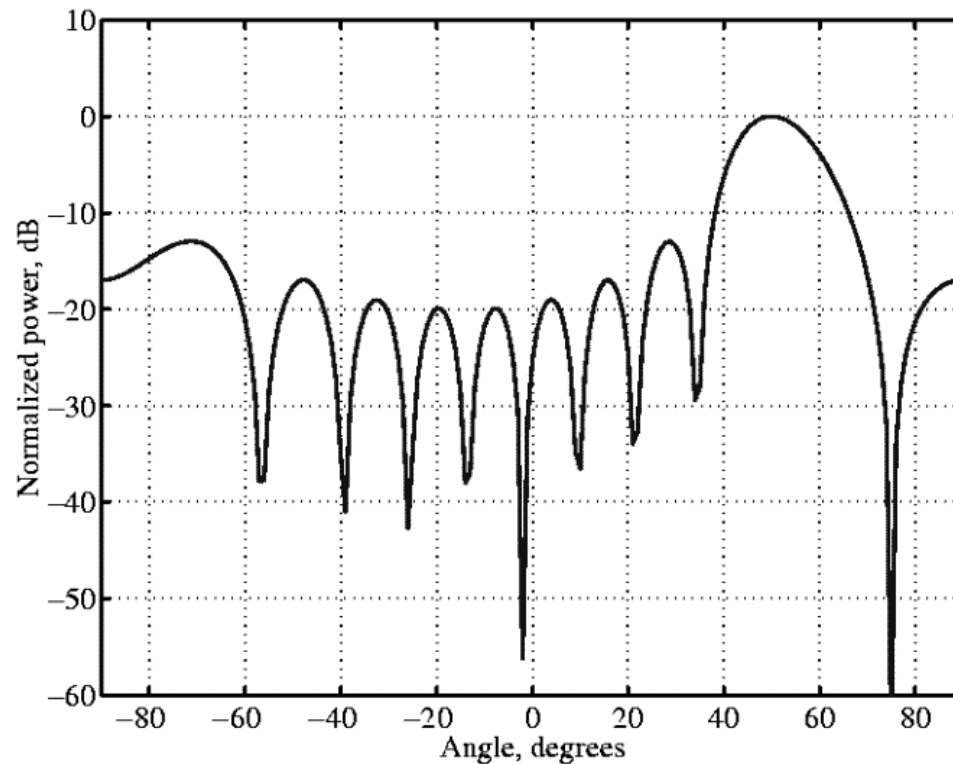
- Fixed Beamforming Network at base station (BS)
 1. Mobile (MS) sends a pilot signal
 2. BS does 360-degree beam scanning (switched beam)
 3. BS estimates channel spatial gain pattern (CSGP)
 4. BS determines beams and their angles, based on CSGP
 5. Space-Time Block Coding (STBC) is applied and symbols 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



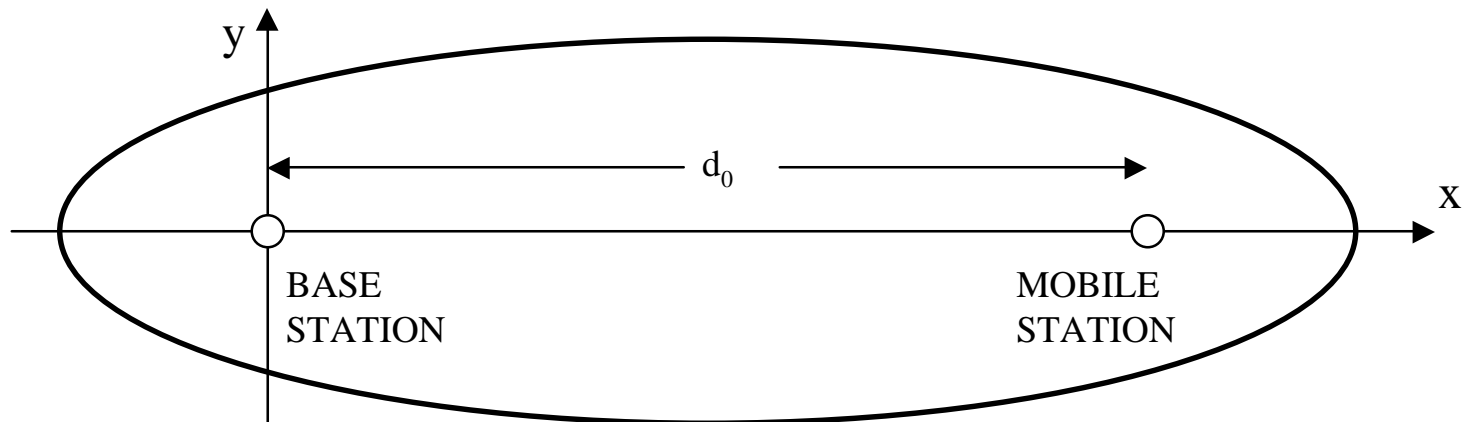
Example Pattern with 4-Antenna Array



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

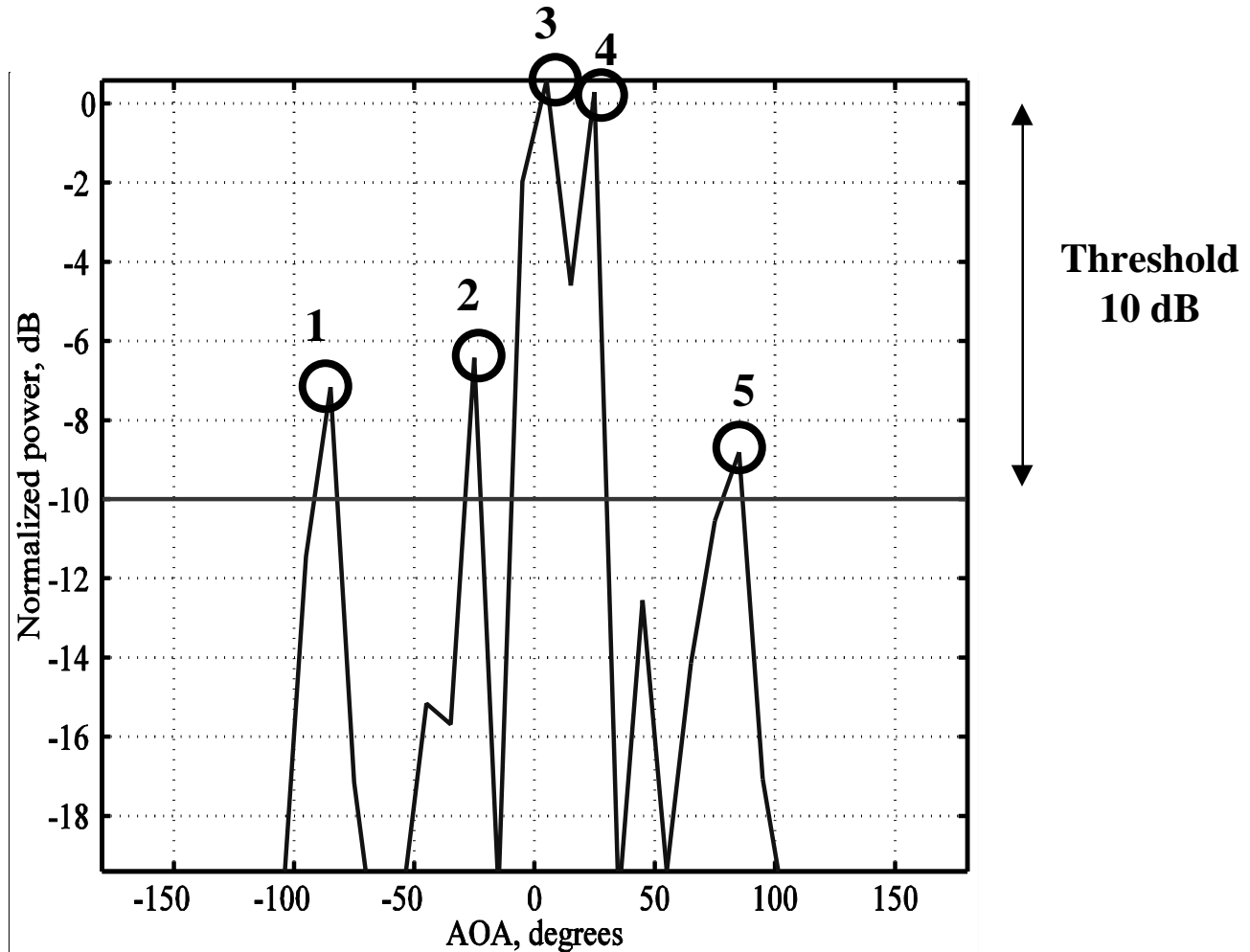
$n=4$ (Loss exponent)

d_0 : Uniform [1,100] m

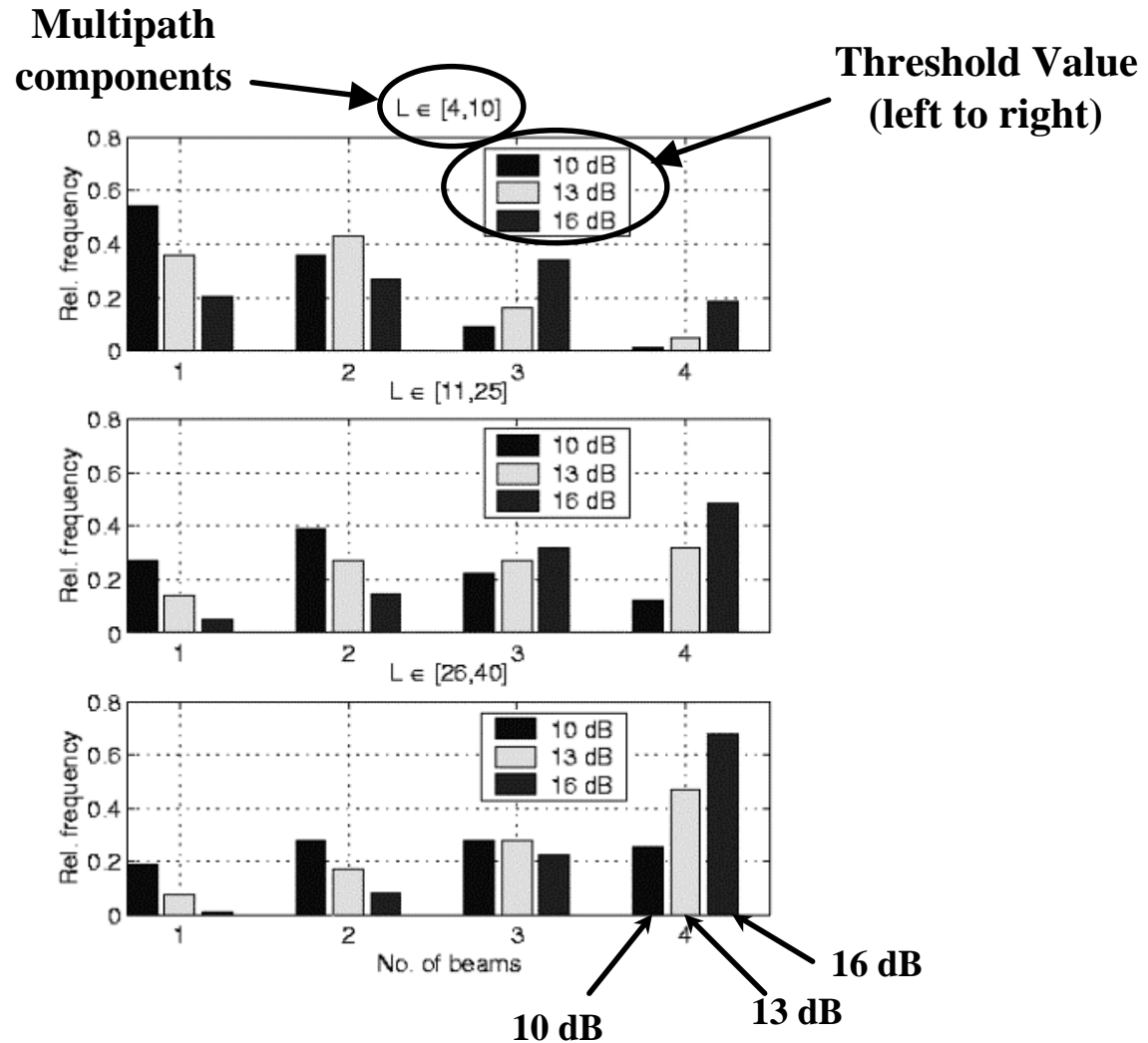
$\tau_m=2\tau_0$ (Maximum delay)

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

Peak Detection



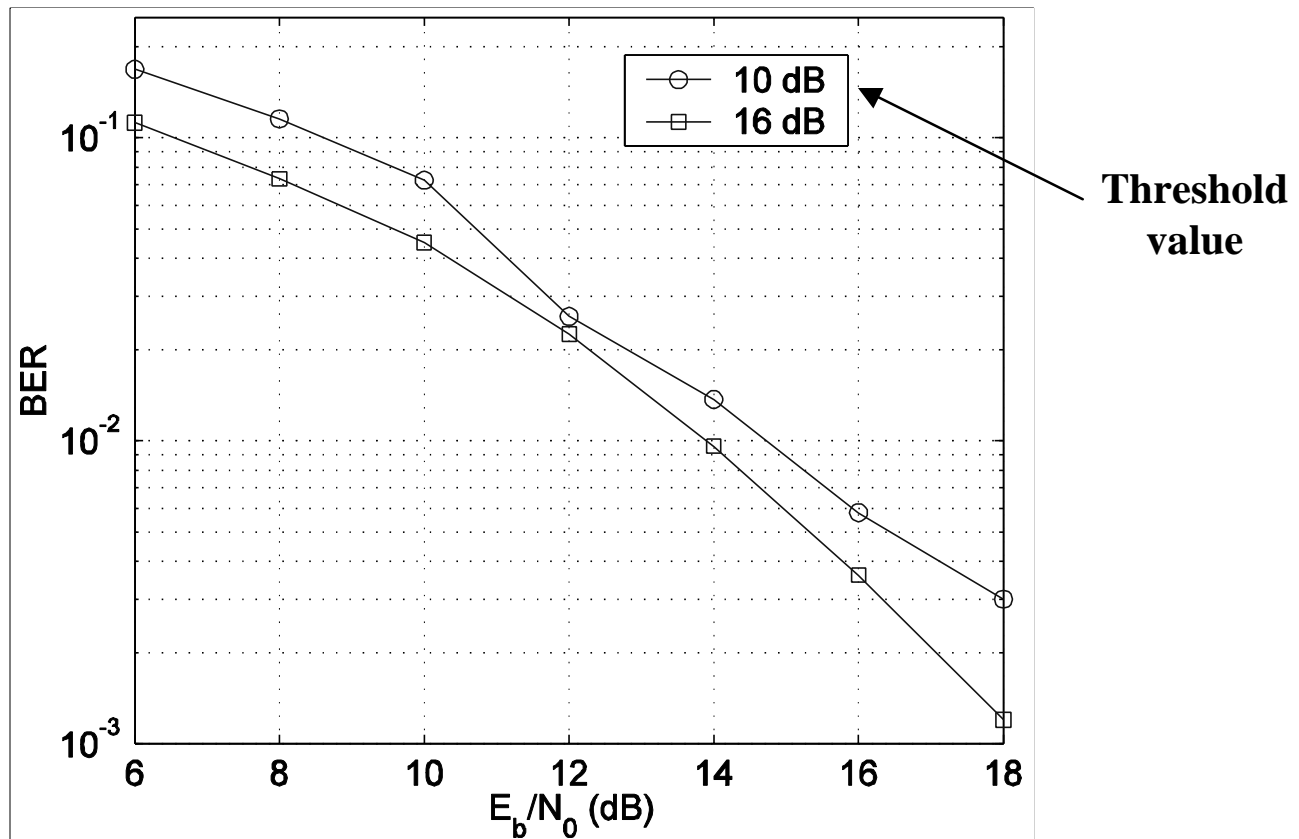
Distribution of Number of Beams



Adaptive Modulation

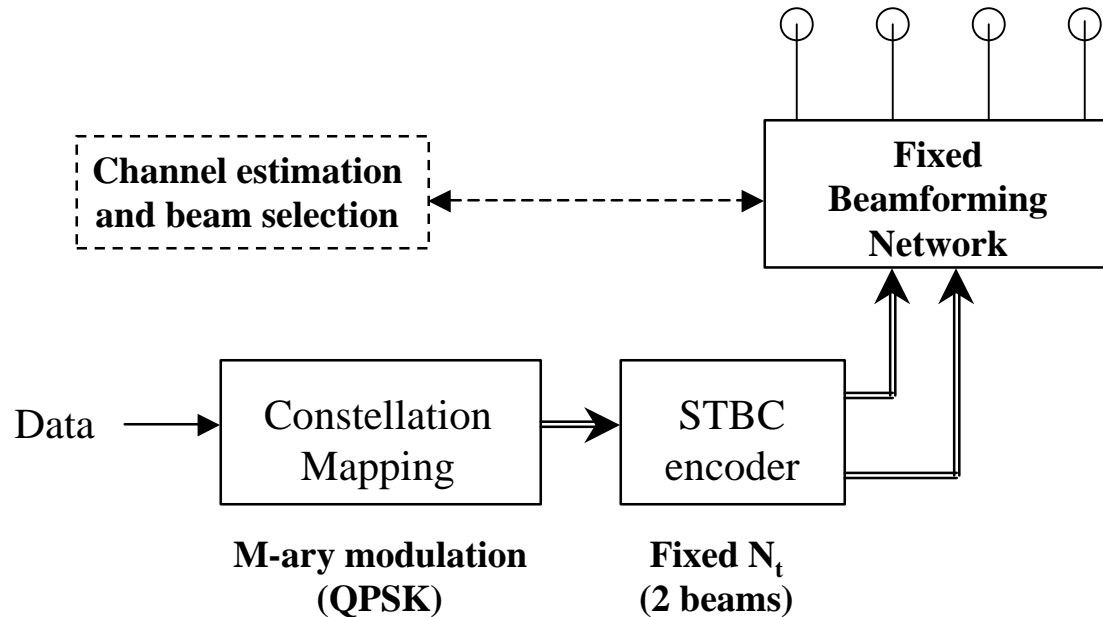
- In accordance to the number of transmit beams, the constellation is modified, to compensate for the rate loss of the STBC scheme:
 - $n_t=2$: $K/T = 1$ **QPSK modulation** (2 bps/Hz)
 - $n_t=3$ and $n_t=4$: $K/T = 3/4$ **8-PSK modulation** (2.25 bps/Hz)

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

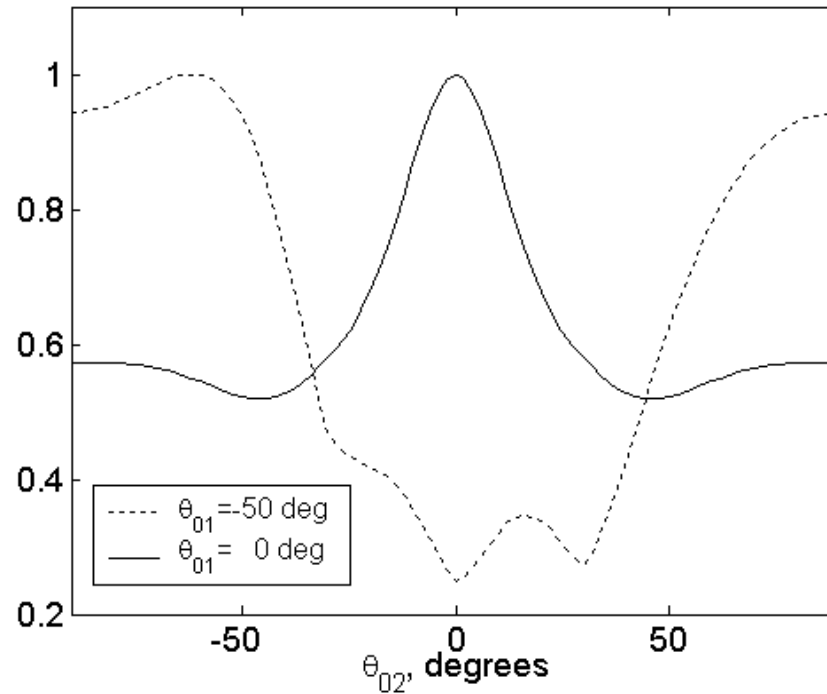


Transmit (Angular) Diversity with Sparse Array Antenna

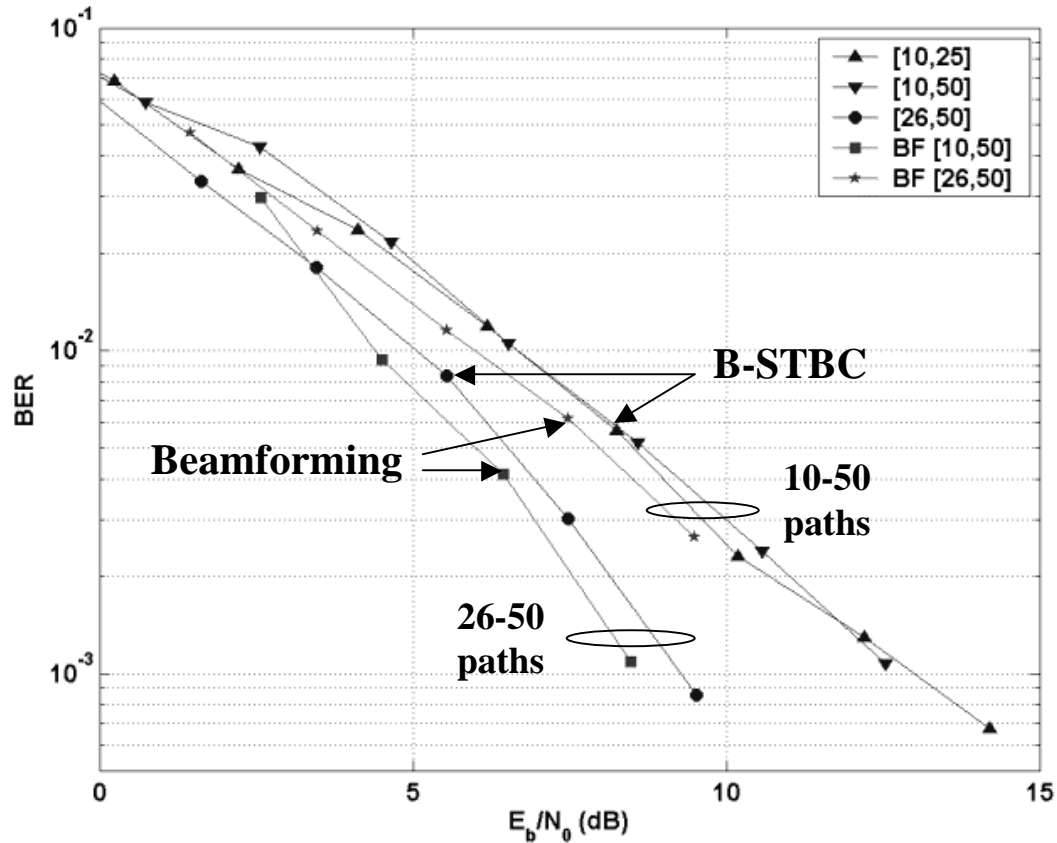
- Linear equally spaced array with $N=4$ elements
- Separation of half wavelength
- Switched-beam system
- Beams spaced by 6 degrees



Beam Correlation with 4 Antennas



Performance of B-STBC: Correlated Beams



Channel Estimation Errors

$$\mathbf{r} = \begin{bmatrix} r_0 \\ r_1^* \end{bmatrix},$$

**Received
vector**

$$\bar{\mathbf{H}} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix},$$

**Equivalent
channel**

$$\mathbf{n} = \begin{bmatrix} n_0 \\ n_1^* \end{bmatrix},$$

AWGN

$$\mathbf{c} = \begin{bmatrix} c_0 \\ c_1 \end{bmatrix}$$

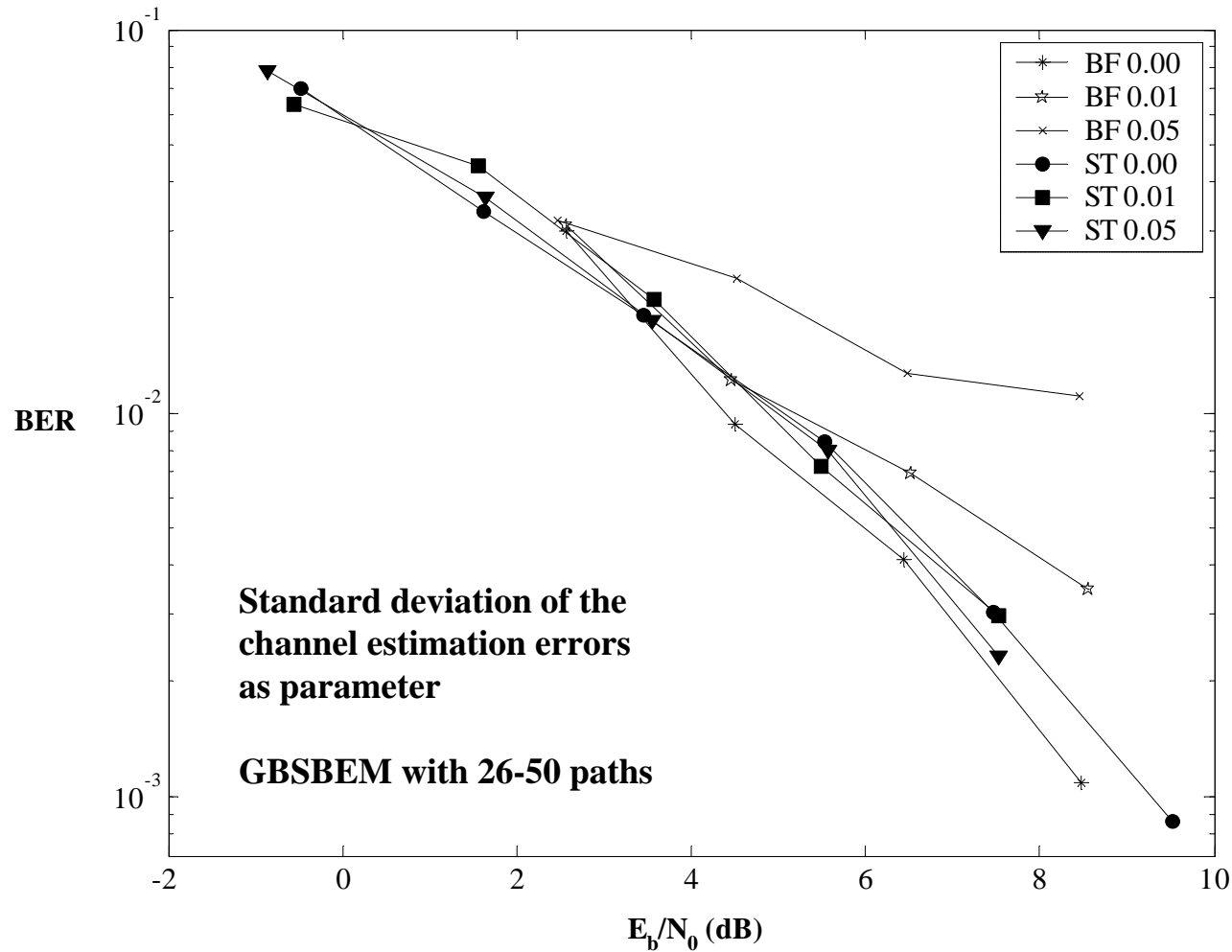
**Transmitted
vector**

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

**Estimation
errors**

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

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*