Multi-channel Communications Fall 2022

Lecture 11
Transmit Diversity

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Transmit Diversity - Overview

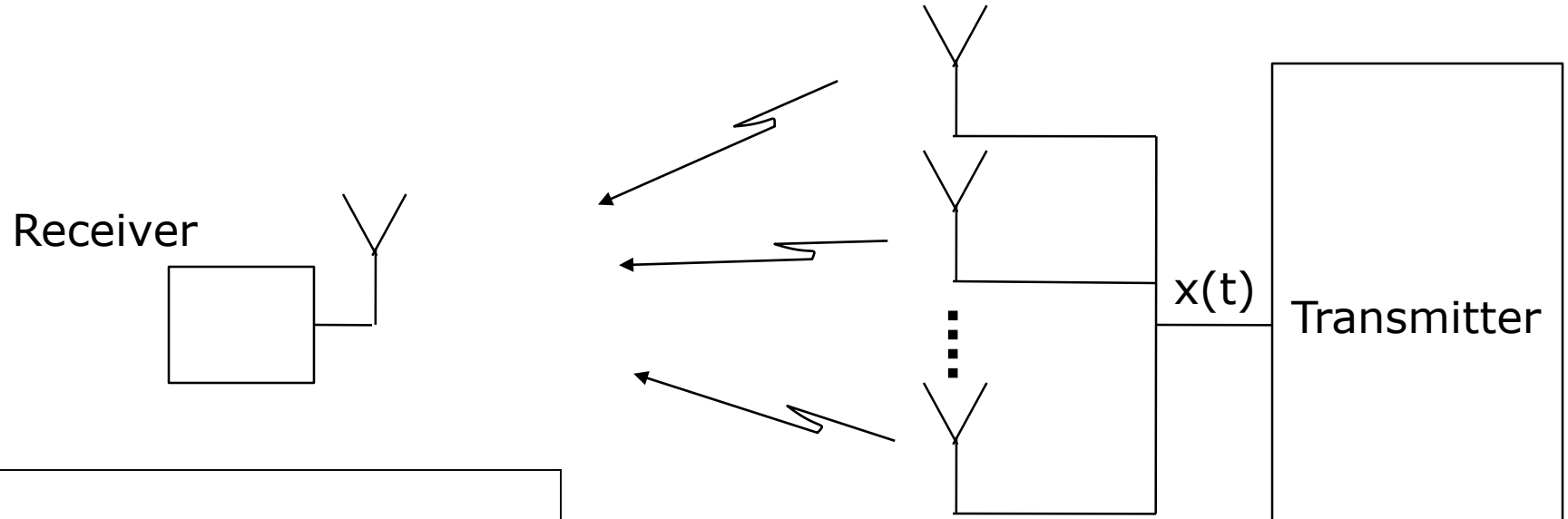
- Motivation
- Basic Concept
- Open-Loop Techniques
  - Delay diversity
  - PSTD
  - Space-Time Block Codes
  - Switch diversity
    - Antenna hopping – transmit from all antennas in round-robin fashion (loses 1/Nt bandwidth efficiency)
- Closed-Loop Techniques
  - Antenna selection
  - Co-phasing
  - Generalized "Beam-forming"
  - Maximum Ratio Transmission

Motivation

- We have seen that diversity can dramatically improve the performance of wireless systems
  - Primary tool against fading
- Receive antenna diversity not always a practical option
  - e.g., downlink of mobile systems
- Would like to move diversity to the transmit side of such systems
  - This is called *transmit diversity*

Concept

- Can we simply transmit from mulitple widely separated antennas?



Go to the board…..

Concept (cont.)

- Thus, we must transmit from multiple antennas intelligently
- Two forms of transmit diversity
  - Open-loop
    - No information is reported to the transmitter
  - Closed-loop
    - Some information is fed-back from the receiver
    - Information could be partial channel information or full channel information
    - Information feedback and feedback errors impair the performance of this scheme

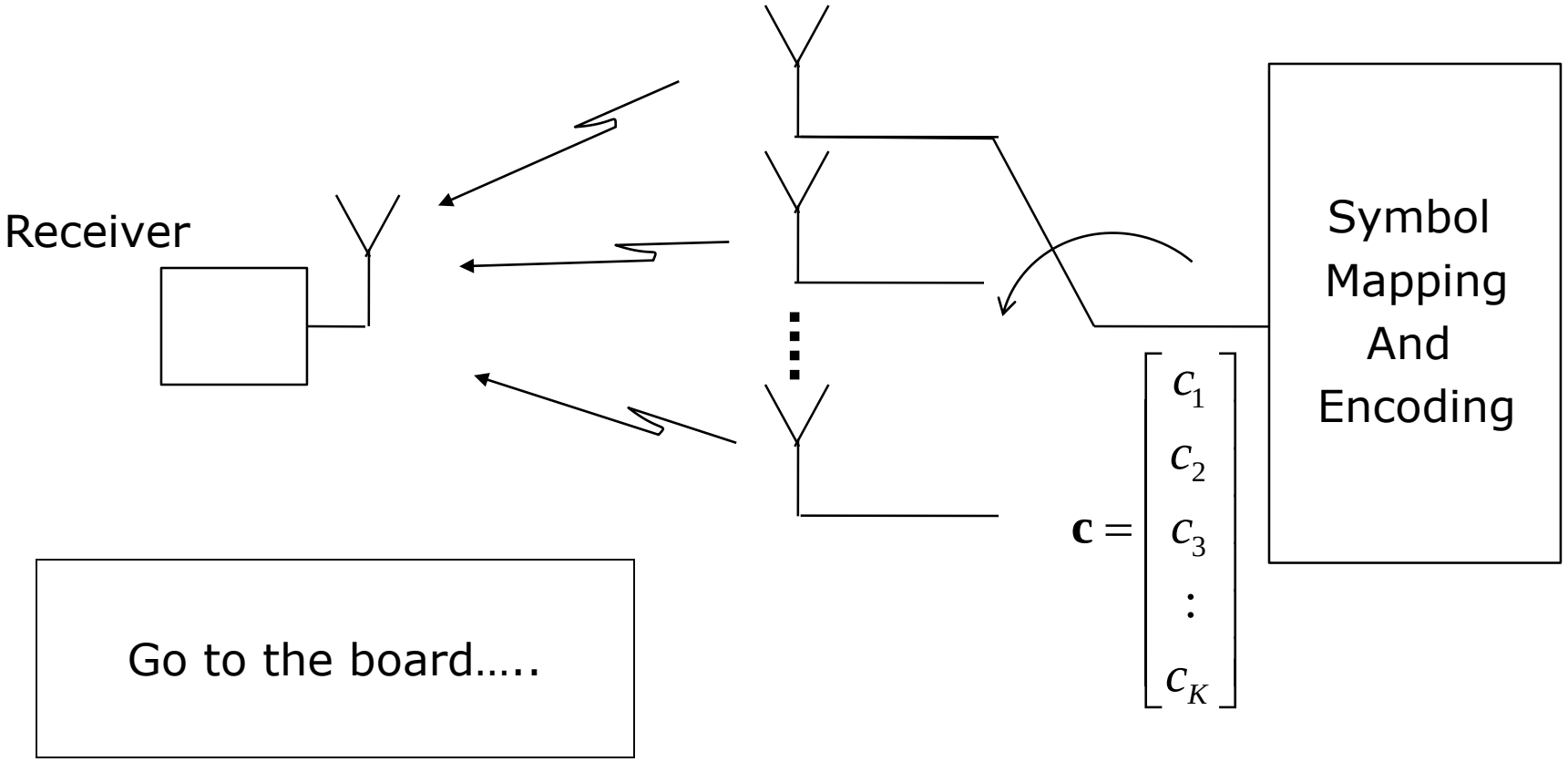
Open-Loop Transmit Diversity

- No information fed-back from receiver to the transmitter
- Since there is no information available at the transmitter, most techniques attempt to convert spatial diversity to temporal diversity which can be exploited by error control coding
  - Antenna hopping (blind antenna switching)
    - Also called orthogonal transmit diversity
  - Phase-sweep transmit diversity
  - Delay Diversity
- One major exception – Space-Time Block Coding
  - Achieves full diversity even without coding

Antenna Hopping

- Concept: Every symbol switch the transmit antenna among N_t possible antennas
  - Could also switch every K symbols and use interleaving
- In the absence of coding, the technique is not helpful, since each transmit symbol still experiences the single-antenna fading
- In the presence of coding, the codeword decision metric will experience diversity

Antenna Hopping



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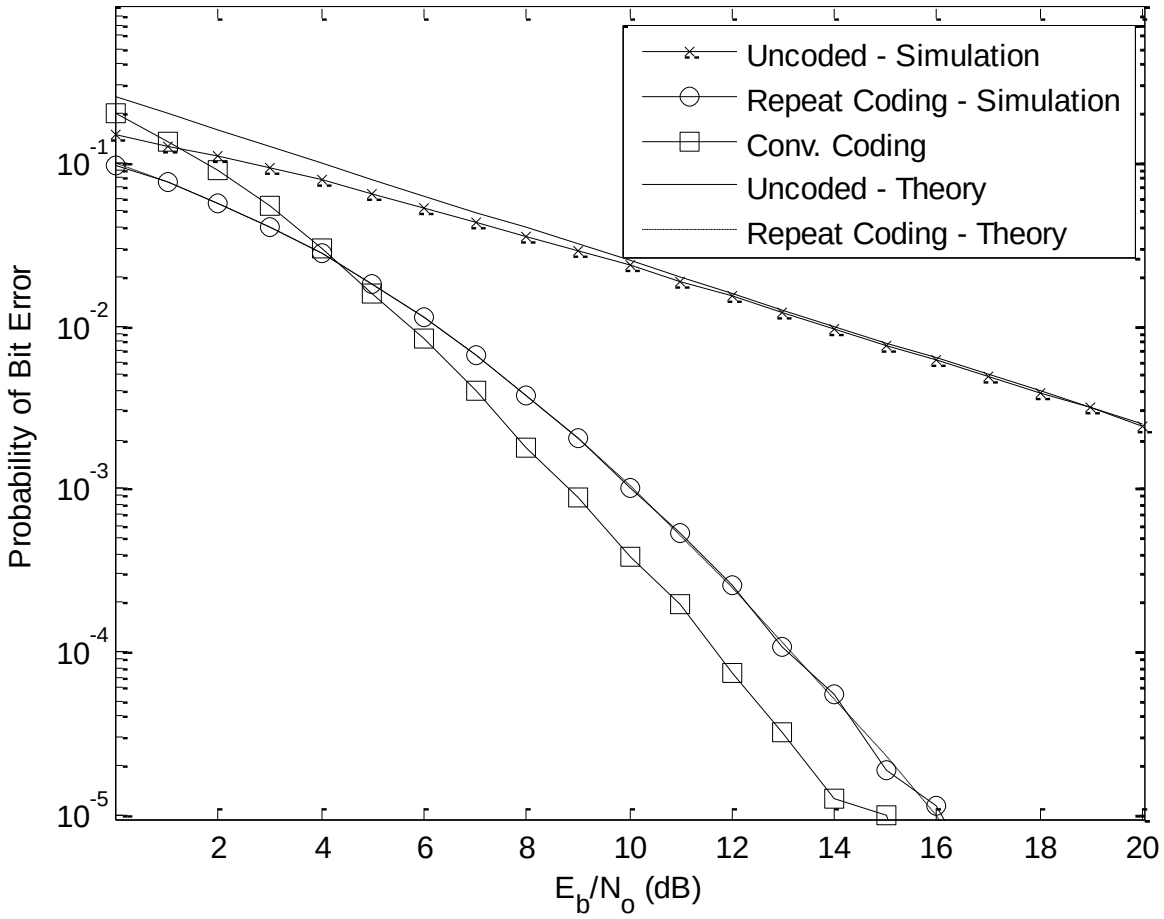
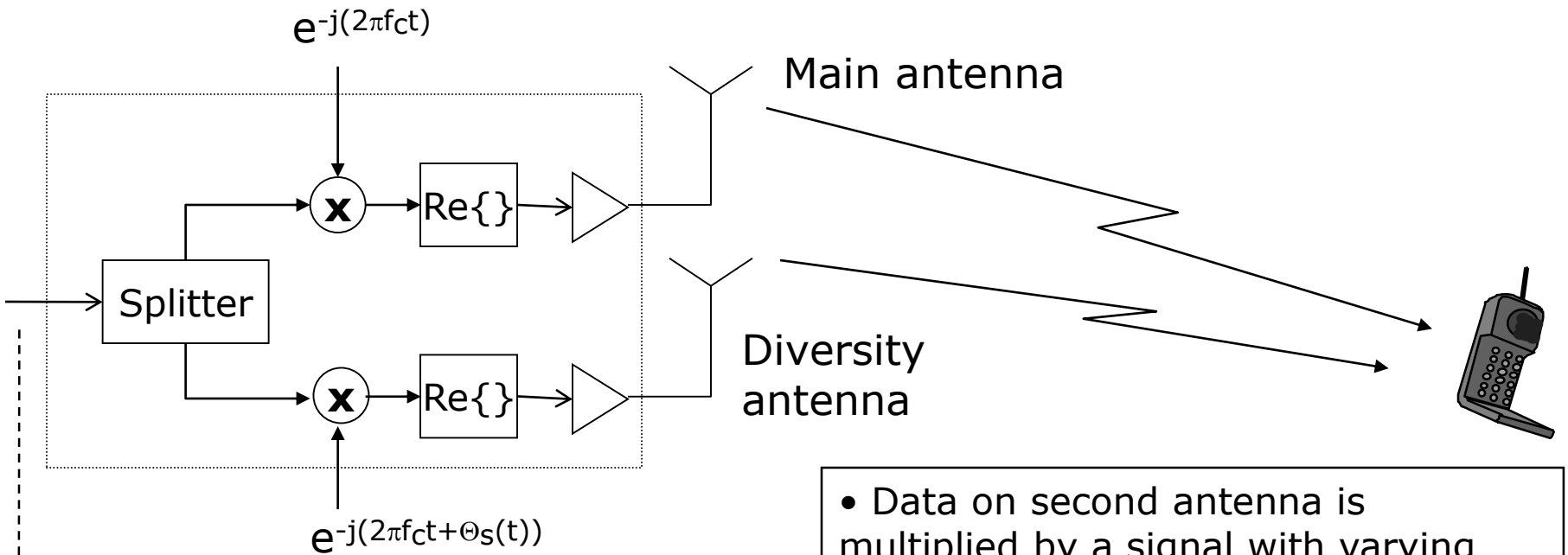
Performance Example



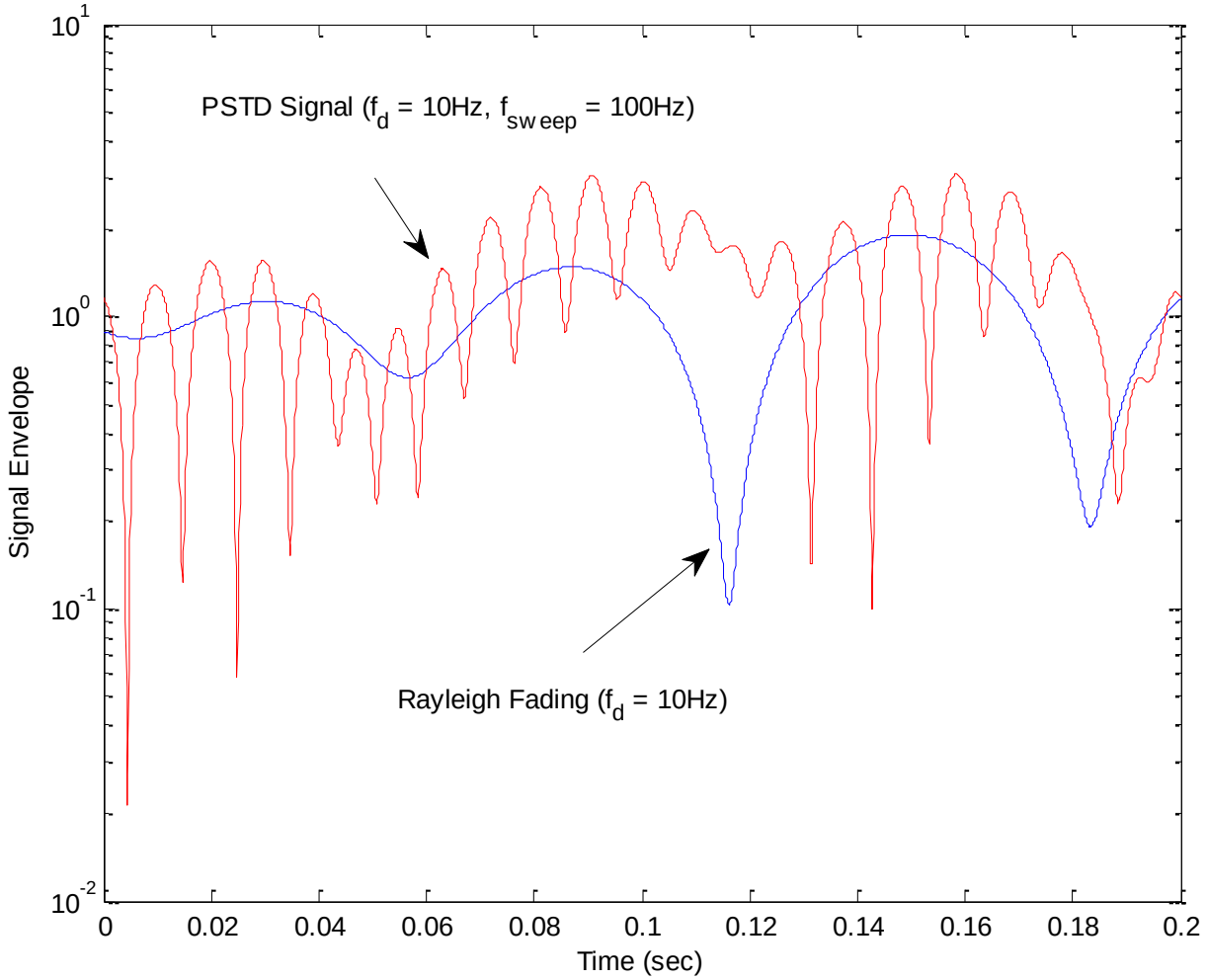
- $N_t = 4$
- BPSK
- Rayleigh fading
- Independent channels
- $K=8$, rate ¼ conv. Coding

Phase Sweep Transmit Diversity



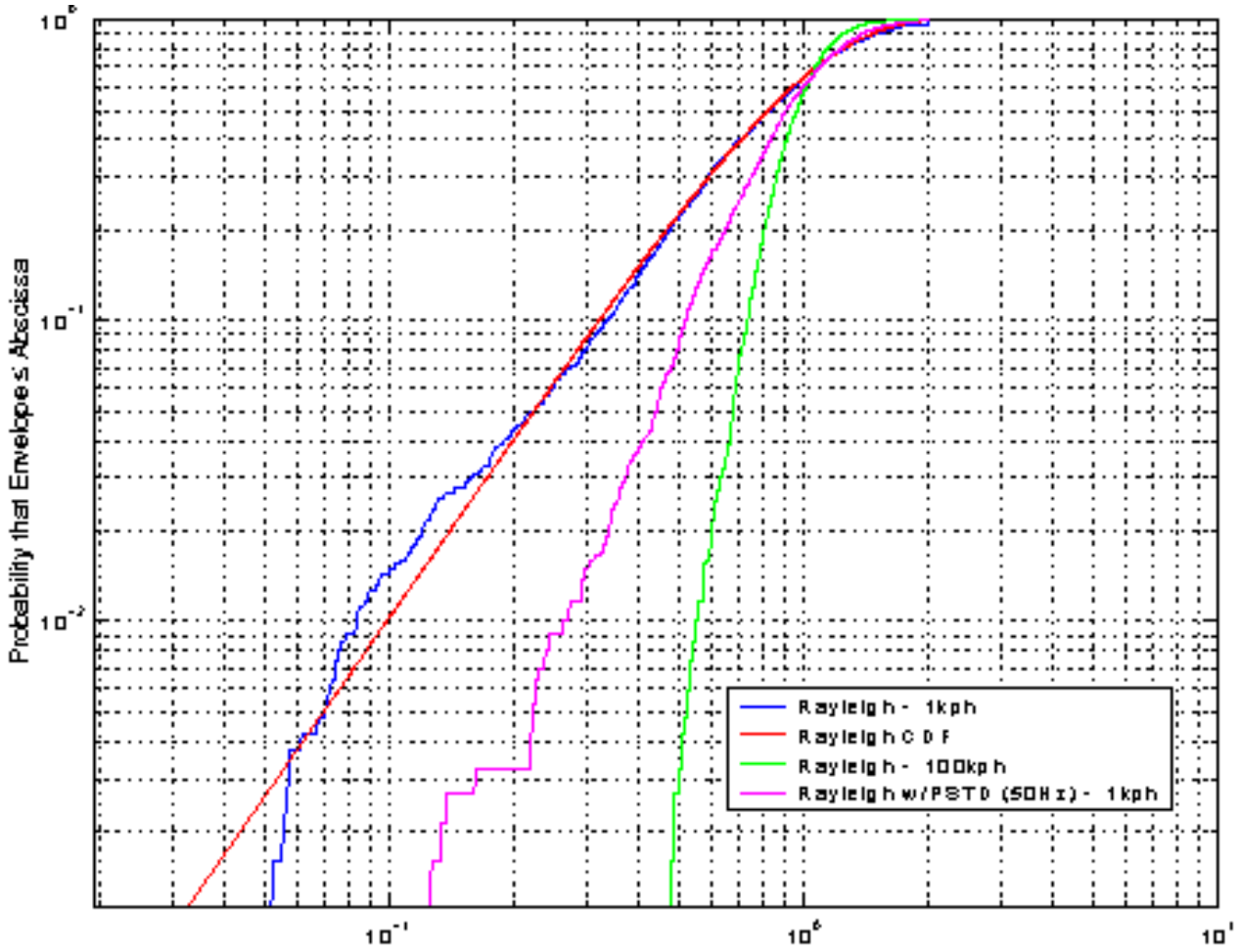
- Data on second antenna is multiplied by a signal with varying phase.
- Fading induced at the mobile, even in static conditions.
- Beneficial in slow Rayleigh fading since it provides time diversity in conjunction with coding and interleaving.

Example



- f_d = 10Hz
- f_{sweep} = 100Hz
- Fades are just as deep, but much shorter
- Allows for better performance with coding

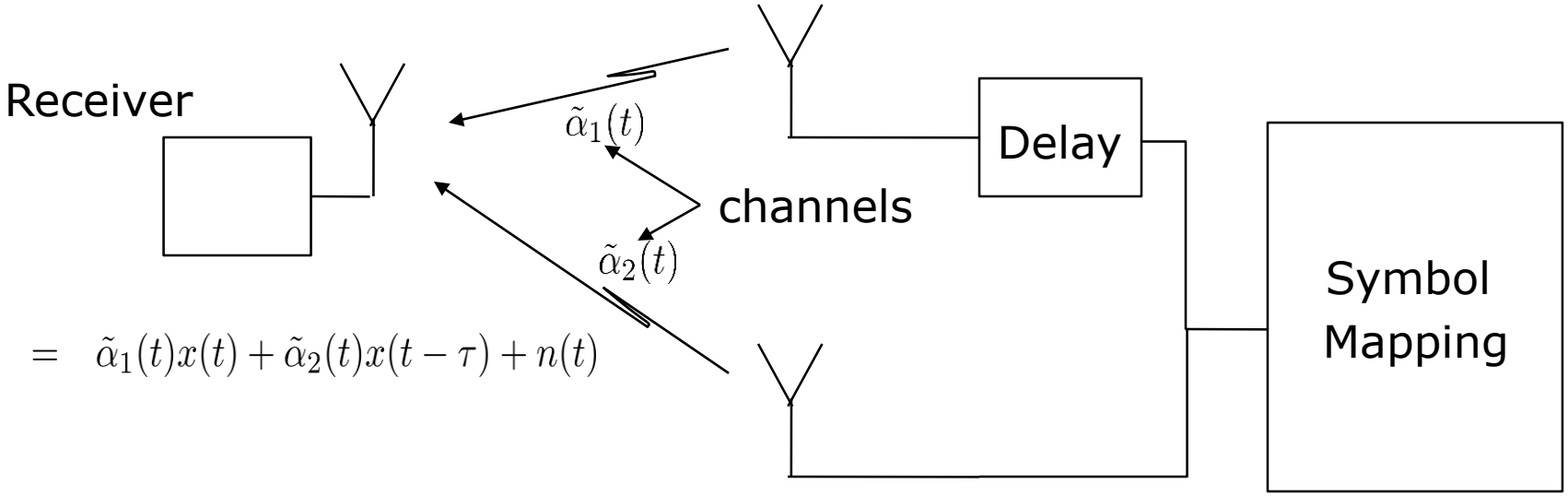
Effect of PSTD - Viterbi Path Metric CDF



- **Constraint length *K* = 9**
- **rate =3/4**

Delay Diversity

- Transmit from two (or more) antennas with the other antennas containing a delay
- Relies on an equalizer or Rake receiver (when spread spectrum is used) to remove self interference
- Provide symbol-level diversity (coding not necessary for diversity benefit



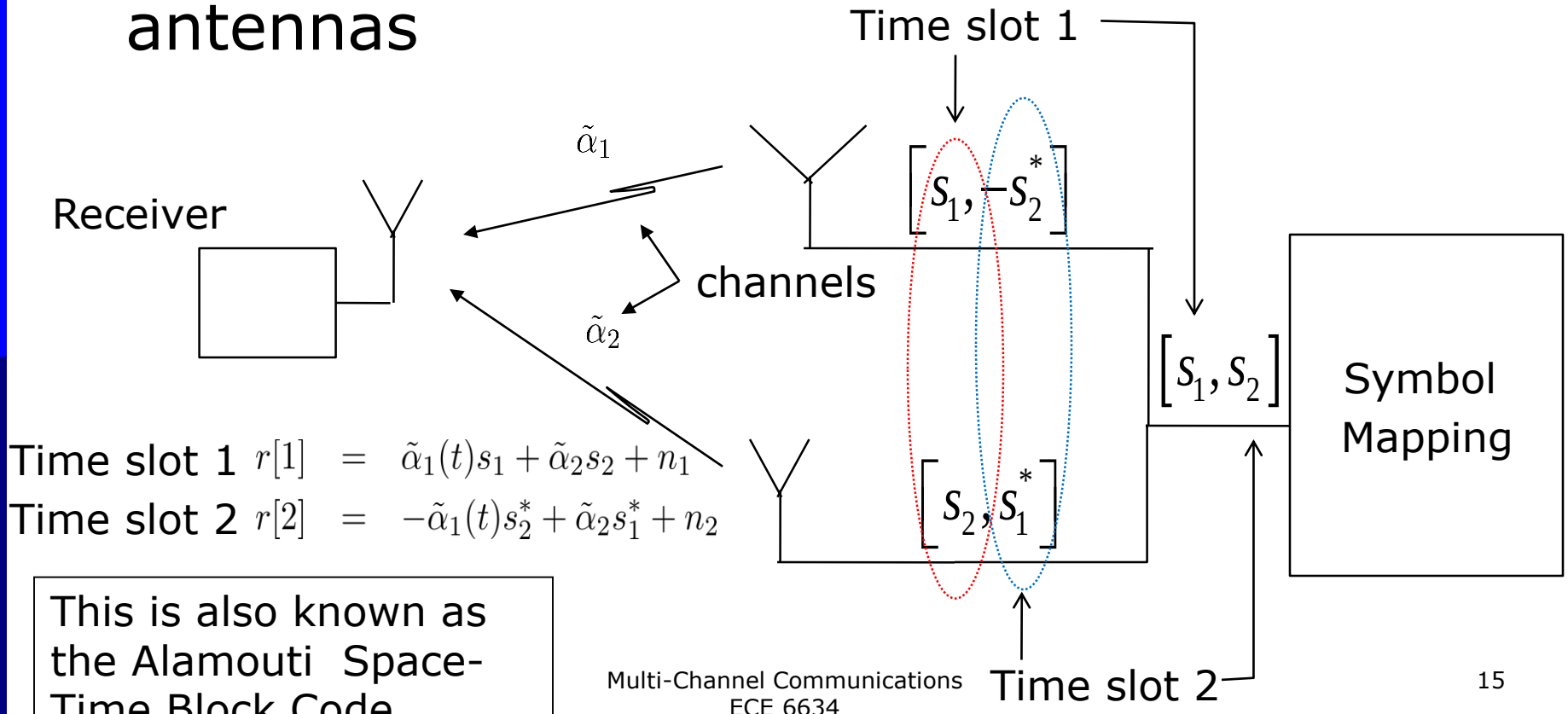
$$r(t) = \tilde{\alpha}_1(t)x(t) + \tilde{\alpha}_2(t)x(t-\tau) + n(t)$$

Space-Time Transmit Diversity

- All of the preceding techniques converted spatial diversity into temporal diversity
- Temporal diversity is typically exploited through channel coding
- One major exception to this approach is space-time transmit diversity which provides two-fold diversity using a very simple but elegant space-time code
  - It can be generalized and is known as space-time block coding

STTD – cont.

- A pair of symbols is re-encoded and transmitted over two time slots on two antennas



Time slot 1 $r[1] = \tilde{\alpha}_1(t)s_1 + \tilde{\alpha}_2 s_2 + n_1$

Time slot 2 $r[2] = -\tilde{\alpha}_1(t)s_2^* + \tilde{\alpha}_2 s_1^* + n_2$

This is also known as the Alamouti Space-Time Block Code

STTD - Decision Metric

- Decision Metric

$$\begin{aligned}\hat{s}_1 &= f\left\{\hat{\alpha}_1^* r[1] + \hat{\alpha}_2 r^*[2]\right\} \\ \hat{s}_2 &= f\left\{\hat{\alpha}_2^* r[1] - \hat{\alpha}_1 r^*[2]\right\}\end{aligned} \Longrightarrow \begin{aligned}\hat{s}_1 &= f\left\{\sqrt{\frac{P_1}{2}}\left(|\tilde{\alpha}_1|^2 + |\tilde{\alpha}_2|^2\right) s_1 + \tilde{n}_1\right\} \\ \hat{s}_2 &= f\left\{\sqrt{\frac{P_1}{2}}\left(|\tilde{\alpha}_1|^2 + |\tilde{\alpha}_2|^2\right) s_2 + \tilde{n}_2\right\}\end{aligned}$$

$$\begin{aligned}f\{x\} &= \text{decision function} \\ \hat{\alpha}_i &= \text{estimate of the } i\text{th complex channel } \tilde{\alpha}_i\end{aligned}$$

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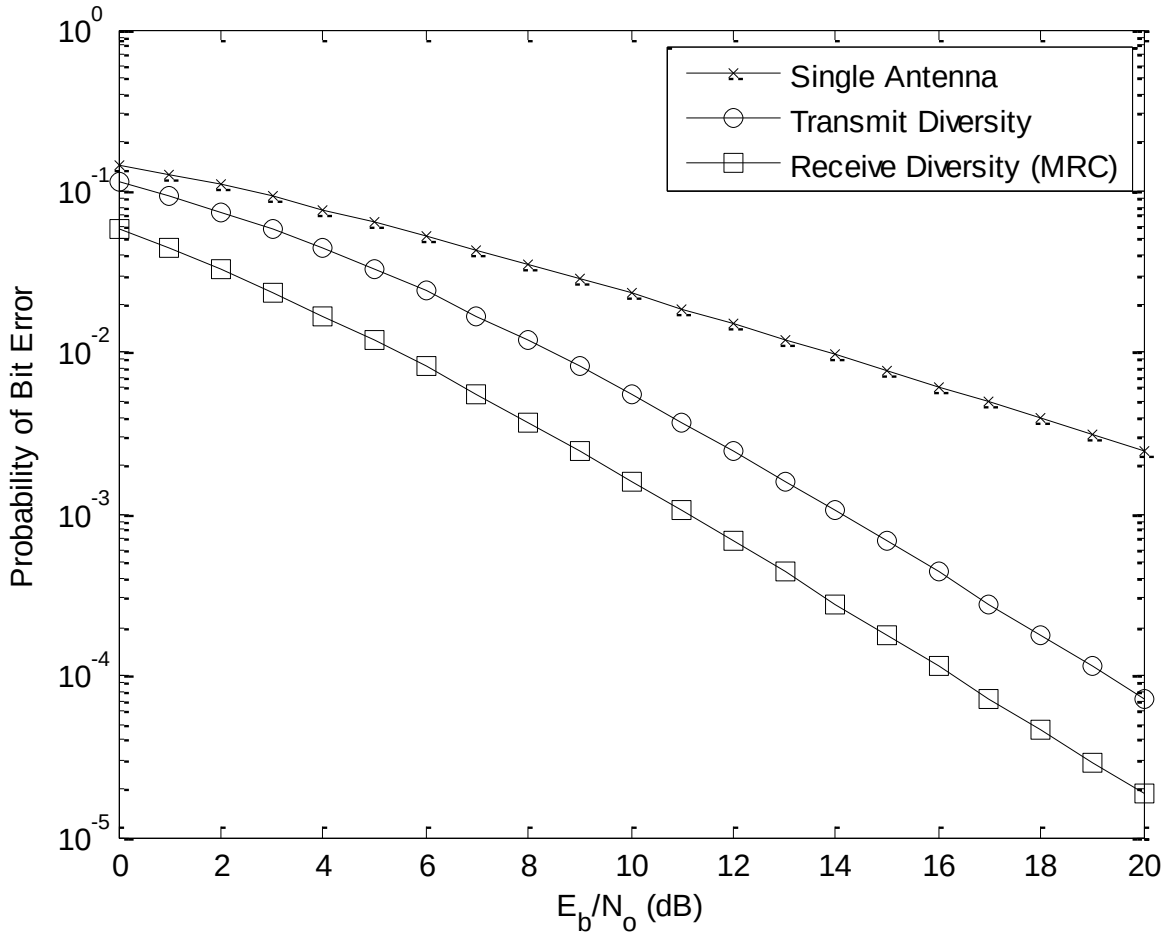
- All cross-interference is eliminated

Performance



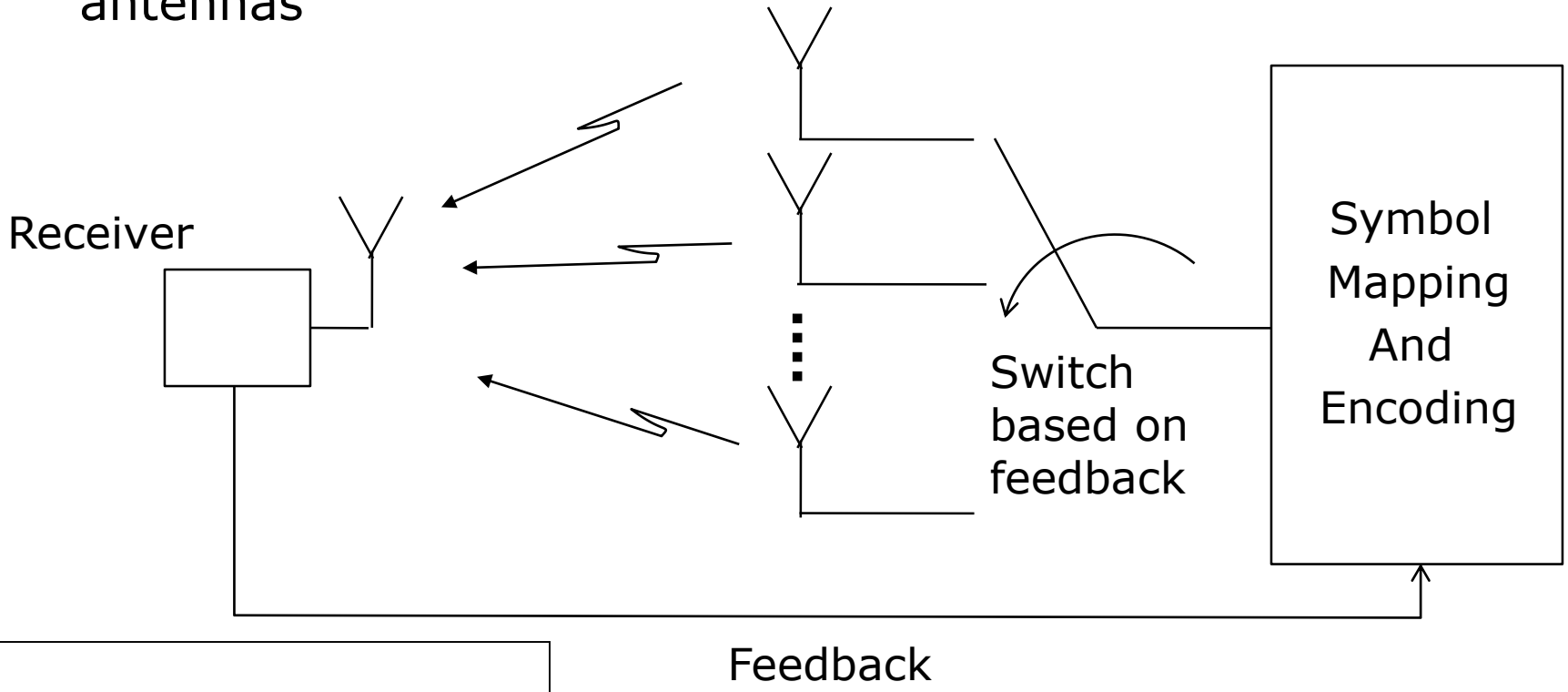
- Rayleigh fading
- Independent channels
- Perfect channel estimates
- STTD is 3dB worse than two-fold receive diversity

Closed-Loop Transmit Diversity

- If information about the channel can be fed back from the receiver to the transmitter before the channel changes, we can exploit this information at the transmitter
  - Can also be done by transmitter itself in TDD systems
- Forms
  - Antenna selection
  - Generalized “beamforming”
  - Maximal Ratio Transmission

Antenna Selection

- Best of the N_t channels is fed back to the receiver
- Pilots must be sent from each antenna to measure all antennas



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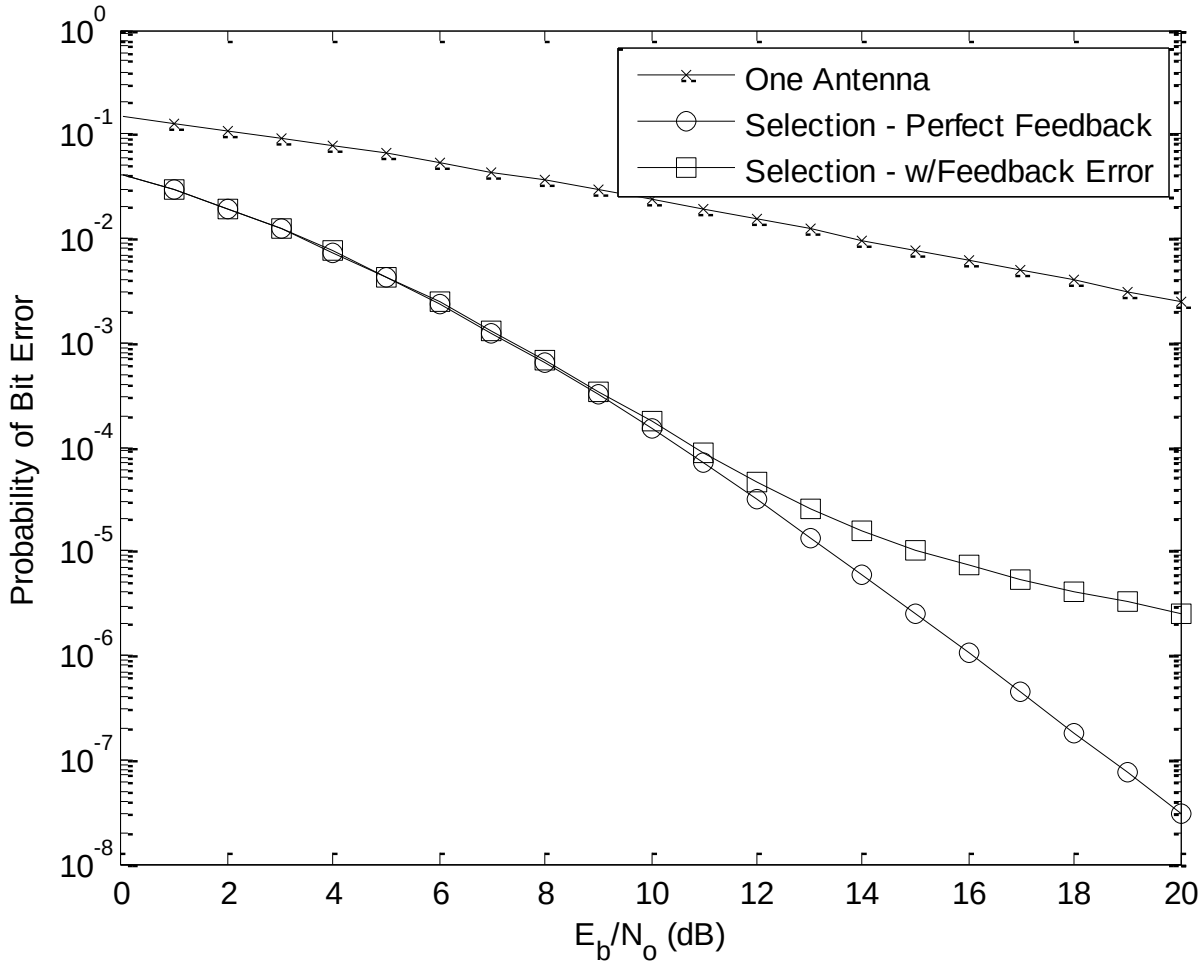
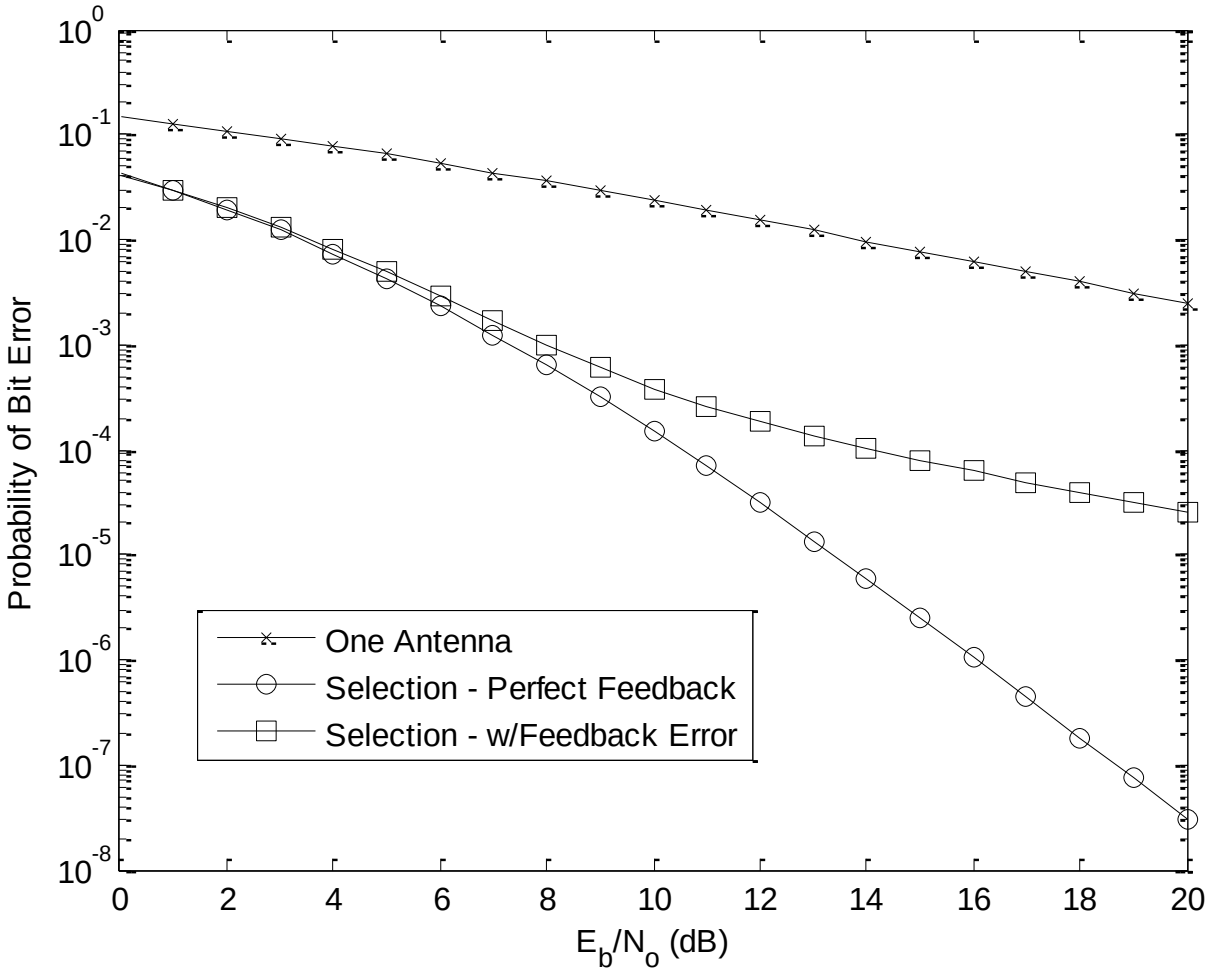
Impact of Feedback Error



- Feeback error = 0.1%
- 4 Tx antennas
- Rayleigh fading
- Independent channels

Impact of Feedback Error



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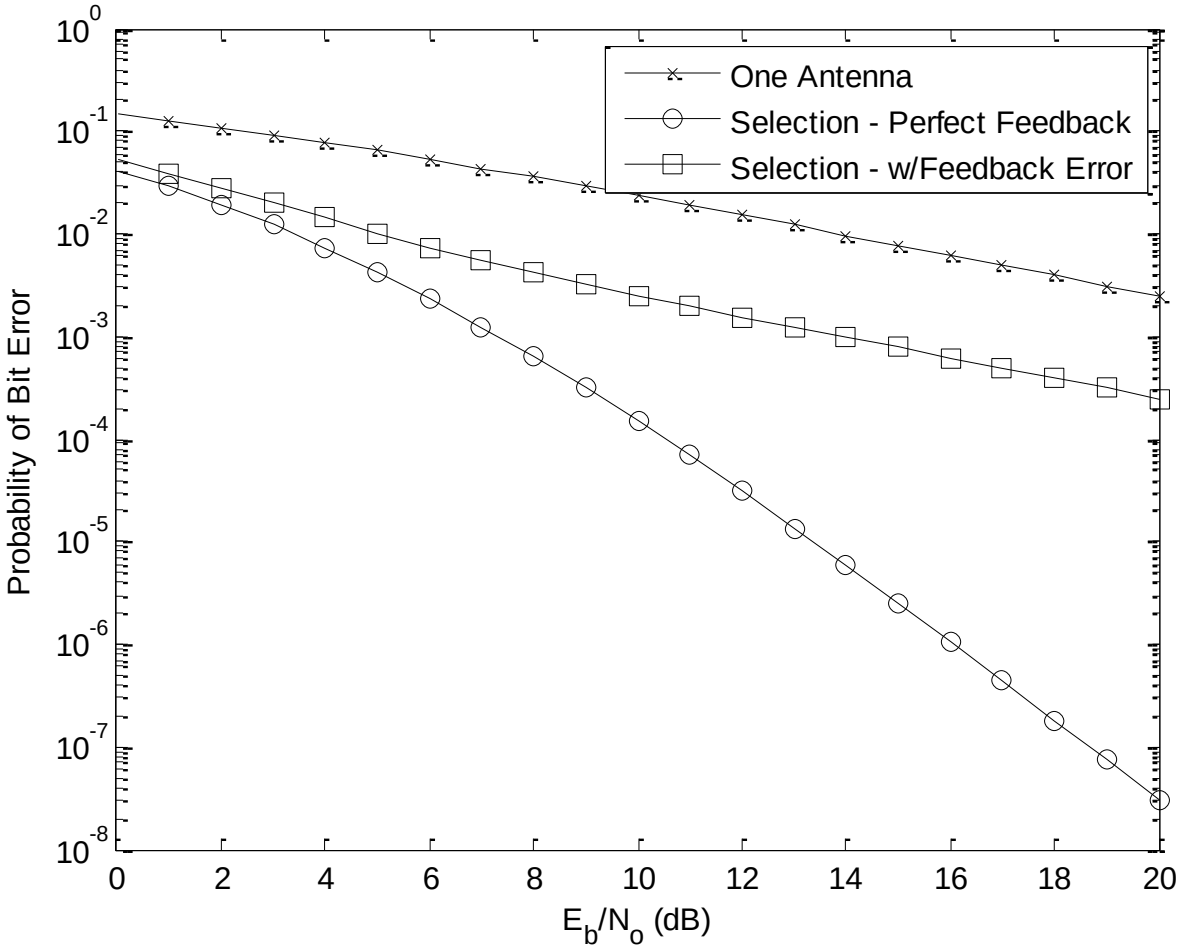
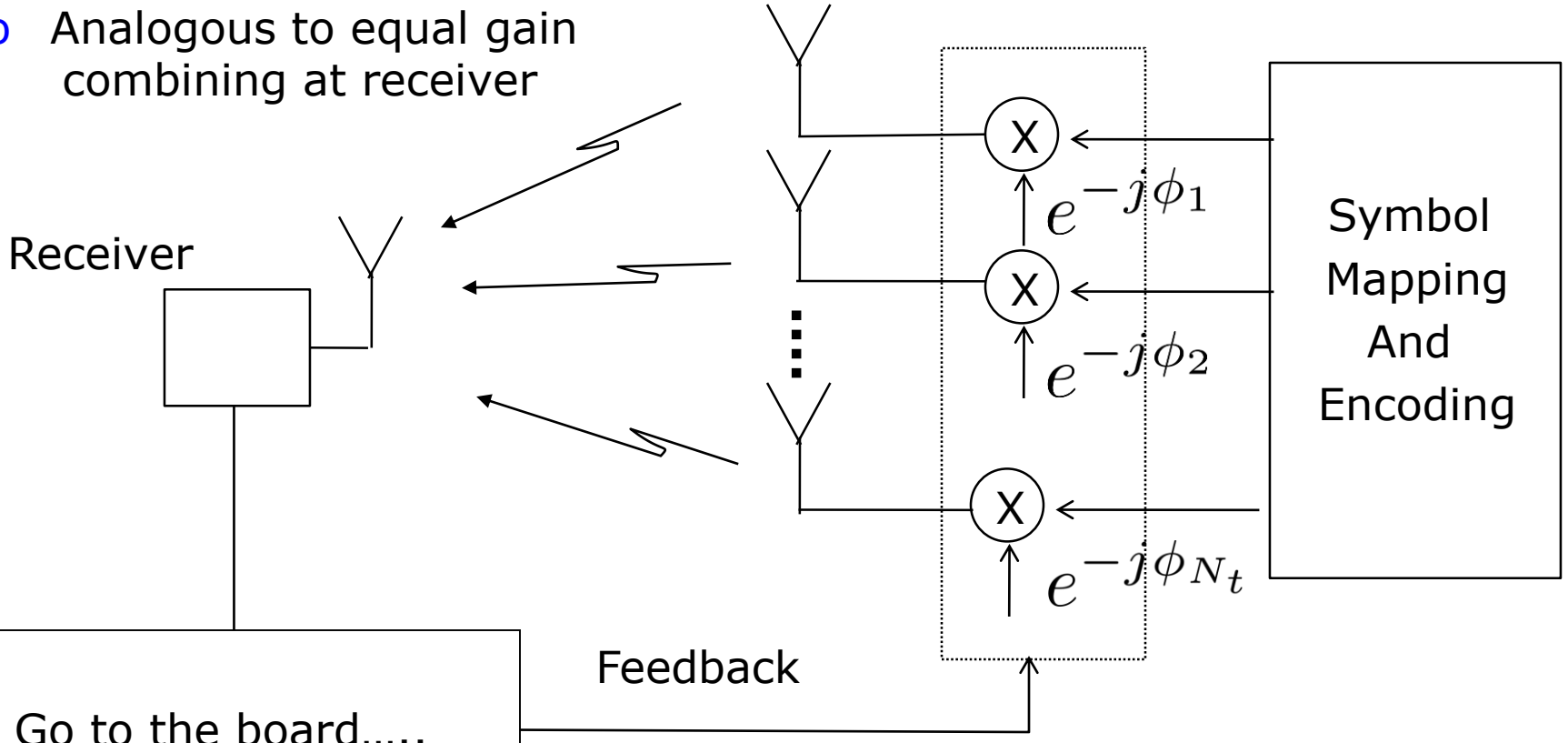
Impact of Feedback Error



- Feeback error = 10%
- 4 Tx antennas
- Rayleigh fading
- Independent channels

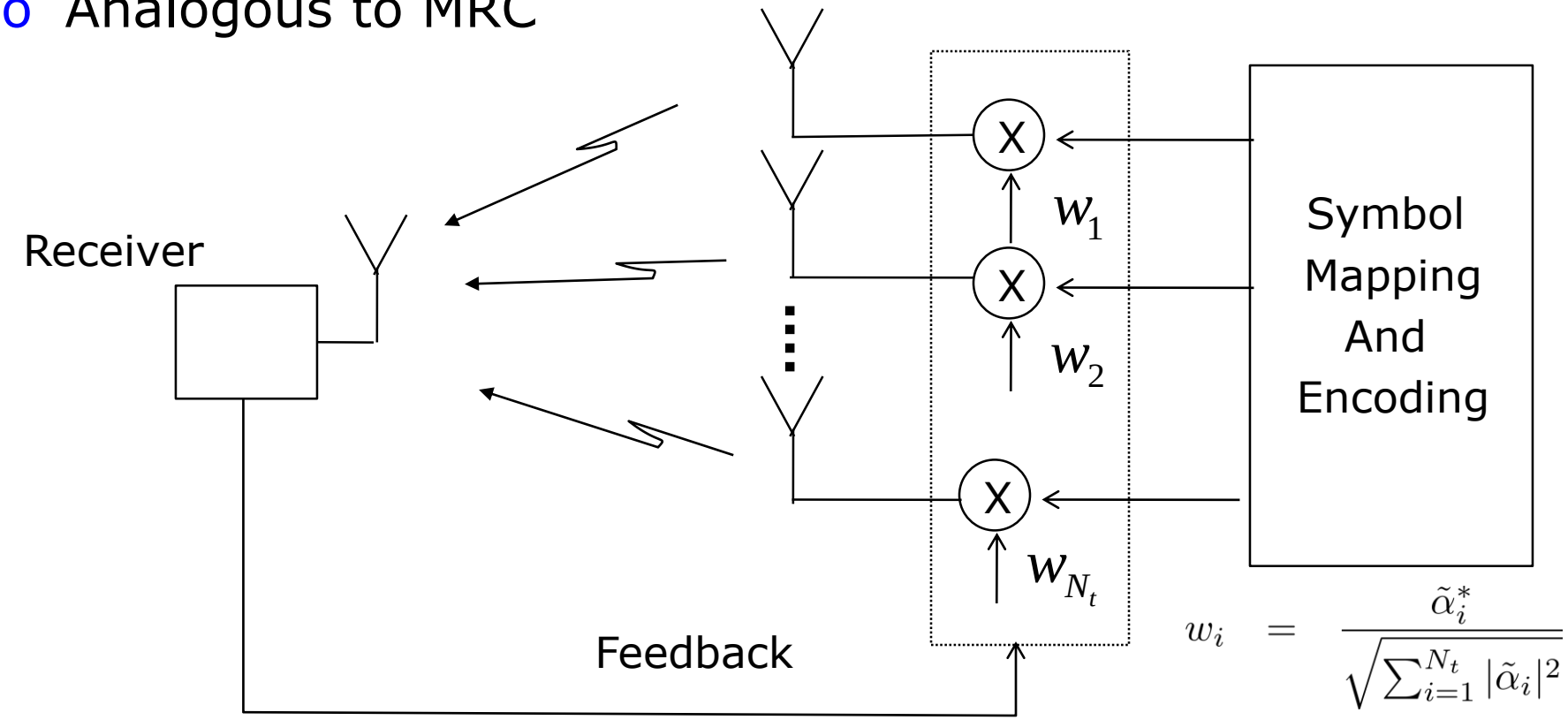
Generalized Beamforming

- Relative phases from all N_t channels are fed back to the receiver
- Pilots must be sent from each antenna to measure all antennas
- Not beamforming in the strict sense since no beams are formed
- Analogous to equal gain combining at receiver



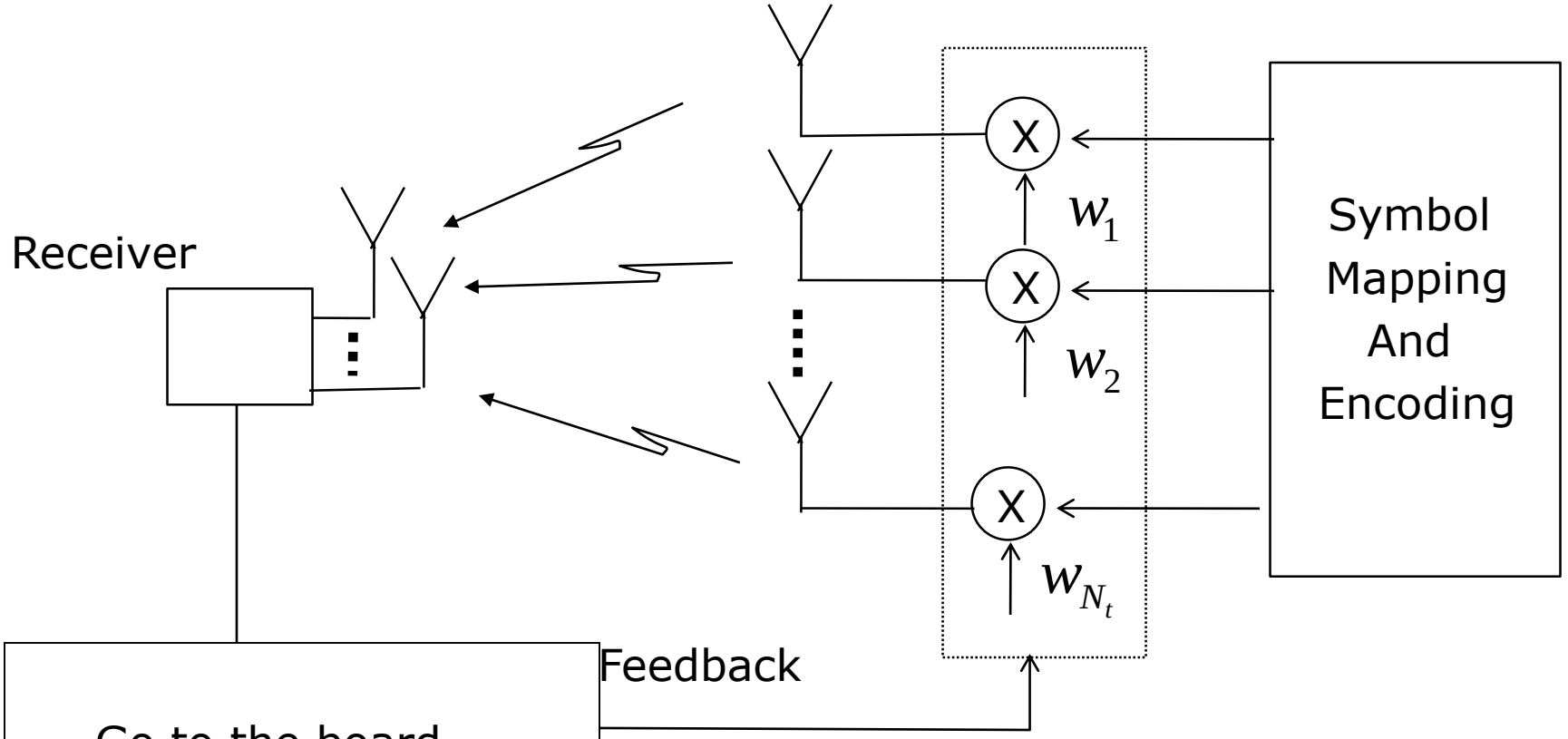
Generalized Beamforming (cont.)

- Better performance can be obtained if the signals are weighted *and* co-phased
- Analogous to MRC

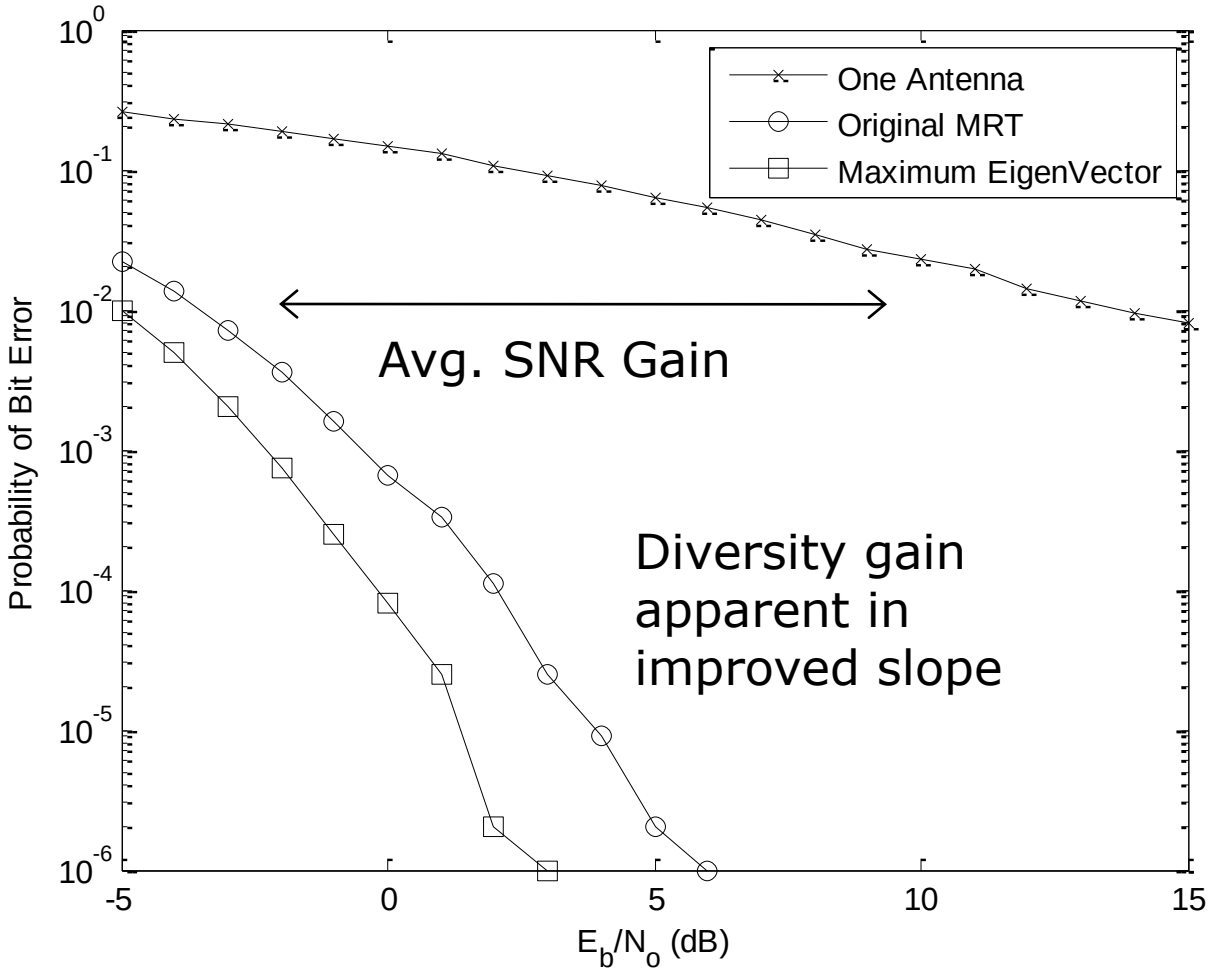


Maximal Ratio Transmission

- Generalized version of the previous scheme with multiple receive antennas

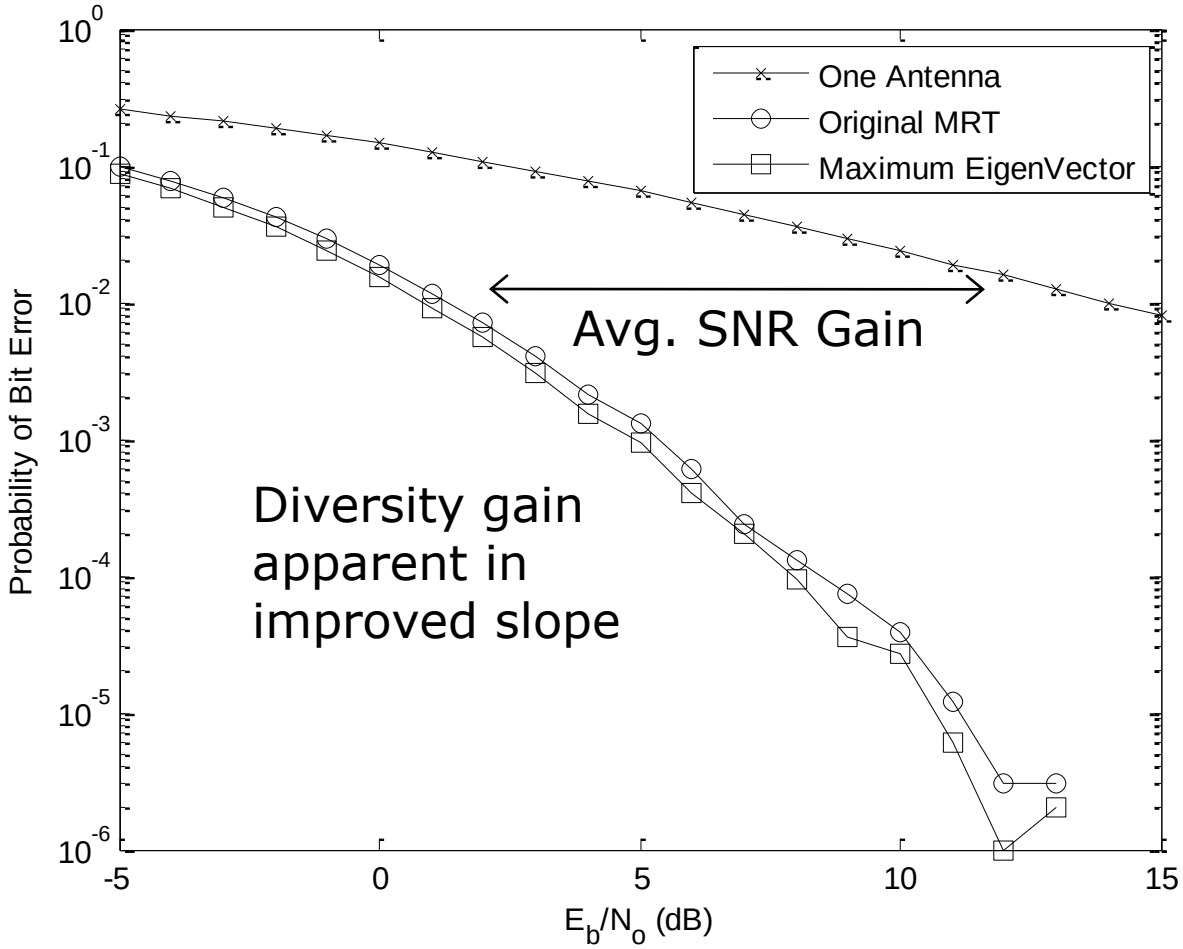


Performance Example



- Simulation results
- $N_t = 4$
- $M_r = 4$
- Rayleigh fading
- Independent channels

Performance Example

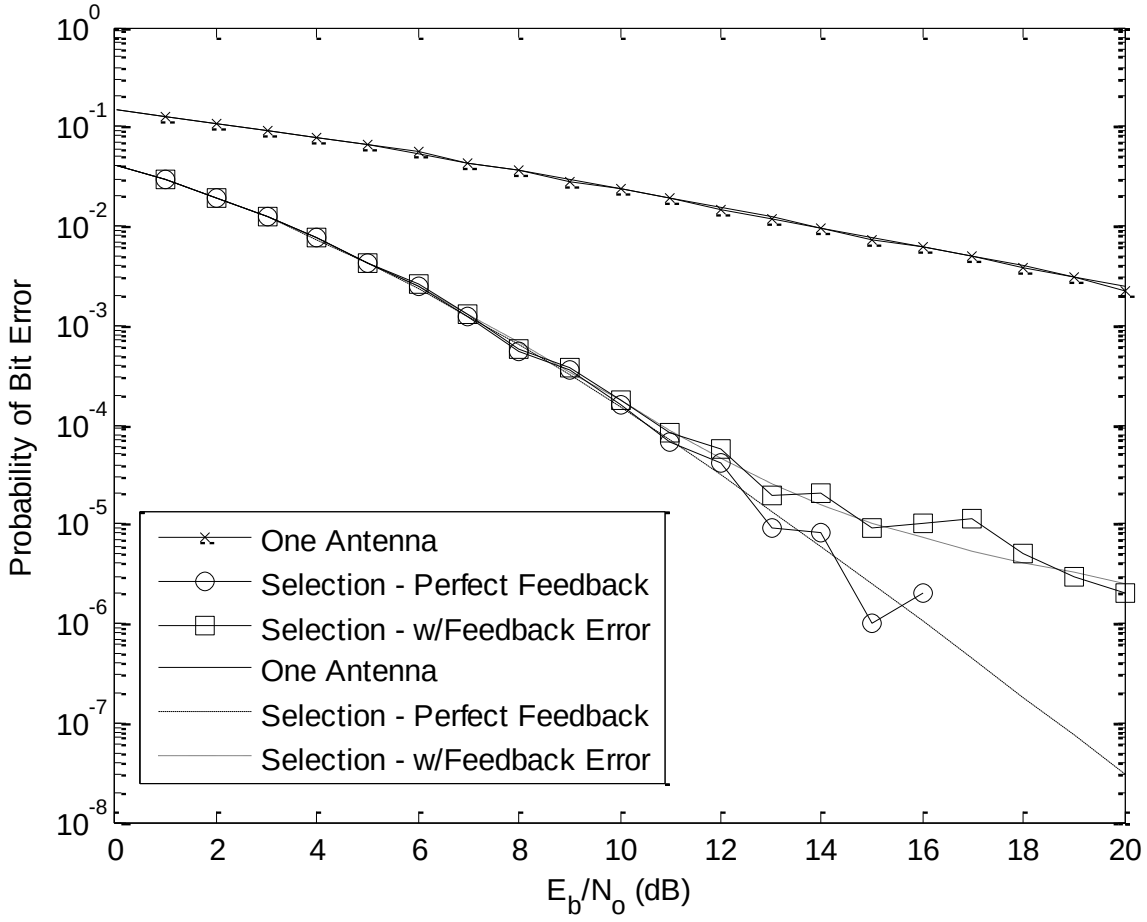


- Simulation results
- $N_t = 2$
- $M_r = 2$
- Rayleigh fading
- Independent channels

Conclusions

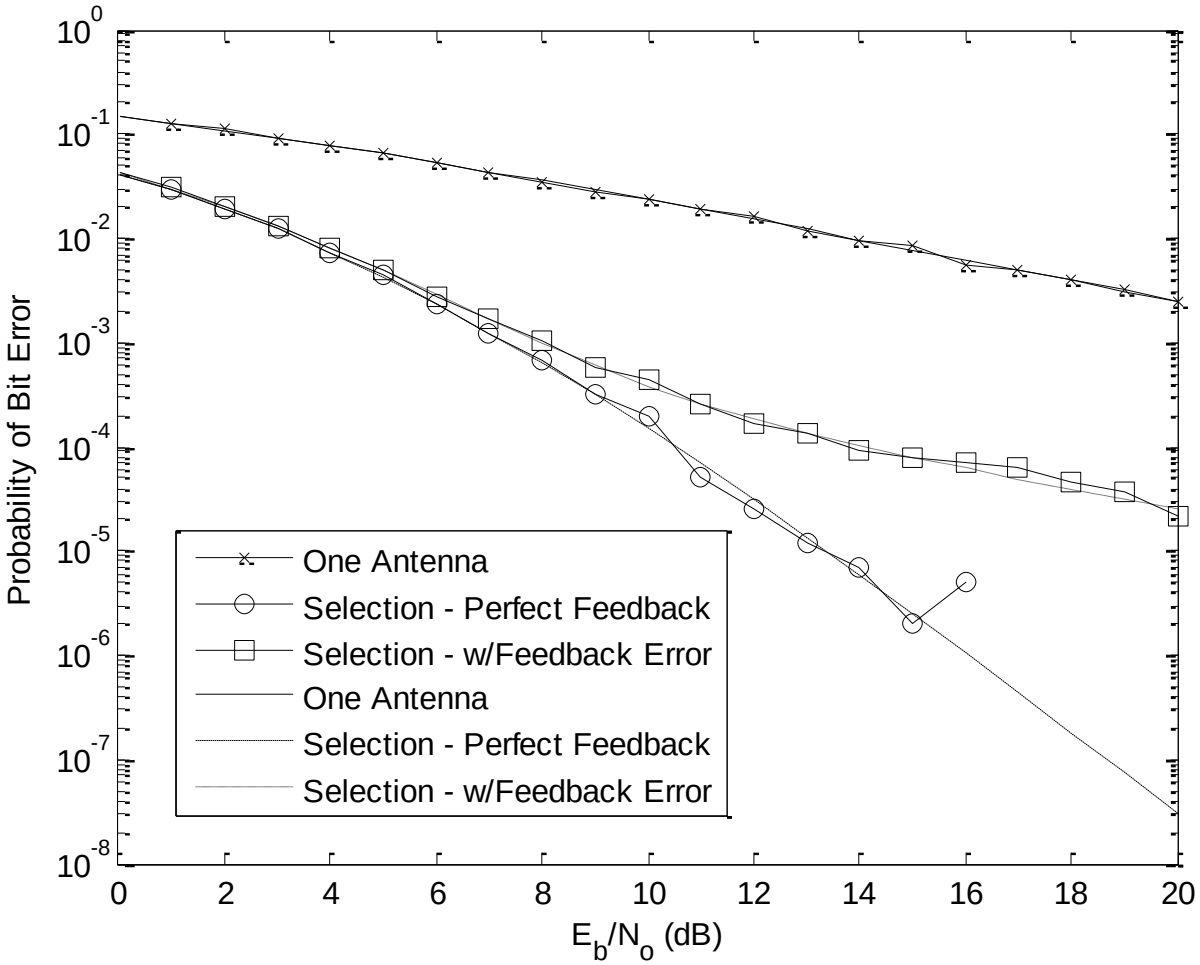
- Today we considered transmit diversity techniques. There are two basic forms
  - Without feedback
    - PSTD
    - Antenna Hopping
    - Space-Time block coding
  - With feedback
    - Antenna selection
    - Generalized beamforming

Backup Slide – Antenna Selection



- Simulation vs. Theory
- Feeback error = 0.1%
- 4 Tx antennas
- Rayleigh fading
- Independent channels

Backup Slide – Antenna Selection



- Simulation vs. Theory
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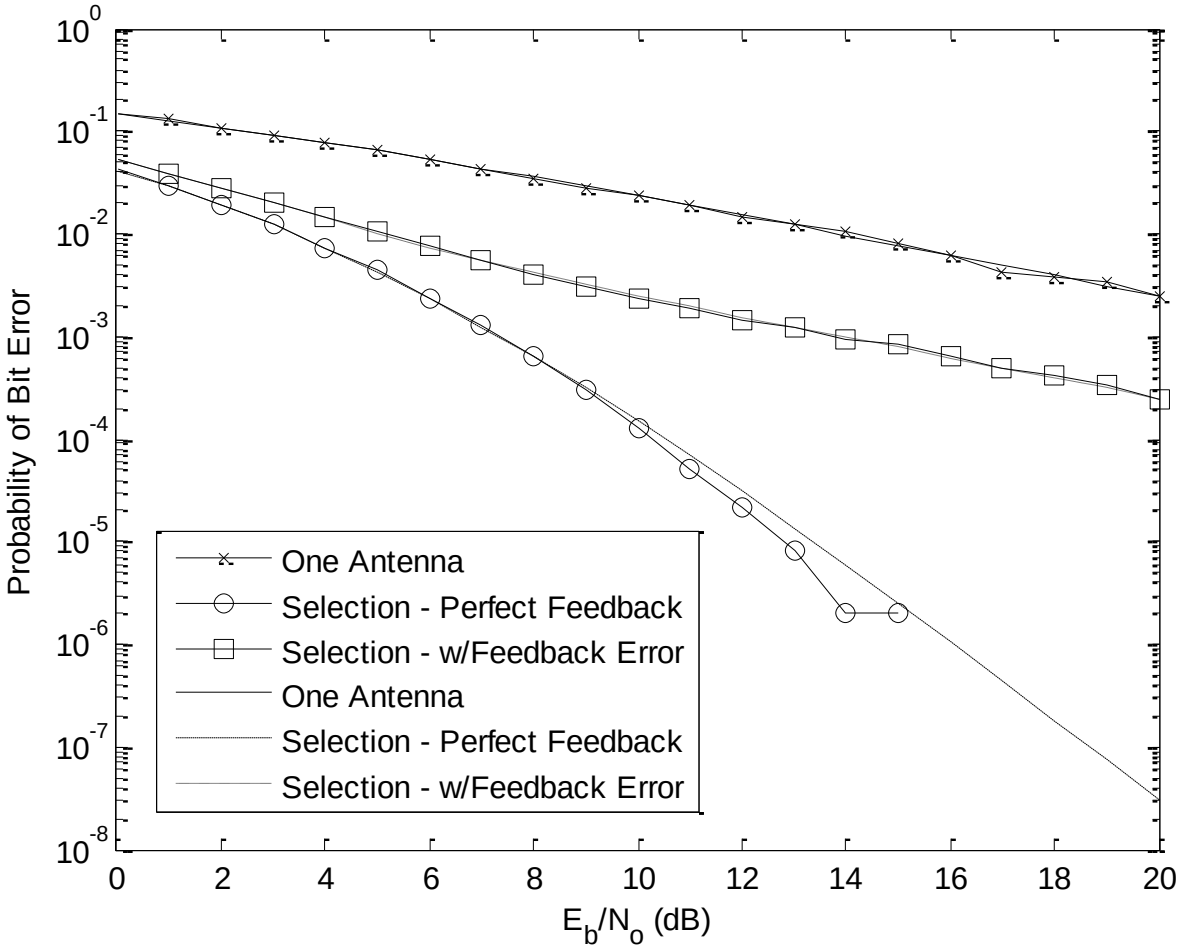
Backup Slide – Antenna Selection



- Simulation vs. Theory
- Feeback error = 10%
- 4 Tx antennas
- Rayleigh fading
- Independent channels