Channel Estimation, Diversity and Preamble Requirements for Broadband Wireless Using OFDM

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Channel Estimation, Diversity and Preamble Requirements for Broadband Wireless Using OFDM

Lek Ariyavisitakul

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September 11, 2001

Outline

- Optimum Channel Estimation
- Time Synchronization
  - Preamble correlation vs. cyclic prefix correlation
- Cyclic prefix issue
- Alamouti and related MIMO techniques

Optimum Channel Estimation

Frequency Domain

Minimizing MSE = $\left\langle \left| R_\ell - \hat{H}_\ell X_\ell \right|^2 \right\rangle$

$\langle \cdot \rangle$: average over training blocks

$$\hat{H}_\ell = \frac{\langle R_\ell X_\ell^* \rangle}{\langle |X_\ell|^2 \rangle} = \left\langle \frac{R_\ell}{X_\ell} \right\rangle$$

$|X_\ell|^2$: constant

Optimum Channel Estimation

Mixed Domain (Li, Seshadri, Ariyavisitakul, IEEE JSAC, Mar. 1999)

Minimizing MSE :

$$\left\langle \sum_{n=0}^{M-1} \left| r_n - \sum_k \hat{h}_k x_{n-k} \right|^2 \right\rangle = \left\langle \frac{1}{M} \sum_{\ell=0}^{M-1} \left| R_\ell - \left(\sum_{n=0}^{K} \hat{h}_n e^{-\frac{j2\pi n\ell}{M}} \right) X_\ell \right|^2 \right\rangle$$

$\langle \cdot \rangle$: average over training blocks

$$\hat{H}_\ell = \mathrm{FFT}\left(\hat{h}_k\right)$$

$$\begin{pmatrix} \hat{h}_0 \\ \vdots \\ \hat{h}_K \end{pmatrix} = \left\langle \left| X_\ell \right|^2 \right\rangle \mathbf{R}^{-1} \begin{pmatrix} \tilde{h}_0 \\ \vdots \\ \tilde{h}_K \end{pmatrix}$$

$\tilde{h}_k : \mathrm{IFFT}\left(\left\langle R_\ell / X_\ell \right\rangle \right)$

$$\mathbf{R} = \begin{pmatrix} \rho_0 & \rho_{-1} & & \rho_{-K} \\ \rho_1 & \rho_0 & \ddots & \\ & \ddots & \ddots & \\ \rho_K & & & \rho_0 \end{pmatrix}$$

(Toeplitz, Hermitian)

$$\rho_n = \left\langle \sum_{m=0}^{M-1} x_m x^*_{m-n} \right\rangle = \left\langle \frac{1}{M} \left| X_\ell \right|^2 \sum_{\ell=a}^{M-1-a} e^{\frac{j2\pi n\ell}{M}} \right\rangle$$

a : number of guard tones

assuming $\left| X_\ell \right|^2$: constant

Optimum Channel Estimation

Mixed Domain (continued)

if $a = 0$, then $\mathbf{R} = I\left\langle \left|X_\ell\right|^2 \right\rangle \Rightarrow \begin{pmatrix} \hat{h}_0 \\ \vdots \\ \hat{h}_K \end{pmatrix} = \mathrm{IFFT}\left(\left\langle R_\ell / X_\ell \right\rangle\right)$

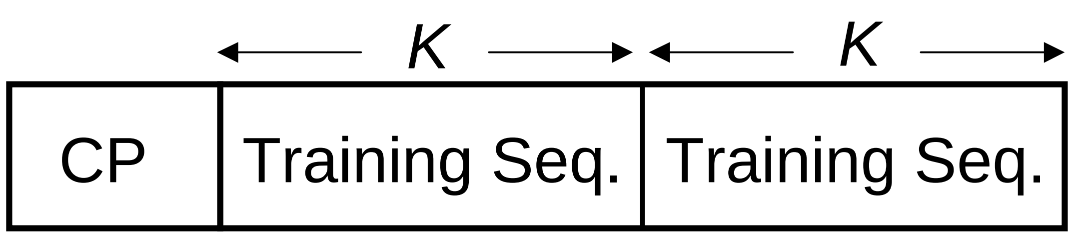
if $a \neq 0$, $\mathbf{R}^{-1}$ needs to be pre-computed for optimum performance

Frequency-Domain Interpolation and Averaging

$\Rightarrow$ *Time-Domain Truncation and Decimation*

Desirable Preamble for Channel Estimation

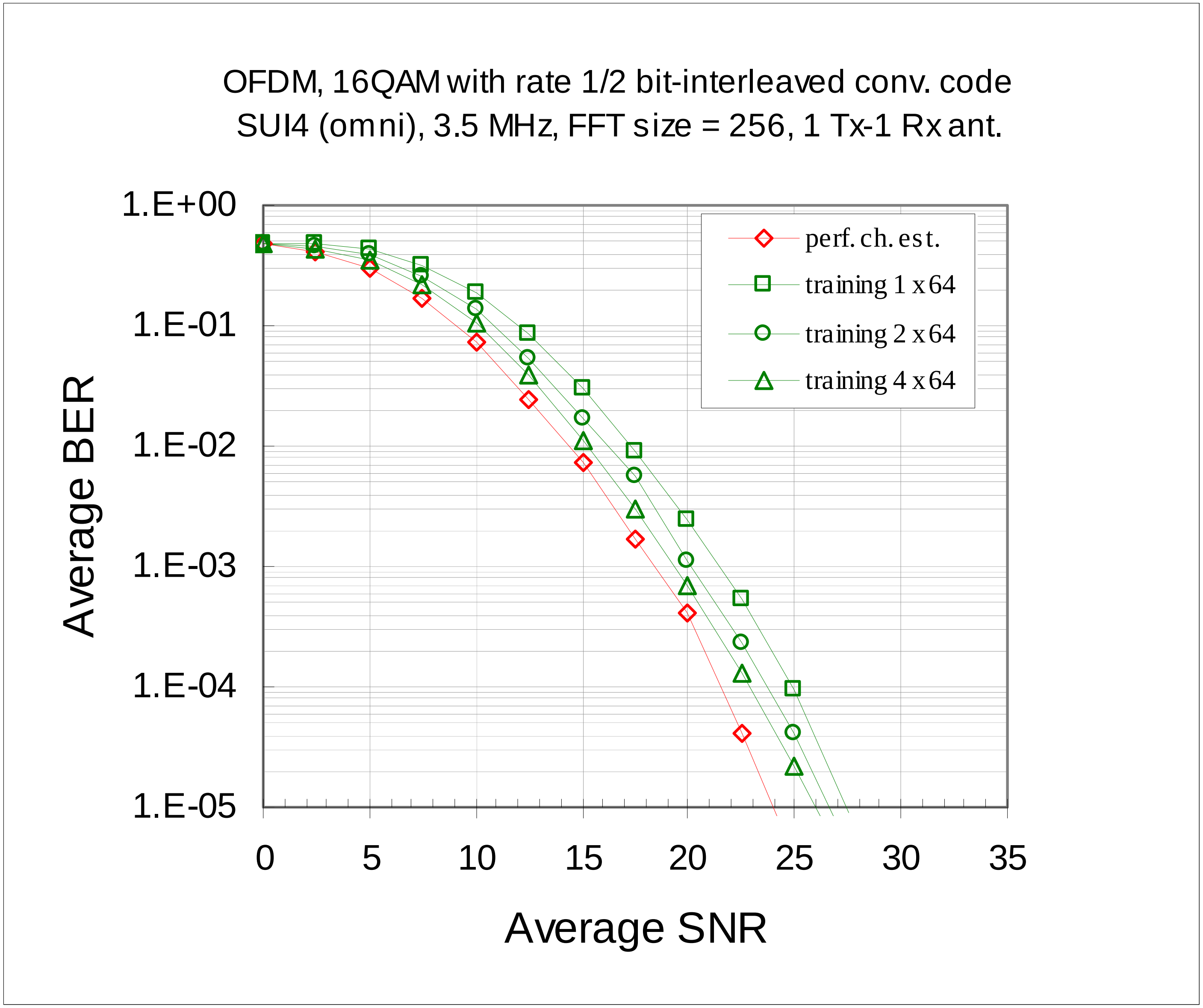
- Has a flat spectrum and low PAR
- Includes multiple sub-blocks, each with length no more than K = maximum channel dispersion



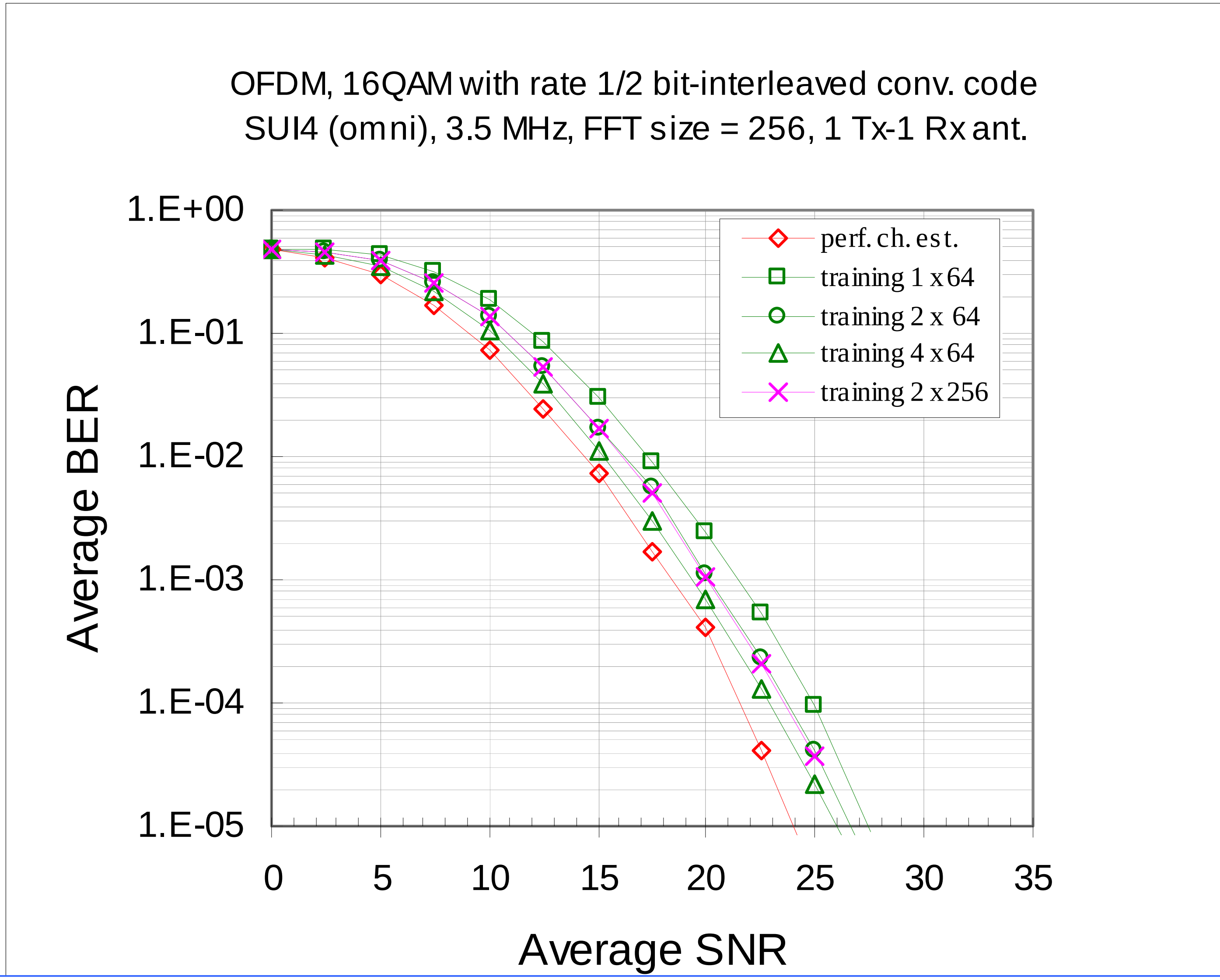
Simulation Assumptions

- Monte-Carlo simulation with 20,000 channel samples
- 256-FFT (only middle 200 tones used), 3.5 MHz OFDM (cf. 802.16.23)
  Sampling frequency = 4.0832 MHz
- Channel models: SUI4 and SUI6 with omni antennas (latest versions)
  Block fading is assumed
- Modulation: 16QAM
- Coding: BICM using rate 1/2 conv. codes with k=7 and Gray mapping
  Each FFT block contains 192 QAM symbols
- Interleaver: as specified in the standard draft—PRBS bit interleaving within each block of 96 QAM symbols, followed by symbol interleaving using a row-column interleaver, each row consisting of 96 QAM symbols
- Cyclic prefix length: 64 (128) samples (maximum specified for 256 FFT)
- Preamble consists of multiple repeated training sequences generated by 256-FFT with nulled tones
  Nonzero tones have constant amplitude and pseudo-random phases
- Time synchronization based on preamble correlation
- Performance measure: ABER
  10^{-3} ABER ≈ 1% ABLER $\quad$ 10^{-4} ABER ≈ 0.1% ABLER
  (1 block in ABLER = 192 QAM symbols)

Performance with Different Numbers of Training Seq.



Increasing Training Sequence Length



Increasing training seq. length gives same performance as interpolation

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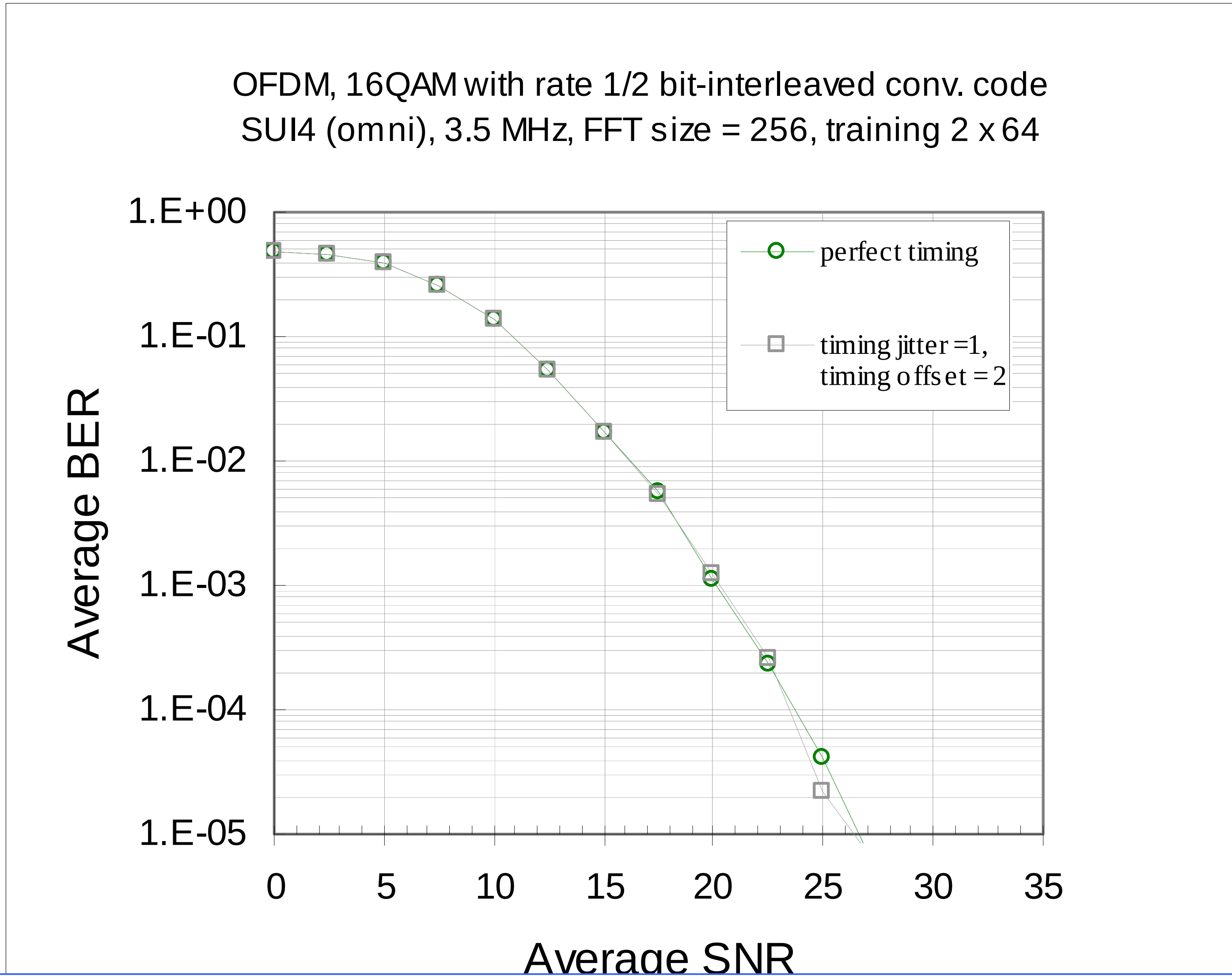
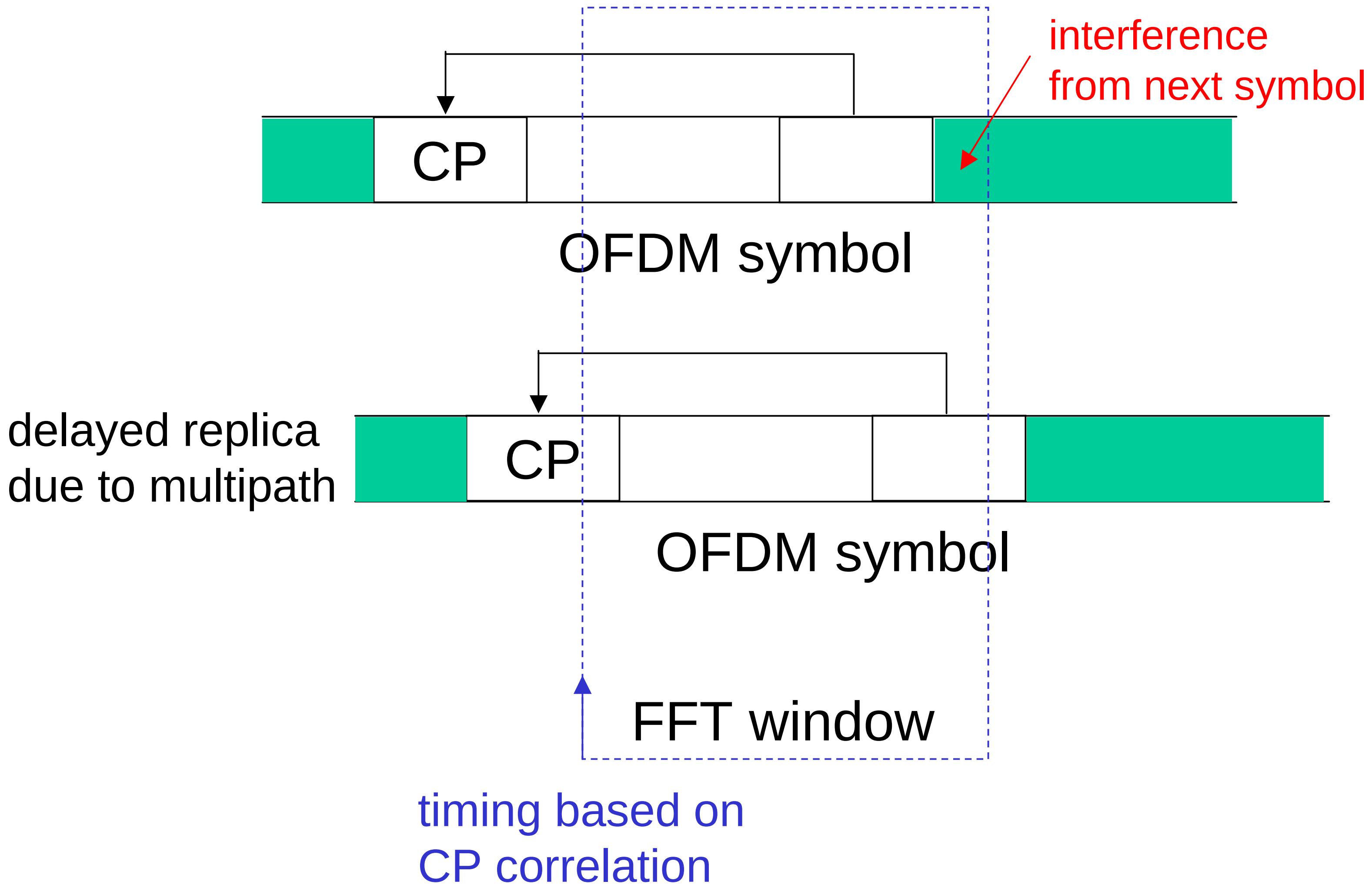
Effect of Imperfect Time Synchronization

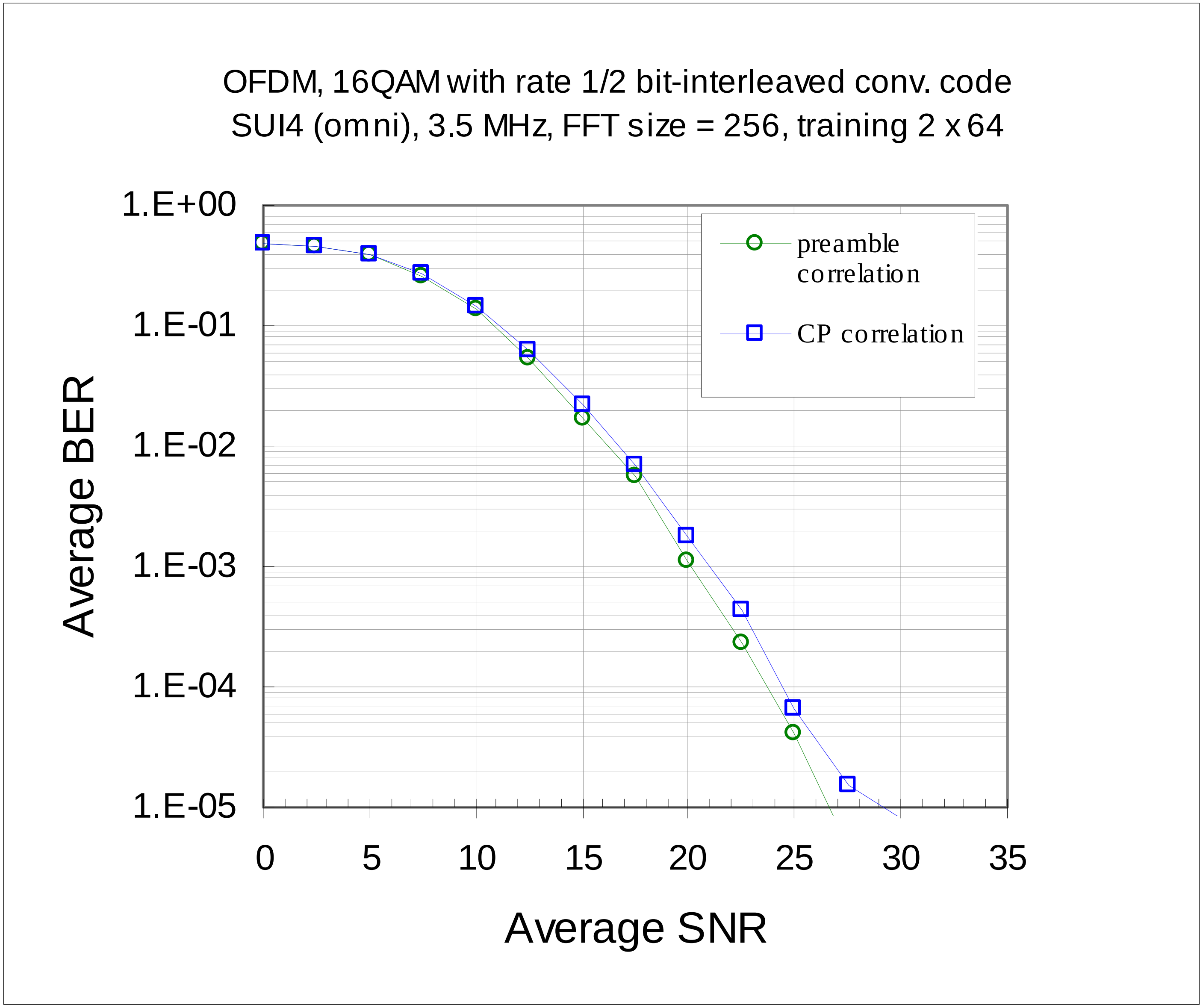


OFDM is insensitive to small timing offset/jitter, however...

Timing Based on Cyclic Prefix Correlation

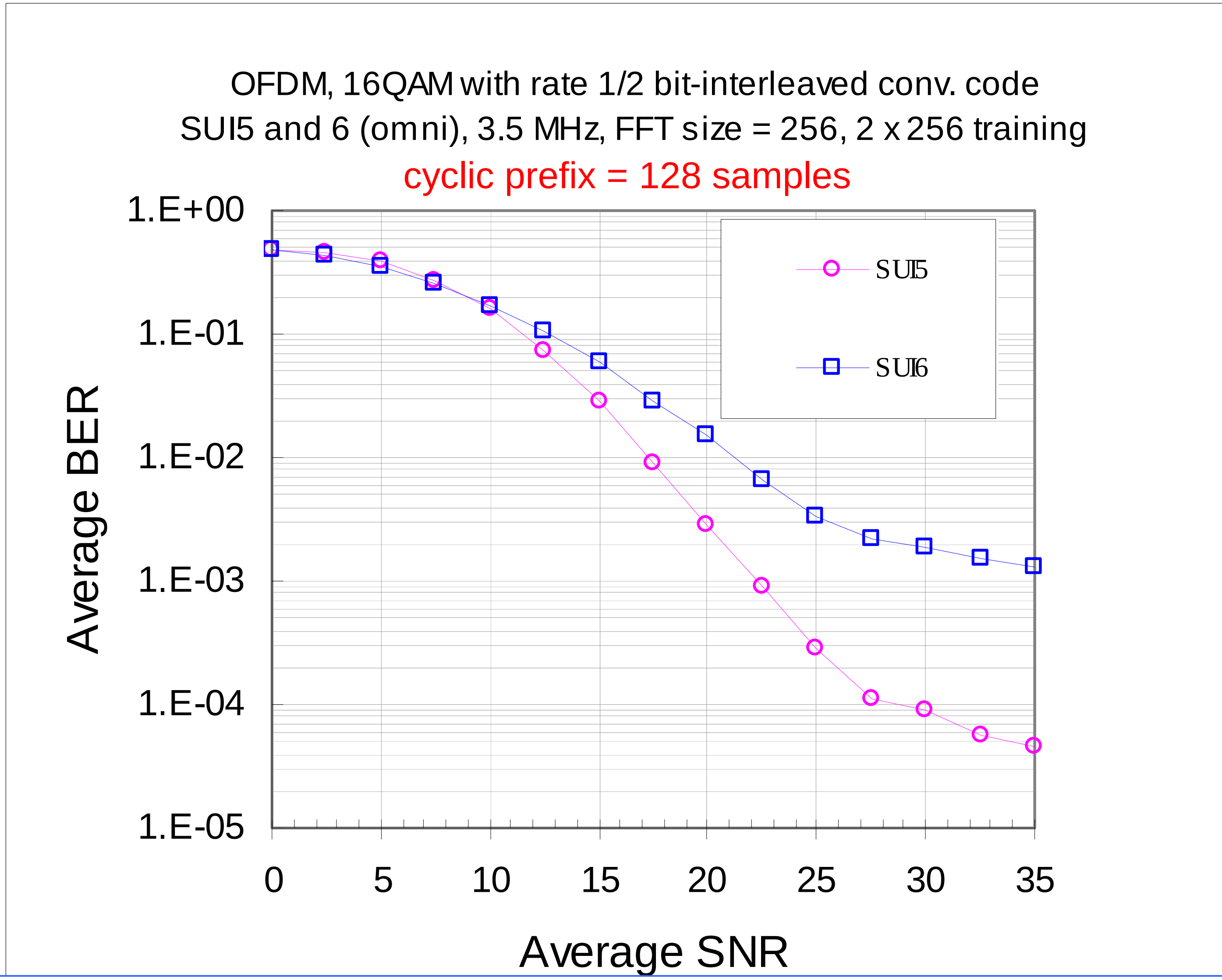


Performance of Cyclic Prefix Correlation over SUI4



Performance of Cyclic Prefix Correlation over SUI5&6

Maximum delay spread K = 41 for SUI5, and K = 82 for SUI6



Cyclic prefix correlation is inadequate for highly dispersive channels

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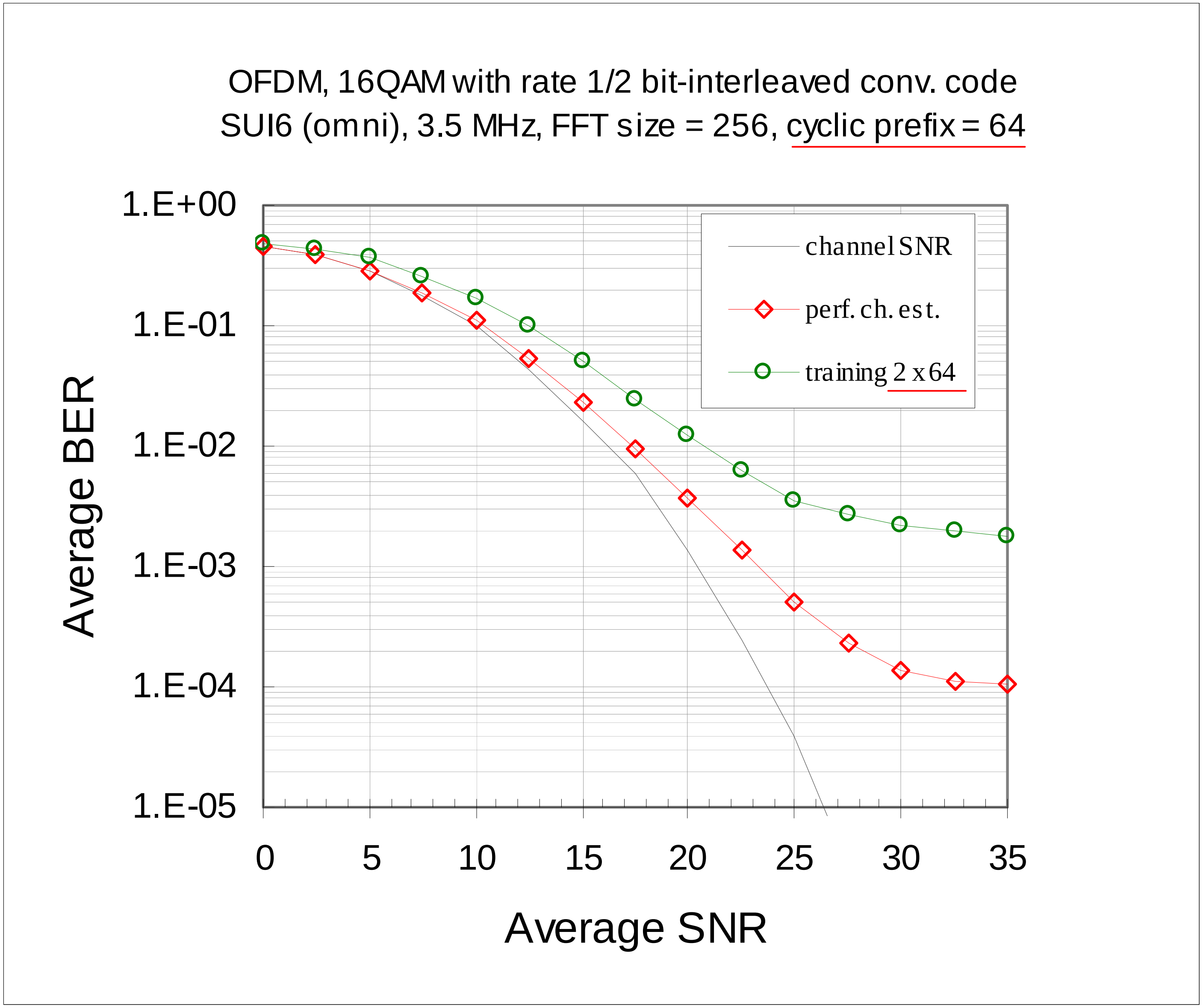
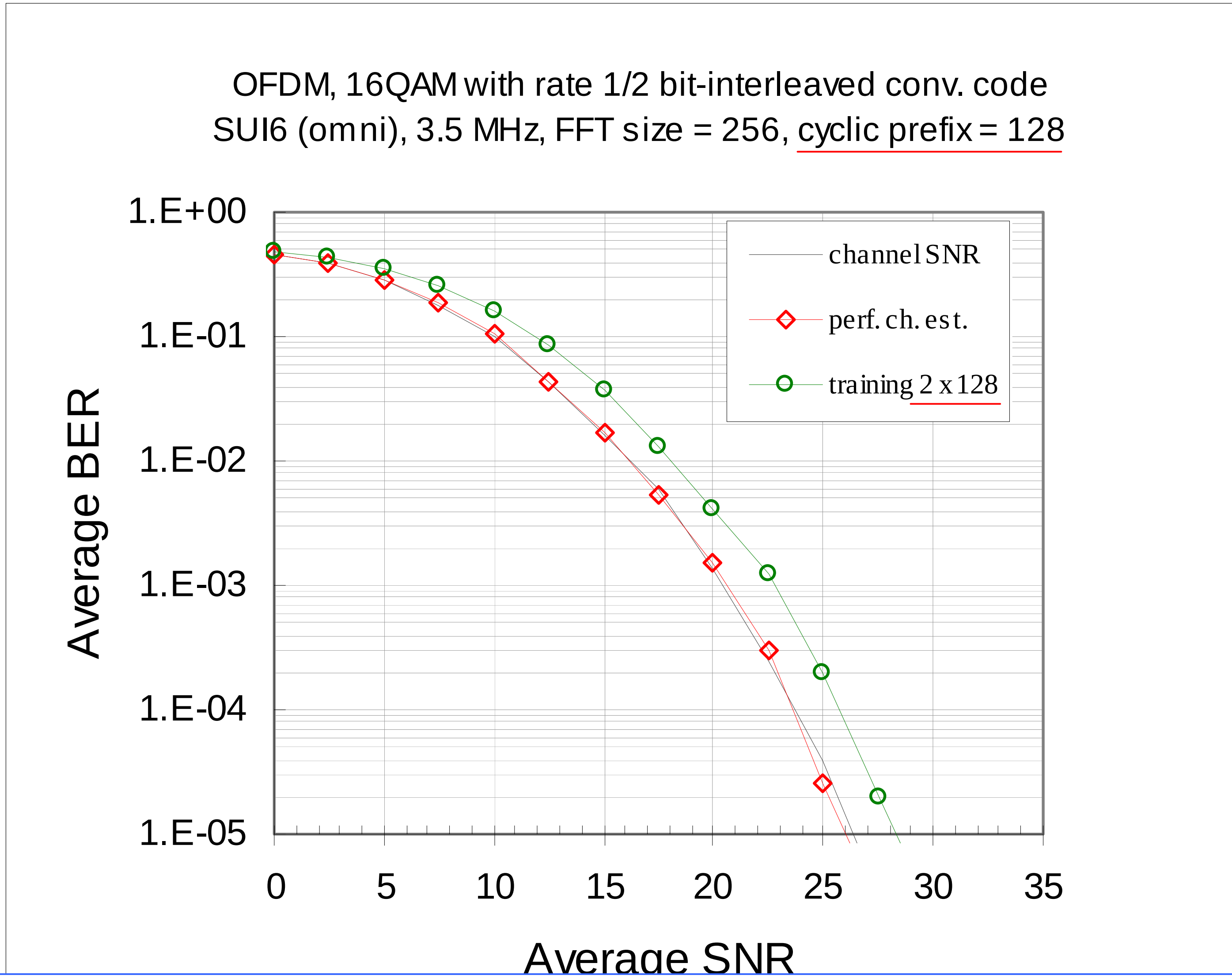
Effect of Insufficient Cyclic Prefix Length

"Channel SNR-based" means perfect channel knowledge and no FFT boundary effects taken into account



Effect of Insufficient Cyclic Prefix Length



Cyclic prefix length MUST BE greater than maximum delay spread

Current Specifications of Maximum Cyclic Prefix Length

256-FFT

ETSI 1.75 MHz	31.35 μs	PCS 2.5 MHz	10.97 μs
ETSI 3.5 MHz	15.67 μs	PCS 5 MHz	5.49 μs
ETSI 7 MHz	7.84 μs	PCS 10 MHz	3.66 μs
ETSI 14 MHz	3.92 μs	UNII 15 MHz	5.6 μs
ETSI 20 MHz	1.96 μs	UNII 10 MHz	5.6 μs
PCS 2.5 MHz	21.94 μs	UNII 20 MHz	2.8 μs

Highlighted: < 20 μs

Need to *either* correct the specs *or* classify operating environment (e.g., antenna heights) and corresponding channel model subset for each system

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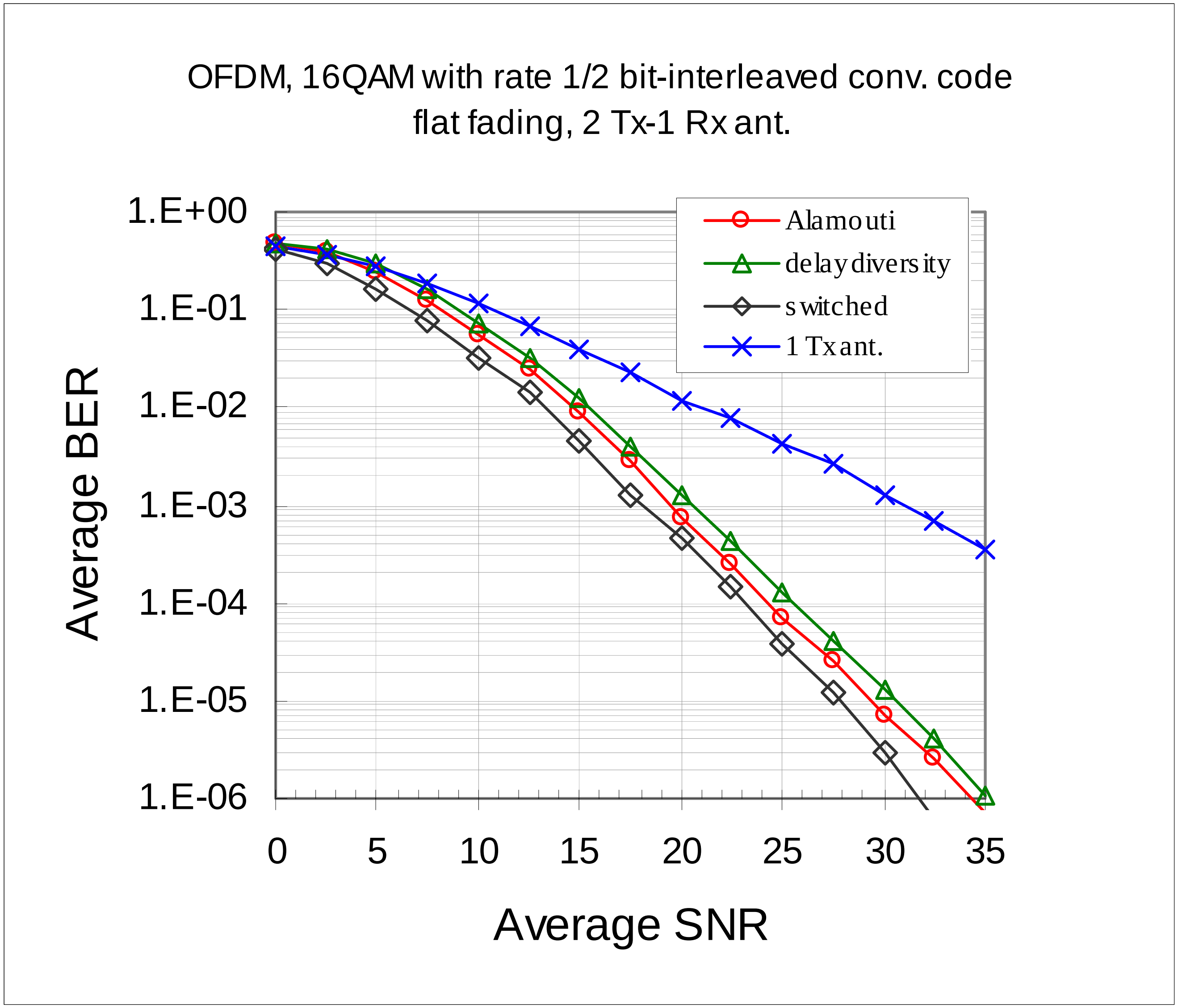
Preview

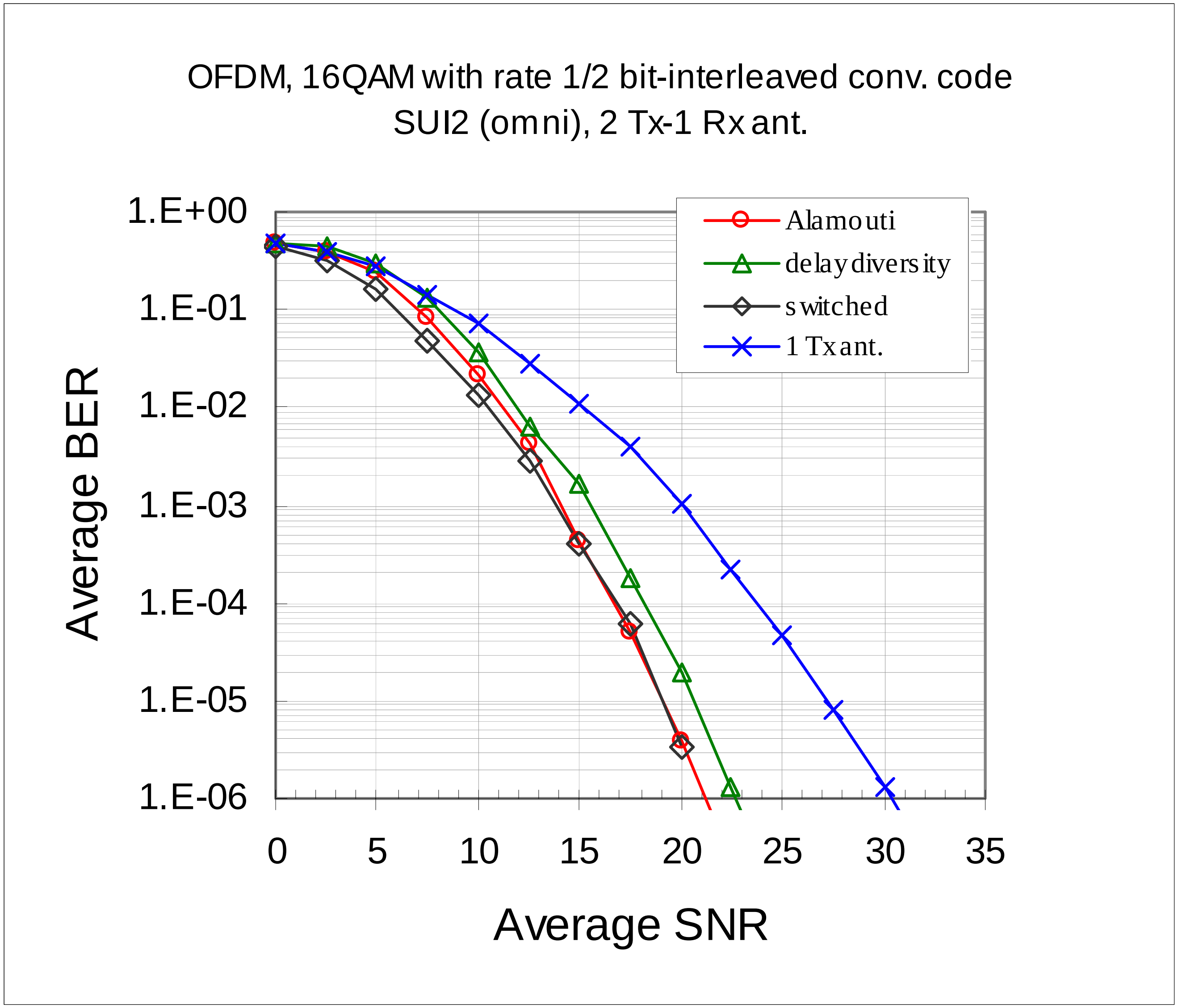
- Alamouti + BICM is an “overall” good transmit diversity and MIMO technique for
  - 2 and 4 (combined with delay diversity) Tx antennas
  - 1 and 2 Rx antennas
  - Up to 4 bps/Hz throughput rate

Comparison of Different Tx Diversity Techniques

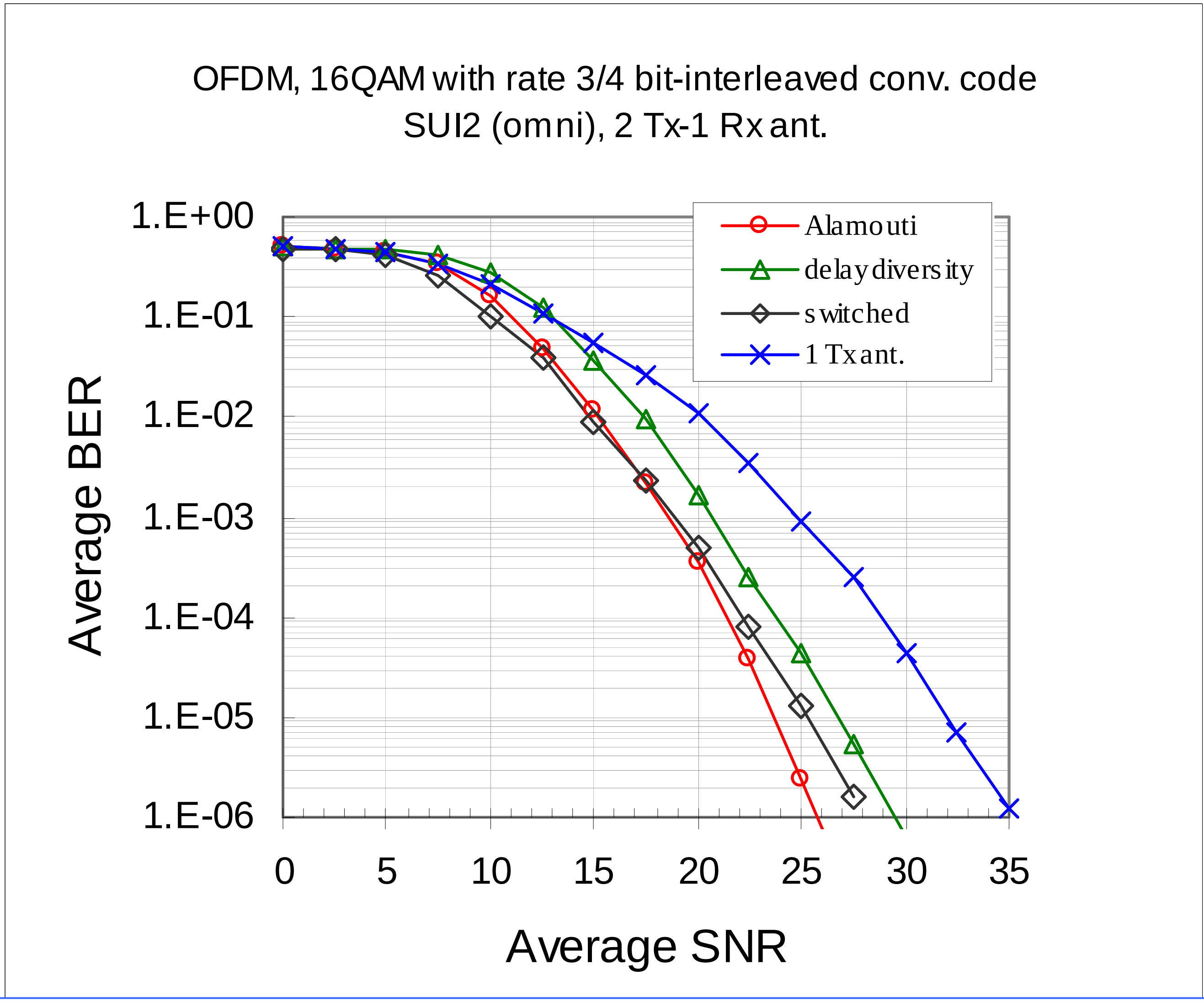
5 MHz, 512-FFT, channel SNR-based for this and the next 5 slides



Comparison of Different Tx Diversity Techniques

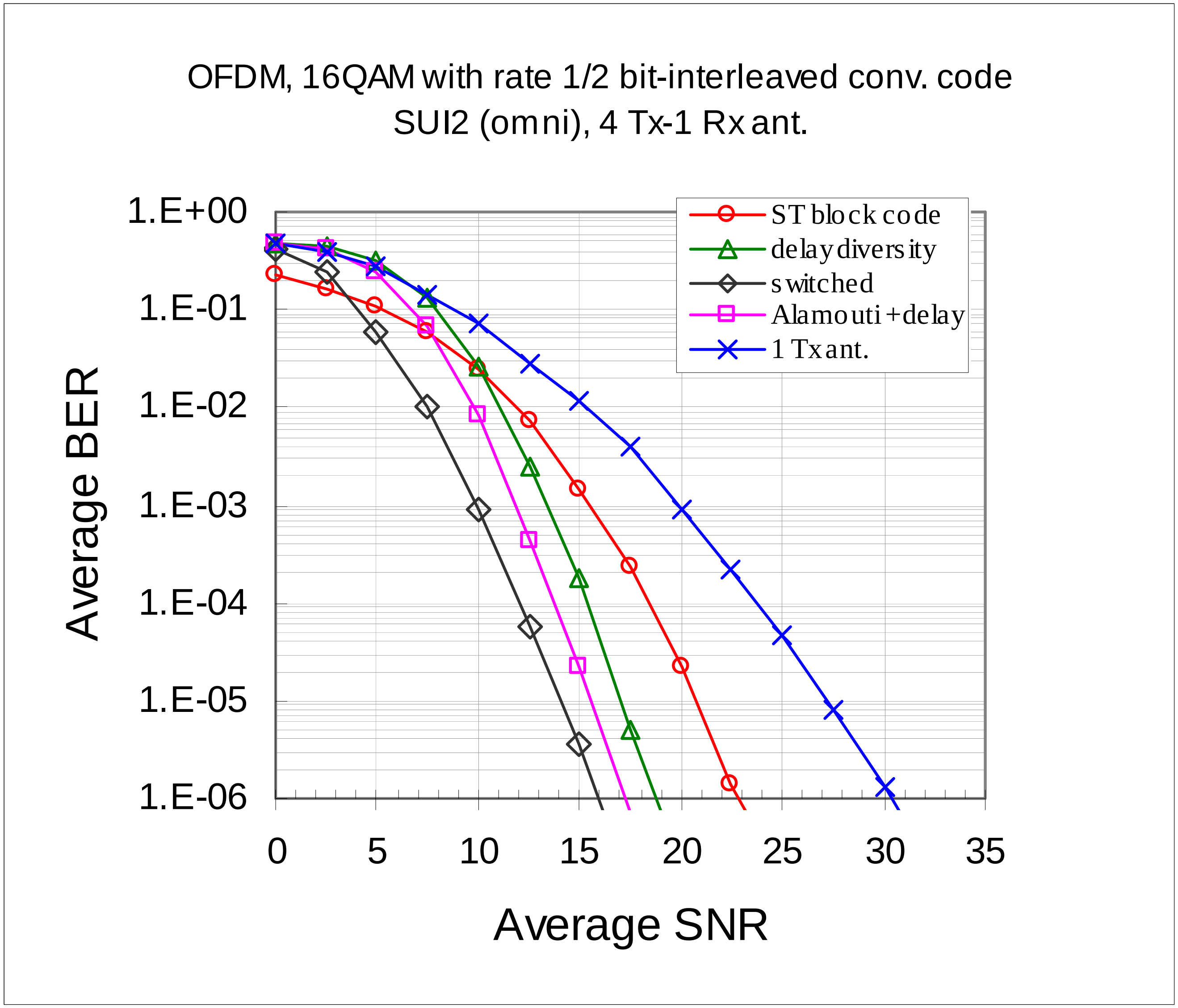


Comparison of Different Tx Diversity Techniques



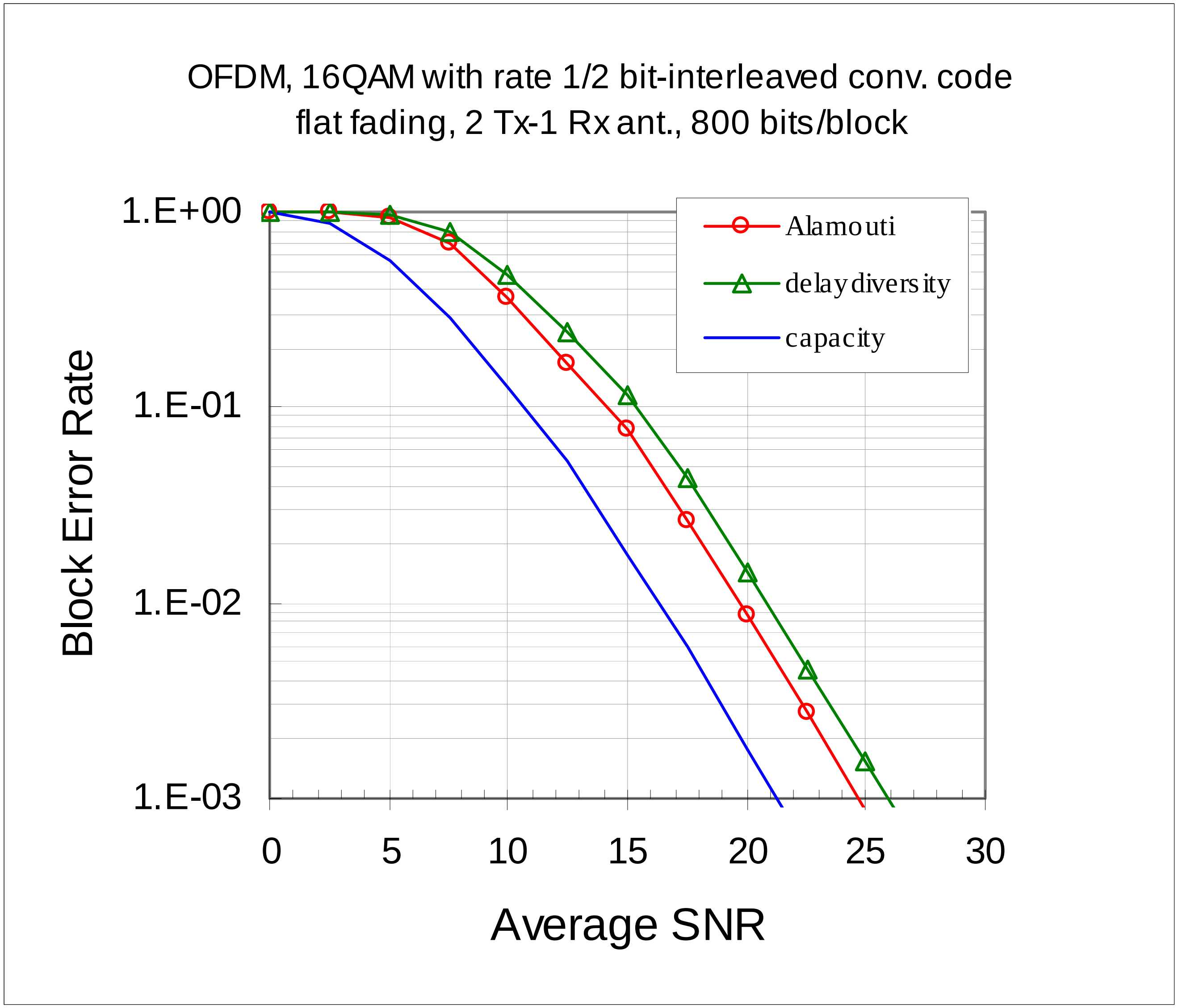
Alamouti is relatively insensitive to code rate and channel conditions

Comparison of Different Tx Diversity Techniques

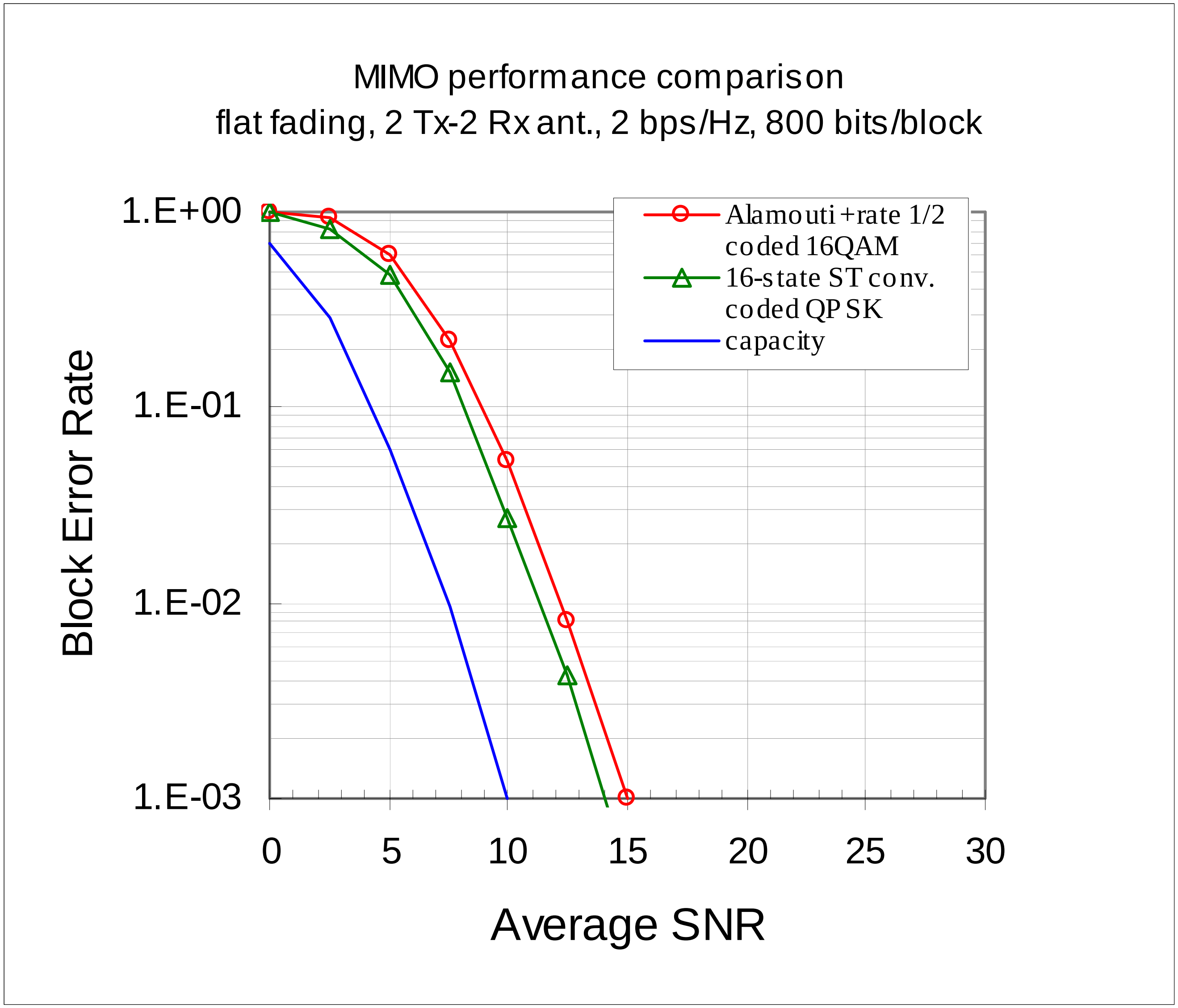


Alamouti + BICM vs. Capacity

“Outage capacity” is the probability that the channel does not support 2 bps/Hz

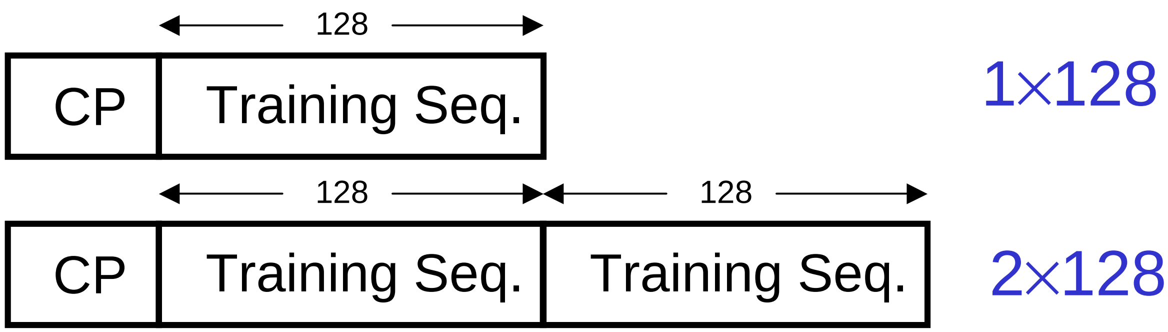


Alamouti + BICM vs. Capacity vs. ST Conv. Code

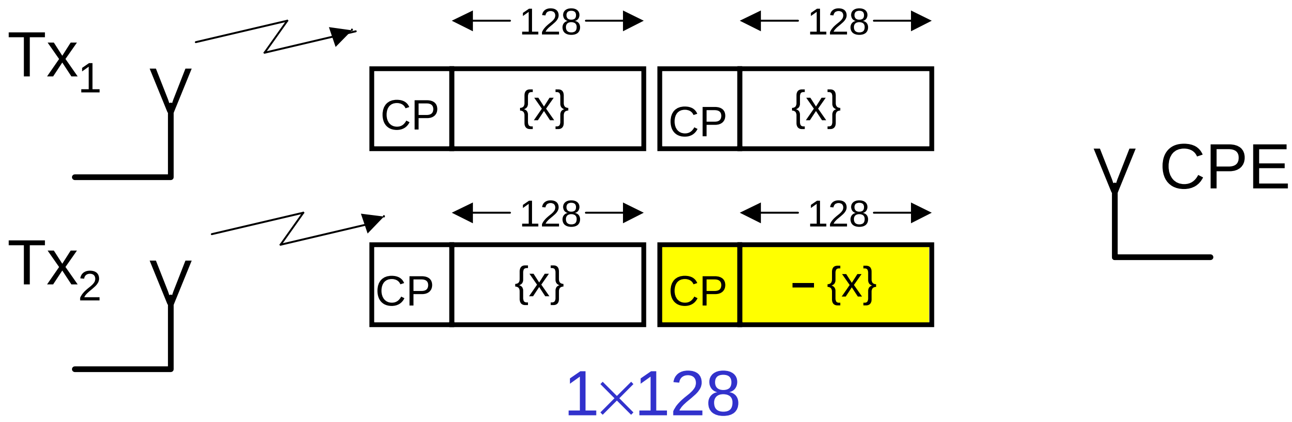


Proposed Preamble Structure

- Basic structure



- 2 Tx antennas



also extendable to > 2 Tx antennas

Proposed Preamble Structure (Cont.)

- Received signal during each preamble block

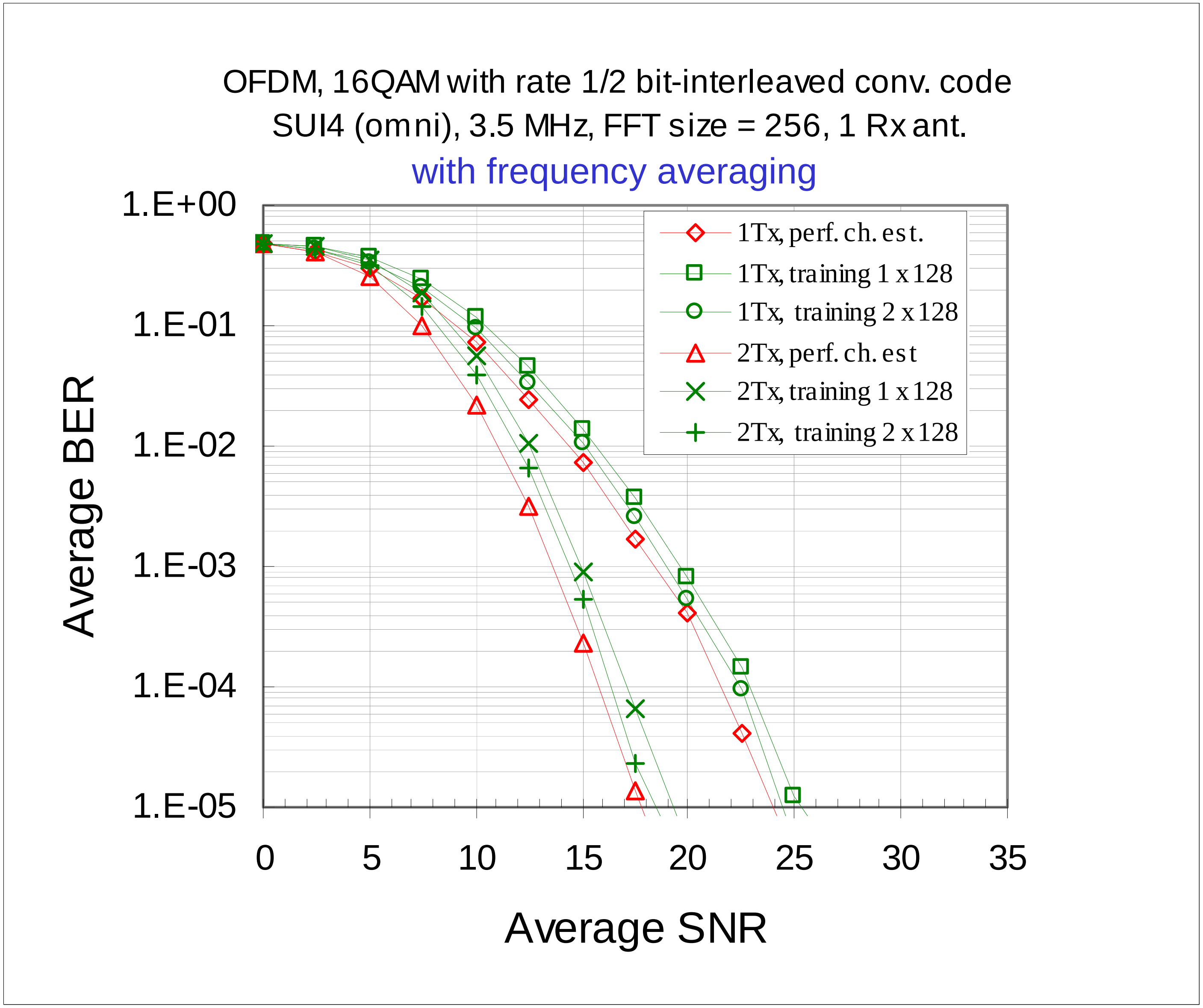
$$R_{a,\ell} = H_{1,\ell} X_{\ell} + H_{2,\ell} X_{\ell} + N_{a,\ell}$$

$$R_{b,\ell} = H_{1,\ell} X_{\ell} - H_{2,\ell} X_{\ell} + N_{b,\ell}$$

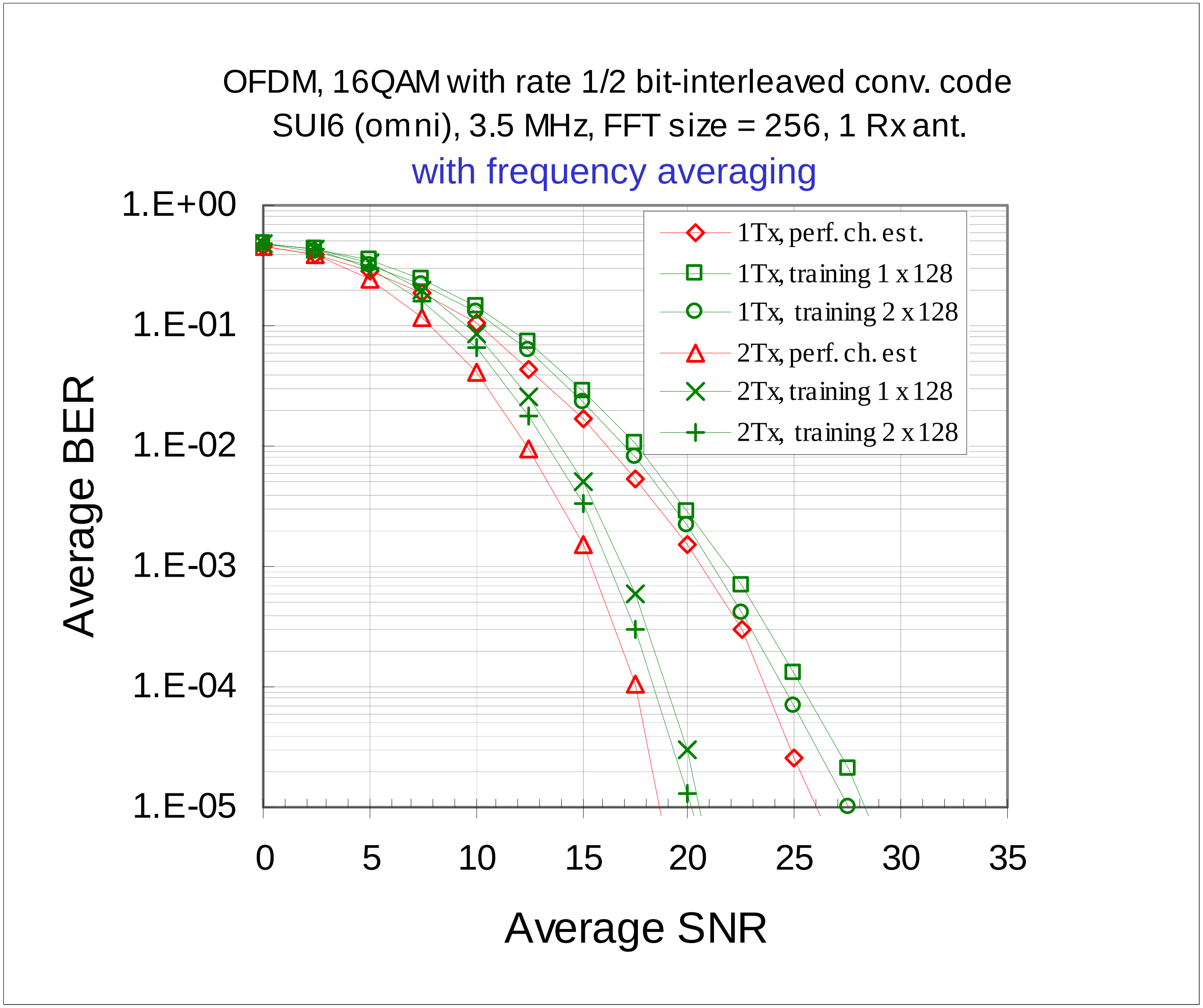
$$\therefore \quad \hat{H}_{1,\ell} = \frac{1}{2}\left(\left\langle \frac{R_{a,\ell}}{X_{\ell}} \right\rangle + \left\langle \frac{R_{b,\ell}}{X_{\ell}} \right\rangle\right) \qquad \hat{H}_{2,\ell} = \frac{1}{2}\left(\left\langle \frac{R_{a,\ell}}{X_{\ell}} \right\rangle - \left\langle \frac{R_{b,\ell}}{X_{\ell}} \right\rangle\right)$$

- Advantages compared to disjoint preamble
  - Lower power amplifier rating requirement by 3 dB
  - Does not require accurate $\frac{1}{\sqrt{2}}$ scaling

Training Performance for SUI4



Training Performance for SUI6



Summary

- Short training sequences not only reduce overhead and processing delay, but also give good performance through frequency-domain interpolation and averaging
- Cyclic prefix correlation is inadequate for highly dispersive channels
- Cyclic prefix length MUST BE greater than maximum delay spread
- Alamouti + BICM is a viable transmit diversity and MIMO technique for small numbers of Tx and Rx antennas
- Proposed preamble structure performs to within
  - 1.5 dB for 1x128
  - 0.5 dB for 2x128

  compared to ideal performance with perfect channel knowledge