MIMO-OFDM Precoder for Minimizing BER Upper Bound of MLD under Imperfect CSI

MCRG Joint Seminar, June the 12th, 2008

(Previously presented at ICC 2008, Beijing on May the 21st, 2008)

Boonsarn Pitakdumrongkija, Kazuhiko Fukawa, and Hiroshi Suzuki
Suzuki-Fukawa Laboratory

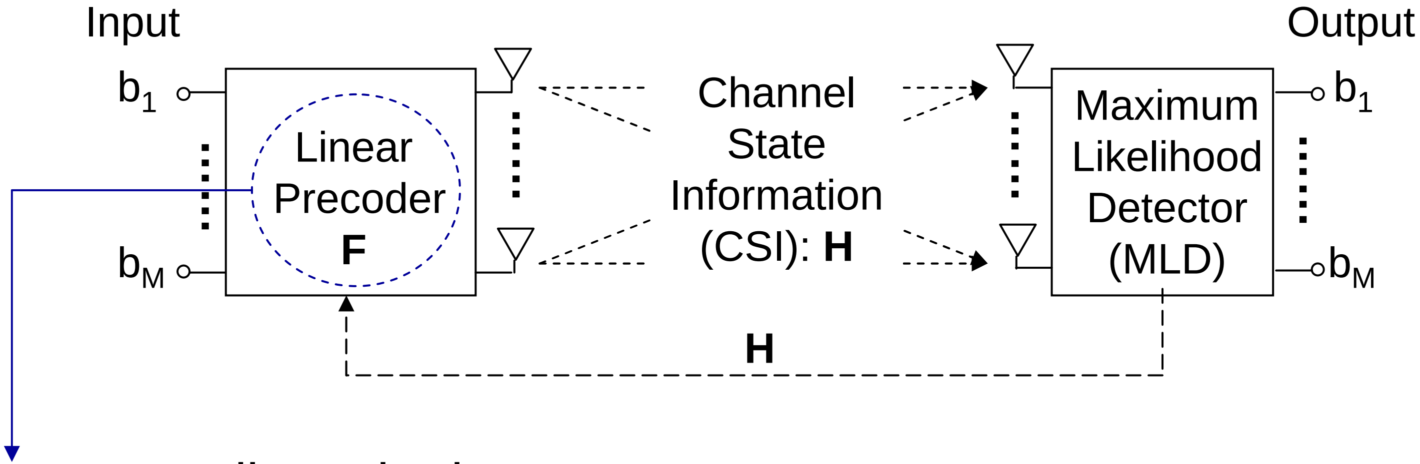
Presentation Outline

- Introduction
  - Research background
- Literature Review
  - Precoder for minimizing BER upper bound under perfect CSI
  - Problem identification under imperfect CSI and research objective
- Proposed Precoding Method under Imperfect CSI
  - Criterion formulation and optimization
  - Computer simulation results
- Conclusions
  - Summary and suggestions for future work

Research Background

- Demands for future mobile communications (High Speed + High Reliability)

- Framework: MIMO-OFDM system with feedback channel

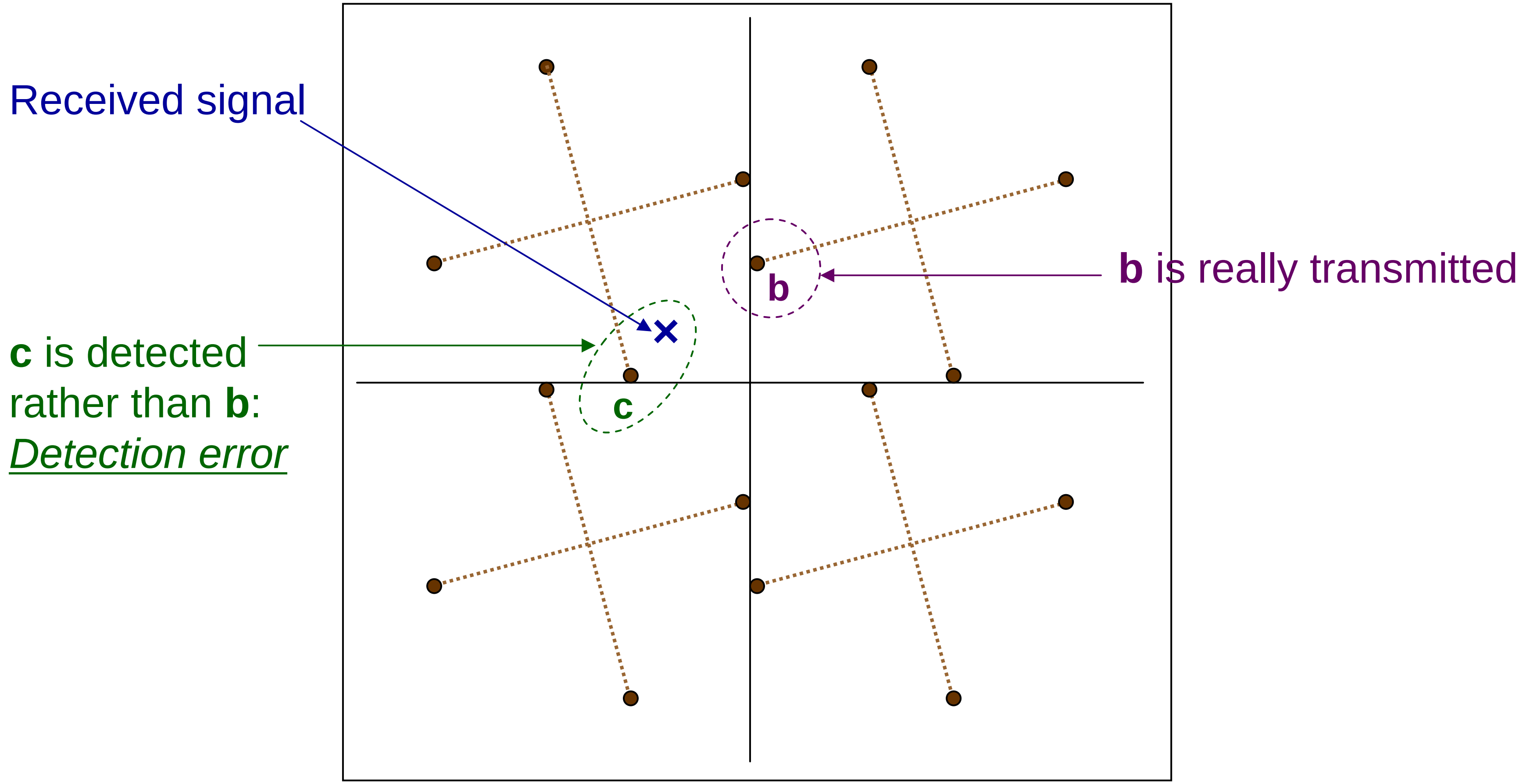


- Linear precoding criteria
  - Maximum Capacity
    - Adaptive Modulation Coding (AMC)
    - Waterfilling-based power allocation
  - Non-Capacity Based
    - Fixed modulation and coding
    - Phase and power optimization:
      - Satisfy QoS
      - Minimize transmit power
      - Minimize bit error rate (MBER)

Increase reliability (BER performance):
Focus of this research

Detection Error and MBER Precoding

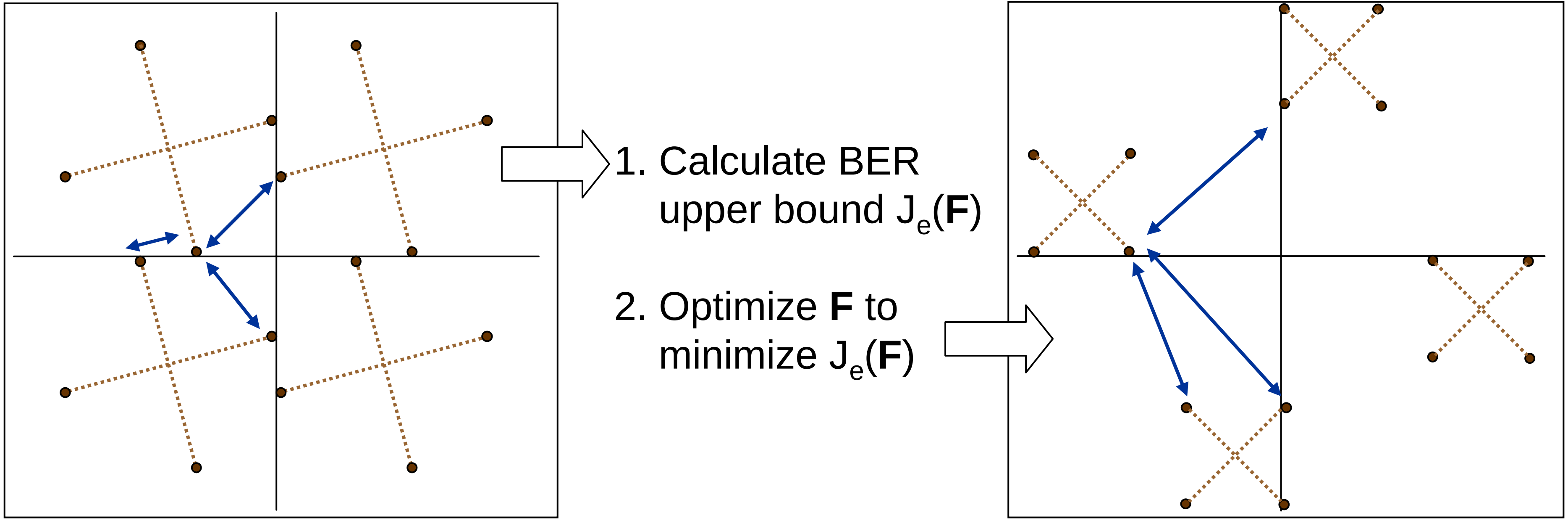
Transmitted signal replica of MIMO
with QPSK and M=2 data streams



- Detection error: Received signal closer to another signal than transmitted one
- MBER precoding: Minimize detection error → Increase reliability

MBER Precoder under Perfect CSI

- Transmitter and receiver: Same CSI
- Procedures at transmitter



No precoder

Transmitted signal replica of MIMO with QPSK and two data streams

1. Calculate BER upper bound $J_e(\mathbf{F})$
2. Optimize **F** to minimize $J_e(\mathbf{F})$

With MBER precoder

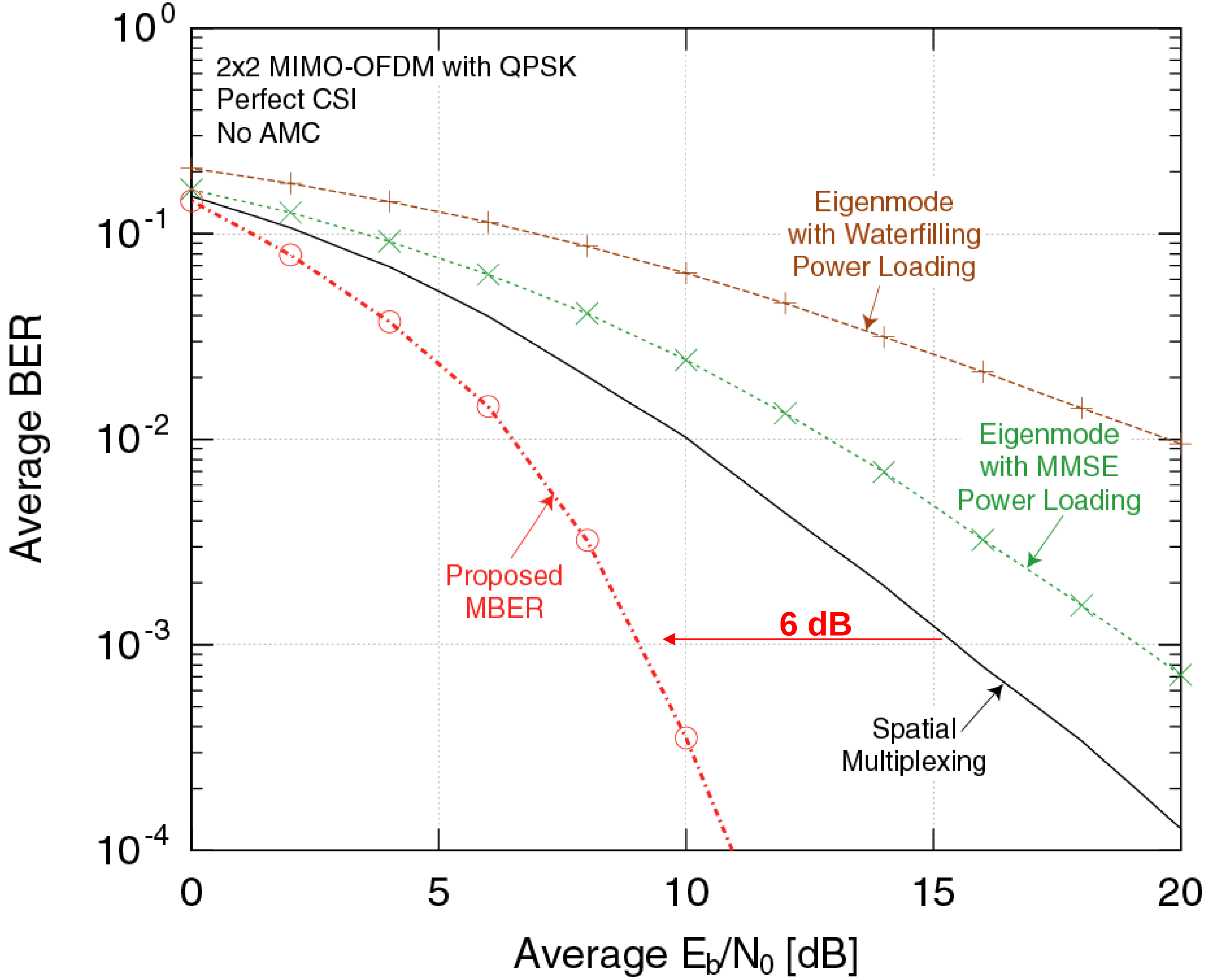
Transmitted signal replica of MIMO with QPSK and two data streams

- Significant BER improvement over spatial multiplexing (nonprecoded) system[1]

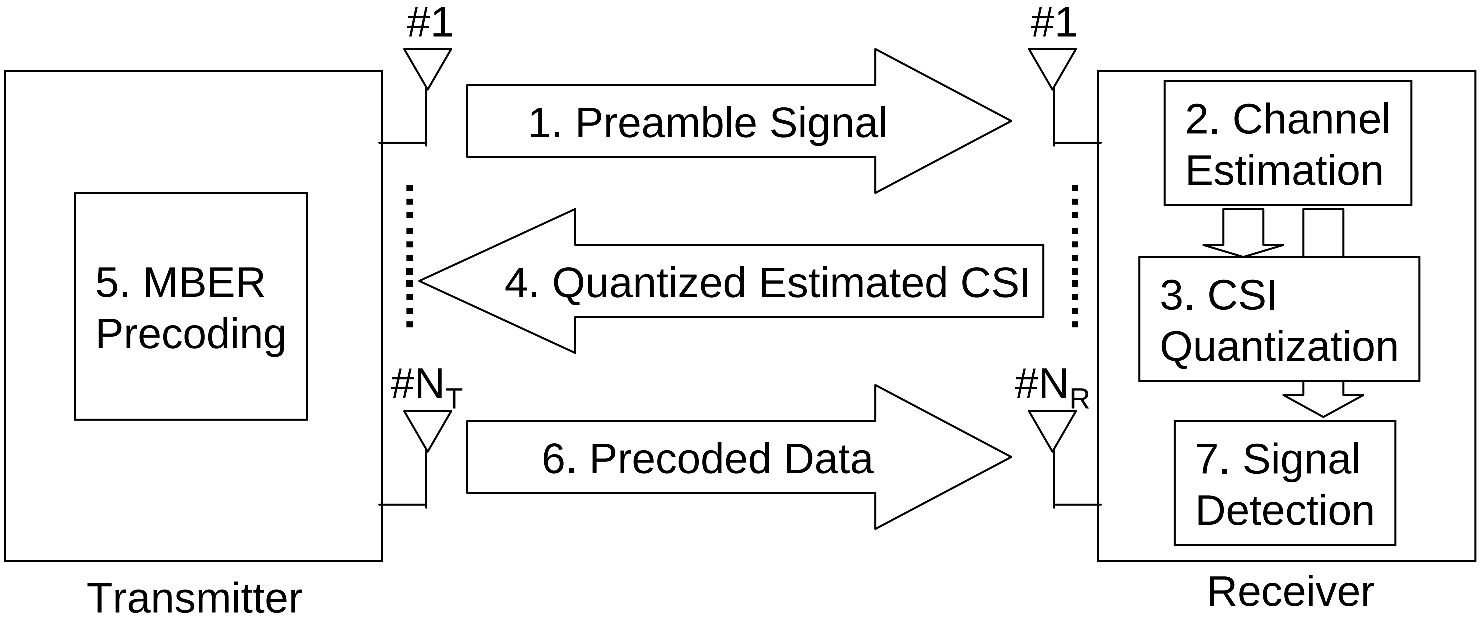
---

[1] B. Pitakdumrongkija, K. Fukawa, H. Suzuki, and T. Hagiwara, “Linear precoding with minimum BER criterion for MIMO-OFDM systems employing ML detection,” IEEE ICC 2007, pp. 2522-2527, June 2007.

Uncoded BER under Perfect CSI



System Model under Imperfect CSI



- CSI model

  - Receiver: Channel Estimation Error

  - Transmitter: Channel Estimation Error + Quantization Error

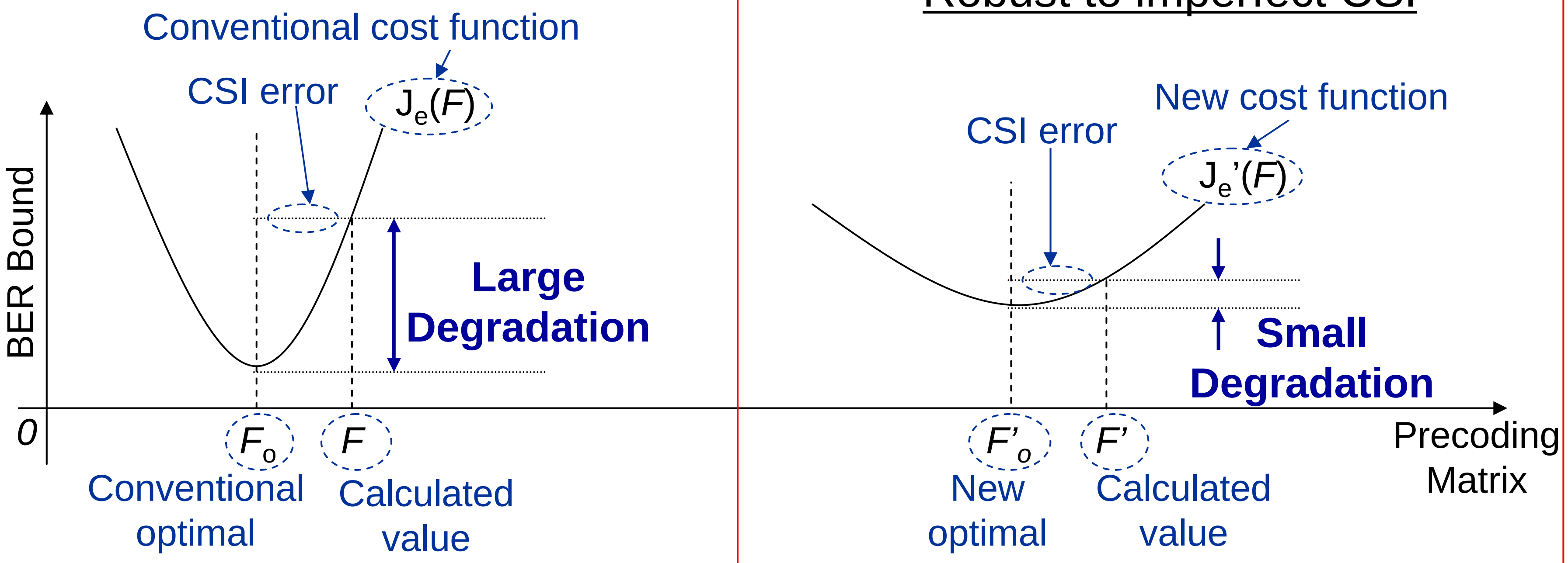
- Transmitter and receiver: Different CSI

Problem and Proposed Solution

- Problem with conventional MBER precoder (designed by assuming perfect CSI)

- Proposed solution

New BER cost function:
Robust to imperfect CSI



CSI error → Large degradation

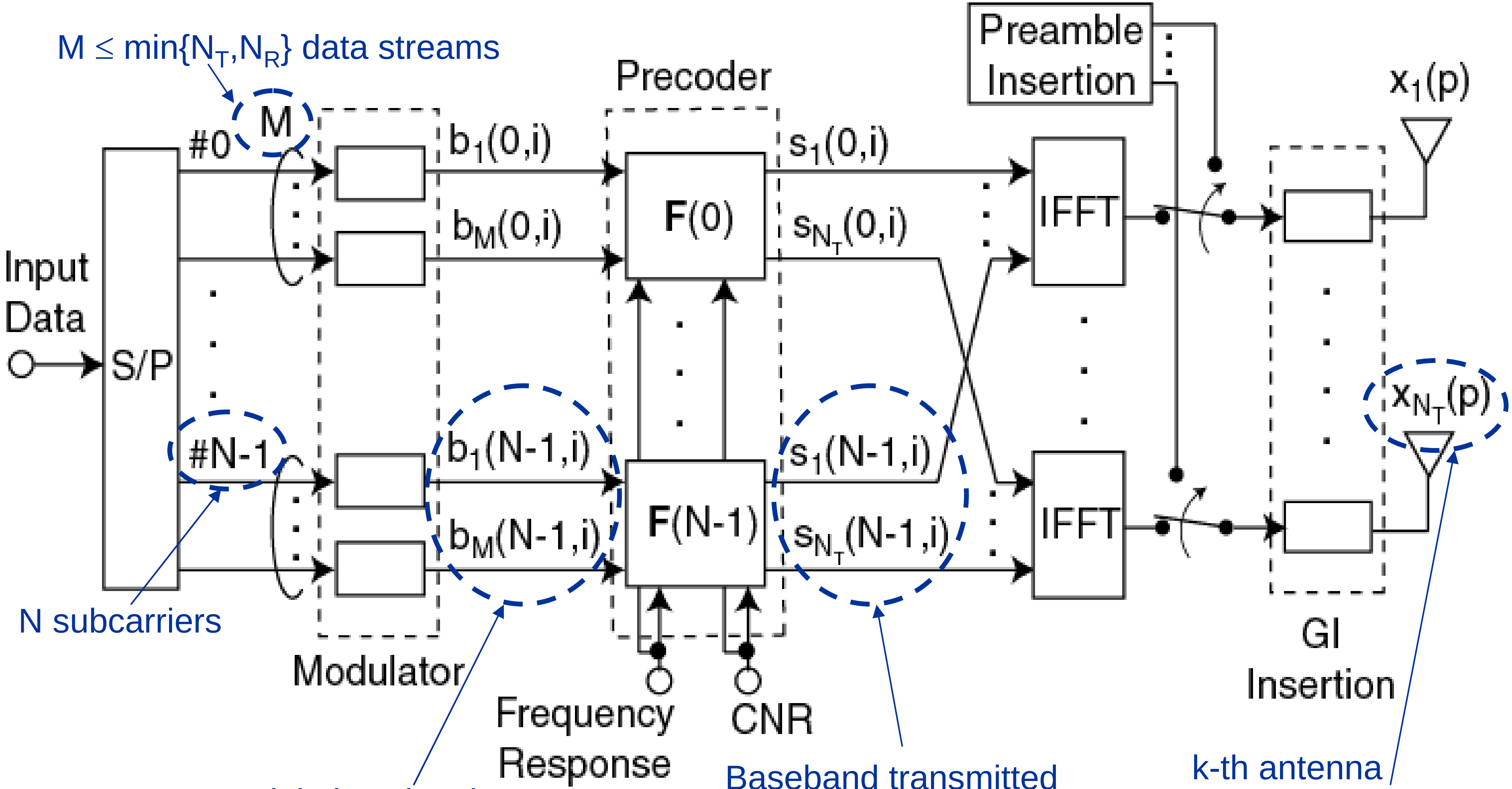
CSI error → Small degradation

Presentation Outline

- Introduction
  - Research background
- Literature Review
  - Precoder for minimizing BER upper bound under perfect CSI
  - Problem identification under imperfect CSI and research objective
- Proposed Precoding Method under Imperfect CSI
  - Criterion formulation and optimization
  - Computer simulation results
- Conclusions
  - Summary and suggestions for future work

MIMO-OFDM Transmitter

- System with N_T transmit and N_R receive antennas



$M \leq \min\{N_T, N_R\}$ data streams

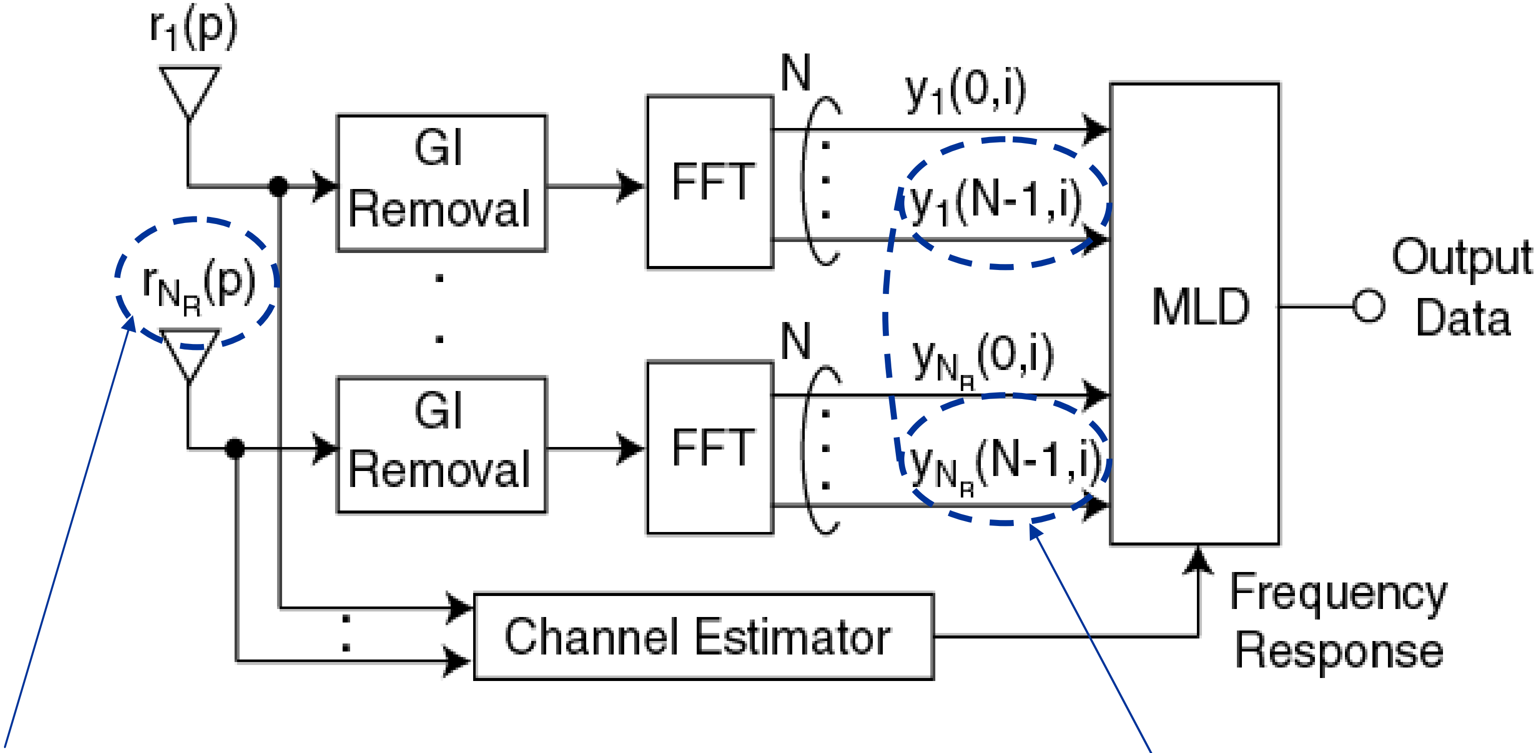
N subcarriers

Modulation signal vector $\mathbf{b}(n,i)$

Baseband transmitted signal vector $\mathbf{s}(n,i) = \mathbf{F}(n)\mathbf{b}(n,i)$

k-th antenna transmitted signal $x_k(p) = \mathrm{IDFT}\{s_k(n,i)\}$

MIMO-OFDM Receiver



l - th antenna received signal :

$$r_l(p) = \sum_{k=1}^{N_T} \sum_{d=0}^{D} \boxed{h_{lk,d}} x_k(p-d) + \boxed{n_l(p)}$$

d-th path impulse response between l-th and k-th antennas

AWGN
zero mean
and variance σ_n^2

Baseband received signal vector :

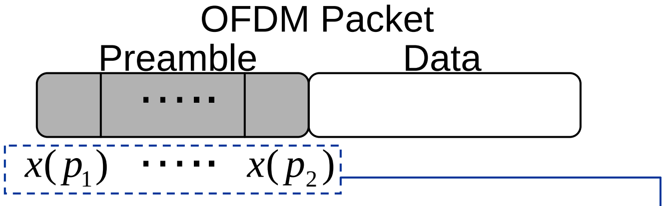
$$\mathbf{y}(n,i) = \boxed{\mathbf{H}(n)} \mathbf{F}(n) \mathbf{b}(n,i) + \boxed{\mathbf{z}(n,i)}$$

N_R-by-N_T channel
frequency response matrix

N_R-by-1 noise vector

CSI Error Model

- CSI at receiver: $\tilde{h}_{lk,d} = h_{lk,d} + \boxed{\psi_{lk,d}}$ ← Estimation error
- CSI at transmitter: $\hat{h}_{lk,d} = h_{lk,d} + \boxed{\psi_{lk,d}} + \boxed{\upsilon_{lk,d}}$ ← Quantization error
- MMSE channel estimation



$$\tilde{\mathbf{h}}_l = \arg\min_{\mathbf{h}_l} \sum_{p=p_1}^{p_2} \lambda^{p_2-p} \, | r_l(p) - \mathbf{h}_l^H x(p) |^2$$

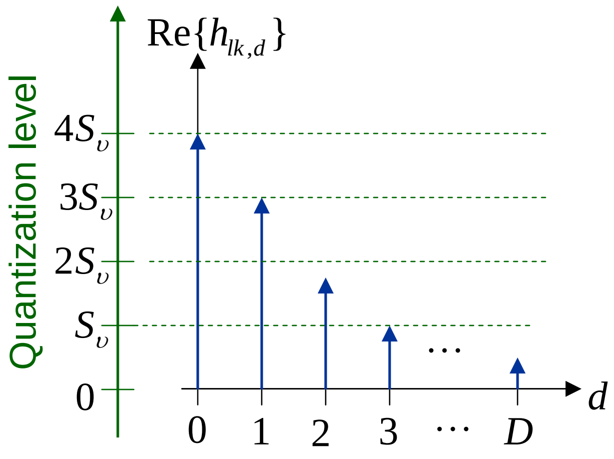
$$= \mathbf{h}_l + \boldsymbol{\psi}_l$$

- Estimation error statistics:

$$\langle \boldsymbol{\psi}_l \rangle = \mathbf{0}$$

$$\langle \boldsymbol{\psi}_l \boldsymbol{\psi}_l^H \rangle \approx \sigma_n^2 \mathbf{I}$$

- Uniform quantization



- Quantization error statistics:

$$\langle \upsilon_{lk,d} \rangle = 0$$

$$\langle \upsilon^*_{l_1 k_1, d_1} \upsilon_{l_2 k_2, d_2} \rangle = \boxed{\sigma_\upsilon^2} \delta_{l_1 l_2} \delta_{k_1 k_2} \delta_{d_1 d_2}$$

$\sigma_\upsilon^2 / 2 = S_\upsilon^2 / 12$

- If $\mathrm{Re}\{h_{lk,d}\} \in [-1,1]$, then

$$\boxed{B} = \log_2(2 / S_\upsilon)$$

No. of quantizing bit per path

Pairwise Error Probability (PEP)

- Detection error condition when σ_υ^2 is small

$$\left(\hat{\mathbf{H}}(n)\right)_{lk} = H_{lk}(n)+\Psi_{lk}(n)+\Upsilon_{lk}(n) \leftrightarrow h_{lk,d}+\psi_{lk,d}+\upsilon_{lk,d}$$

$$\boxed{\underbrace{\left\|\mathbf{y}(n,i)-\hat{\mathbf{H}}(n)\mathbf{F}(n)\mathbf{b}(n,i)\right\|^2}_{B} > \underbrace{\left\|\mathbf{y}(n,i)-\underline{\hat{\mathbf{H}}(n)}\mathbf{F}(n)\mathbf{c}(n,i)\right\|^2}_{C}} \longrightarrow \varepsilon = B - C$$

- **PEP averaged with respect to CSI errors**

$$P(\tilde{b} \to \tilde{c} \mid \hat{H}) = \int_0^\infty \boxed{p(\varepsilon)}\,\mathrm{d}\varepsilon = \frac{1}{2}\operatorname{erfc}\sqrt{\underline{\gamma(\tilde{b} \to \tilde{c})}}$$

Joint p.d.f. between AWGN and CSI errors

$$\gamma(\tilde{b} \to \tilde{c}) = \left\|\hat{\mathbf{H}}(n)\mathbf{F}(n)[\mathbf{b}(n,i)-\mathbf{c}(n,i)]\right\|^2 / \underline{4\sigma_e^2(\mathbf{F}(n))}$$

Error variance: $\sigma_e^2(\mathbf{F}(n)) = \boxed{N^{-1}\sigma_n^2} + \boxed{[\mathbf{F}(n)\mathbf{b}(n,i)]^H \underline{\mathbf{\Delta}(n)}[\mathbf{F}(n)\mathbf{b}(n,i)]}$

Conventional

Proposed additional term

CSI errors: $\mathbf{\Delta}(n) = \underbrace{\left\langle \boldsymbol{\Psi}^H(n)\boldsymbol{\Psi}(n)\right\rangle}_{\text{Estimation error}} + \underbrace{\left\langle \boldsymbol{\Upsilon}^H(n)\boldsymbol{\Upsilon}(n)\right\rangle}_{\text{Quantization error}}$

BER Upper Bound Minimization

- BER upper bound cost function

$$J_e(\mathbf{F}(n)) = \boxed{\sum_{\tilde{b}} \sum_{\tilde{b} \neq \tilde{c}}} \boxed{N_e(\tilde{b} \to \tilde{c})} P(\tilde{b} \to \tilde{c} \mid \hat{H})$$

All pairs of **b**(n,i) and **c**(n,i)

No. of error bit when **c**(n,i) rather than **b**(n,i) is detected

- Solution for optimal precoding matrix

$$\mathbf{F}_o(n) = \boxed{\arg\min_{\tilde{\mathbf{F}}(n)} J_e(\tilde{\mathbf{F}}(n))} \longrightarrow$$

Mathematically Untraceable

- Optimization by the steepest descent algorithm

$$\mathbf{F}^{\boxed{(q)}}(n) = \mathbf{F}^{(q-1)}(n) - \boxed{\mu} \boxed{\frac{\partial J_e(\mathbf{F}(n))}{\partial \mathbf{F}^*(n)}} \Bigg|_{\mathbf{F}^{(q-1)}(n)}$$

Iteration index

Real positive constant

Gradient of J_e(**F**(n))

subjected to

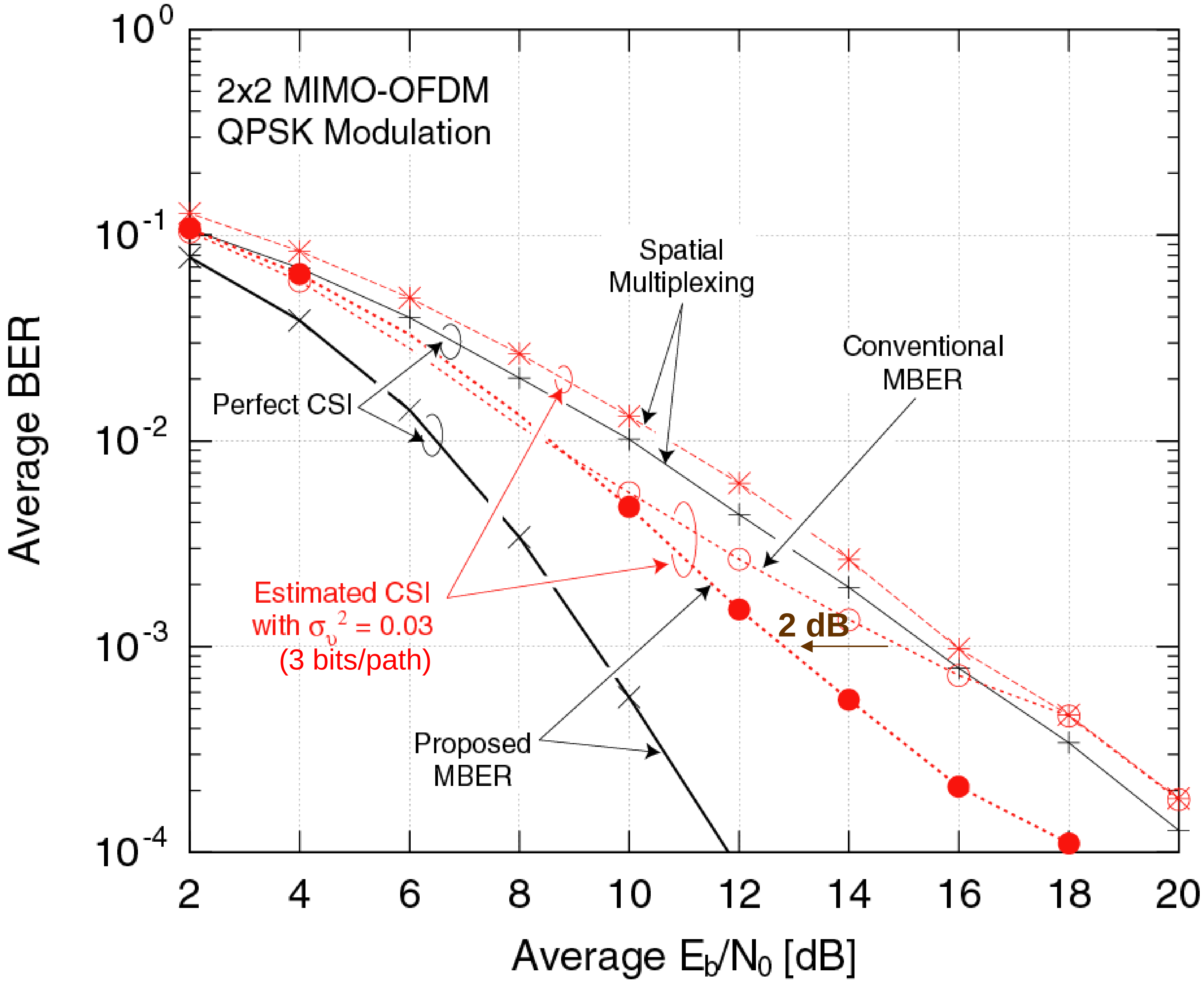
$$\sum_{n=0}^{N-1} \left\langle \left\| \mathbf{F}(n)\mathbf{b}(n,i) \right\|^2 \right\rangle = \sum_{n=0}^{N-1} \mathrm{tr}\left\{ \mathbf{F}(n)\mathbf{F}^H(n) \right\} = \boxed{P_0}$$

Total average transmit power

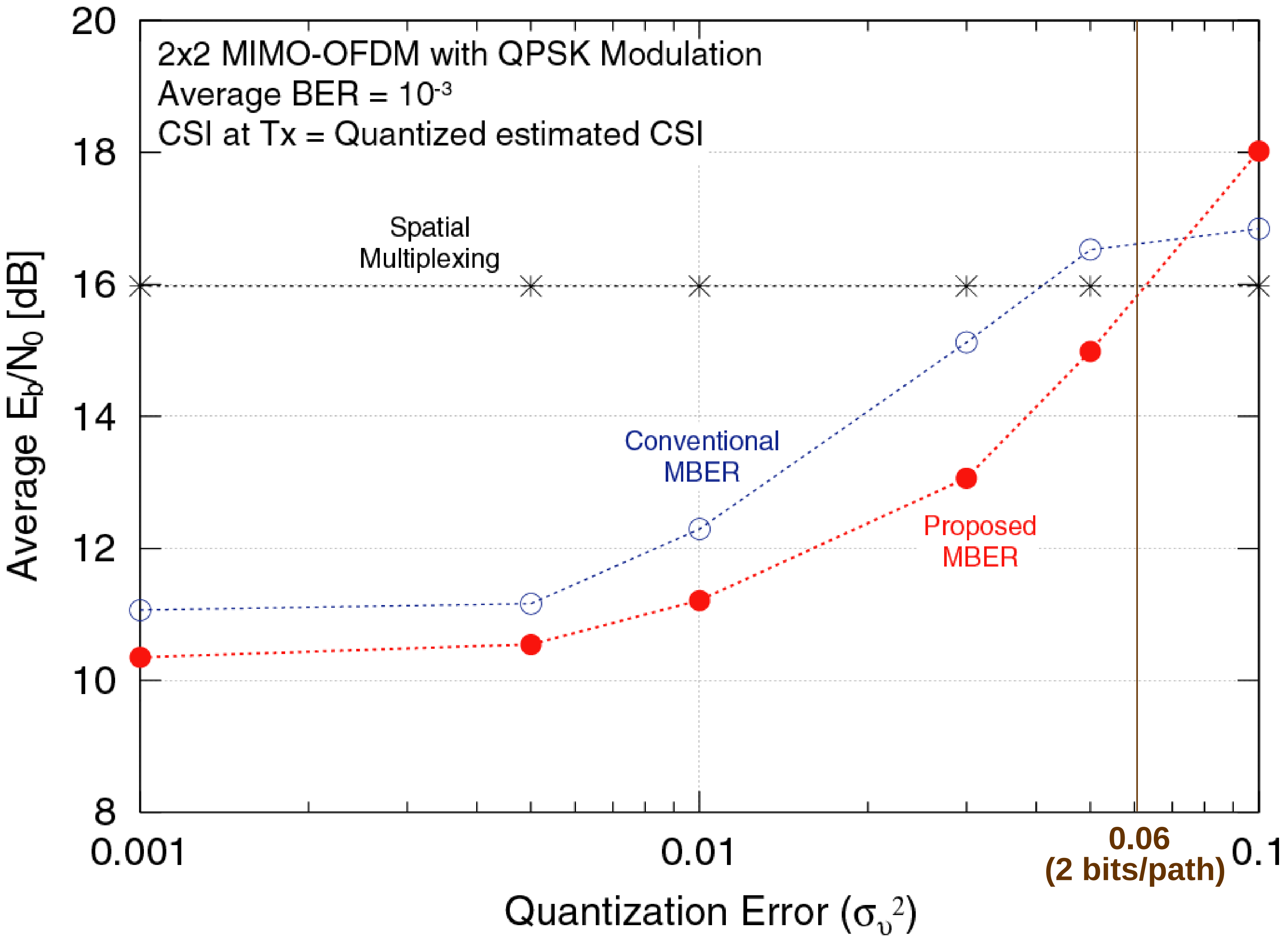
Simulation Conditions

Modulation	QPSK
Tx, Rx antenna (N_T x N_R)	2 x 2
Data stream M	2
OFDM packet format	IEEE802.11a (Preamble: 2 symbols, Data: 10 symbols)
Total subcarrier	64
Effective subcarrier	52 (Pilot:4, Data:48)
GI length	16 points
Channel model	17 path exponential decay Rayleigh fading
Maximum Doppler freq.	0 Hz
CSI at Rx	MMSE channel estimation (λ=1.0)
CSI at Tx	CSI from Rx + Quantization error (σ_{υ}^{2}=0.001-0.1)
Signal detection	MLD

Average BER Performance



Robustness to Quantization Error



Conclusions and Future Works

Conclusions: Proposed MBER precoding technique under imperfect CSI

- Consider channel estimation and quantization errors as CSI imperfection
- Average PEP with respect to CSI errors
- Employ steepest descent algorithm for optimization
- Improve BER robustness to imperfect CSI

Future Works:

- Improvement of optimization and reduction of CSI amount
- Precoding technique for time-varying channel