A Cross-Layer Diversity Technique for Multi-Carrier OFDM Multimedia Networks

Yee Sin Chan, Pamela Cosman and Laurence Milstein
Department of Electrical and Computer Engineering,
University of California San Diego, CA, U.S.A.

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Standard Form 298 (Rev. 8-98)
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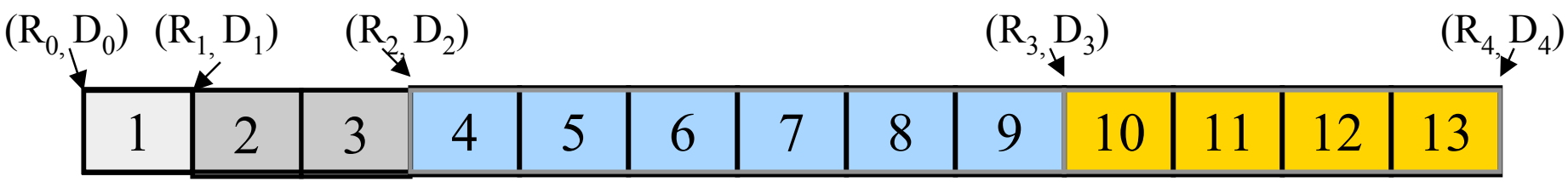
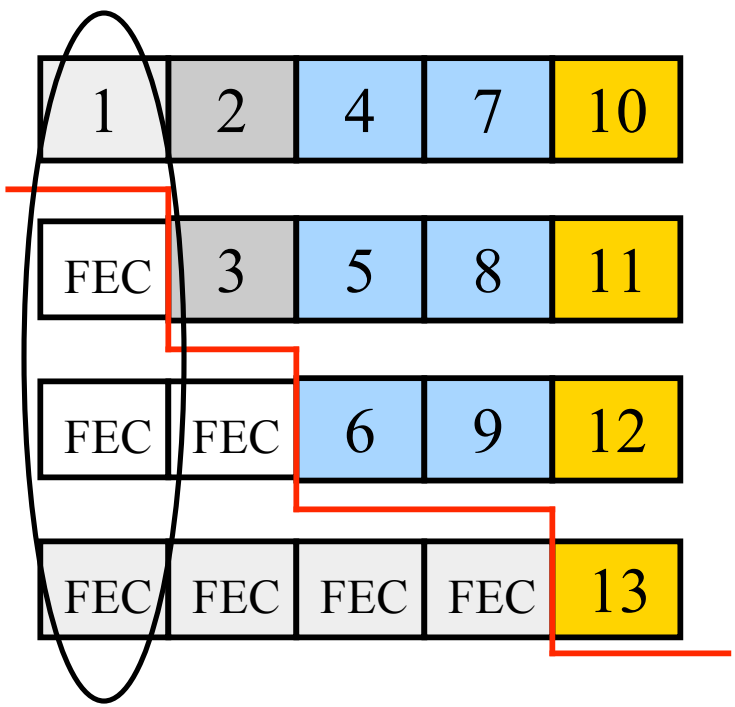
Application Layer Diversity

- **Multiple description coding: transmit and receive distinct descriptions through independently fading channels**
  - Generate multiple distinct bitstreams (descriptions) of the source such that each description independently describes the source with a certain level of fidelity.
  - Losses of some of the descriptions will not jeopardize the decoding of correctly received descriptions.
  - Fidelity improves as the number of received descriptions increases.
  - Typically the composite quality using multiple descriptions is less than that achievable with a single description at the same net rate.

FEC-Based Multiple Description Coding



An embedded bitstream from a source coder partitioned into 5 quality levels



MDS (4,1) erasure code

Embedded bitstream: source can be reconstructed progressively from the prefixes of the bitstream.

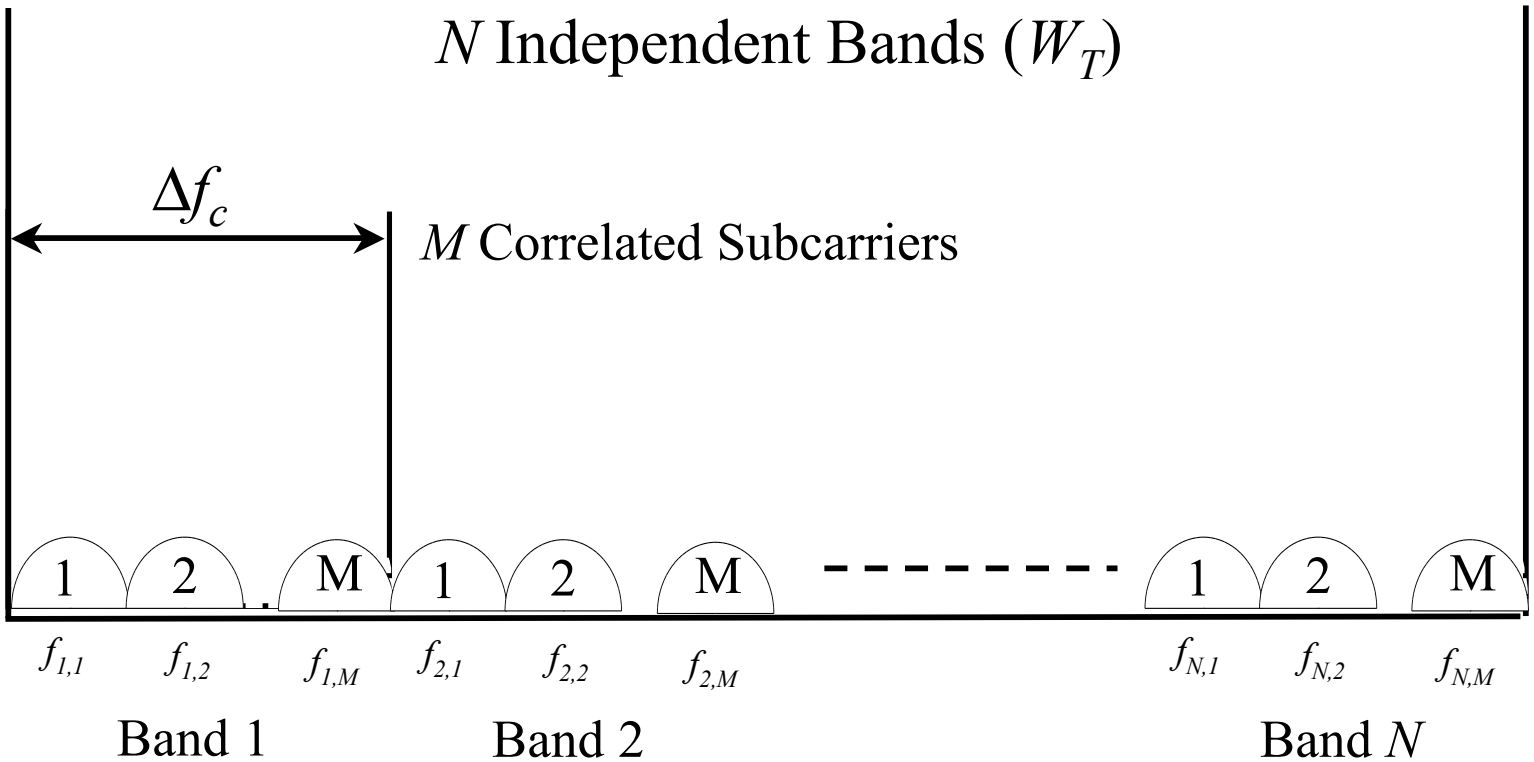
Contiguous information symbols are spread across the multiple descriptions.

Use maximum distance separable codes (MDS) ($n=4,k$) erasure codes (e.g. Reed-Solomon codes)

> k information symbols can be recovered if any k channel symbols are correctly received.

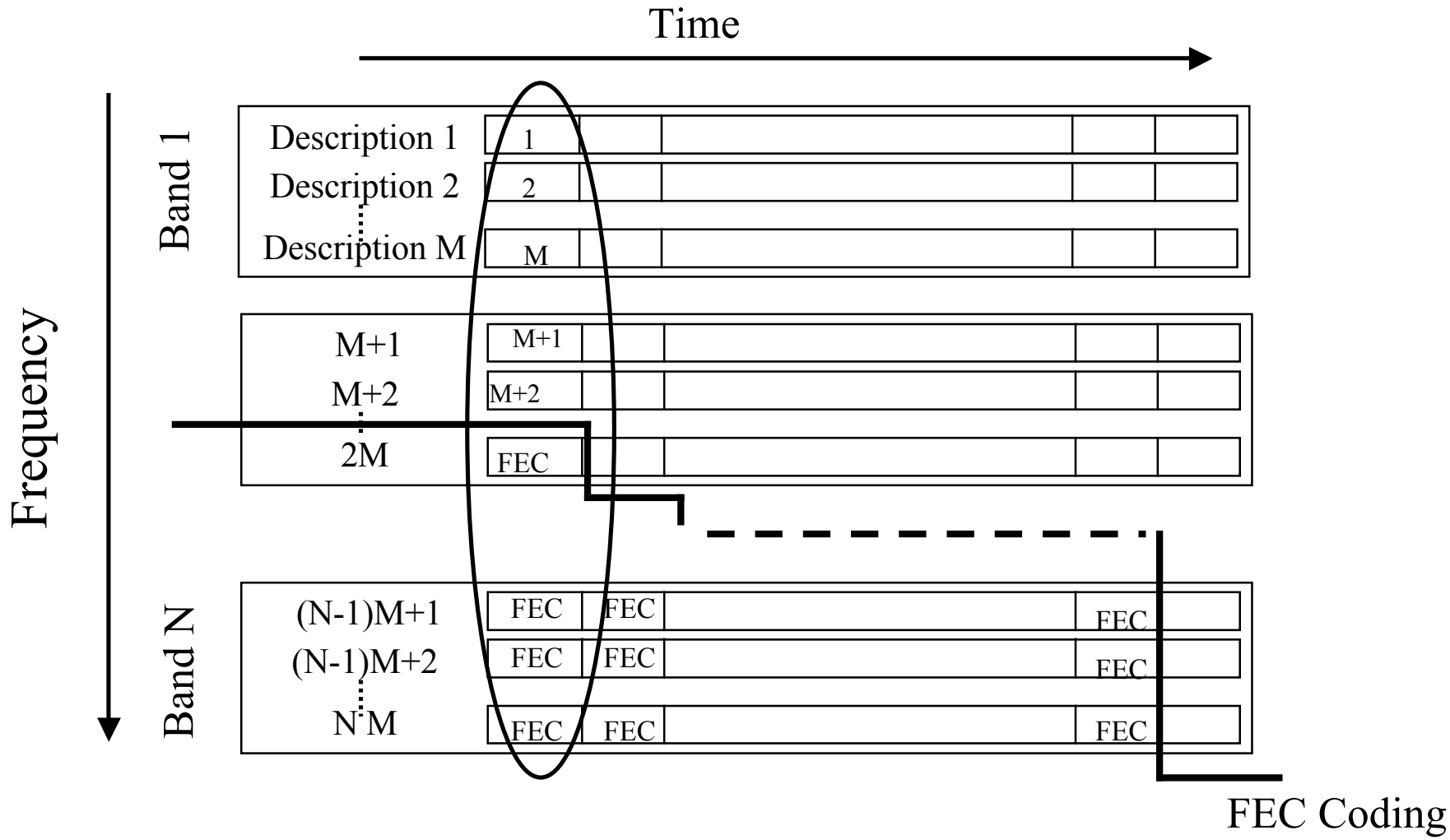
If any g out of n descriptions are received, decoding is guaranteed up to D_g.

Channel Model



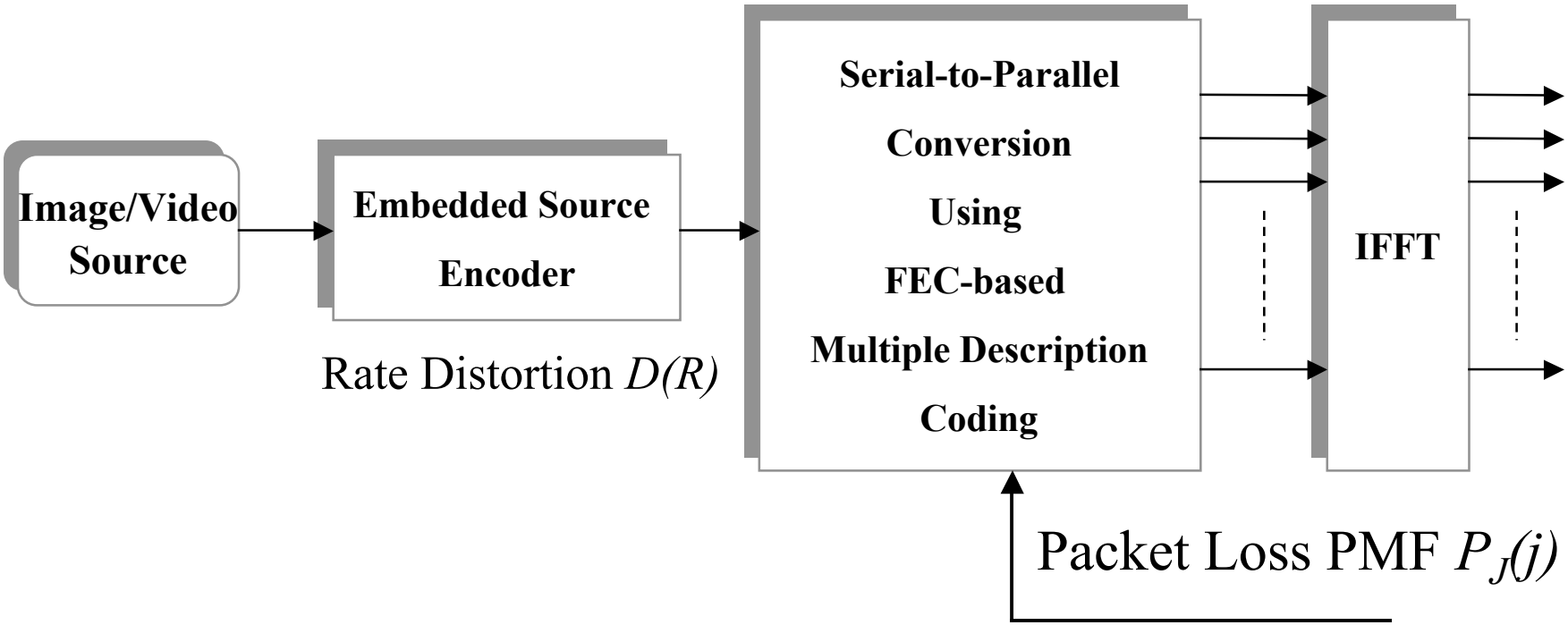
- Assume a frequency selective environment.
- N independent bands, each consisting of M correlated subcarriers.
- $N_t = N \times M$ = total # of subcarriers.
- Each subcarrier is assumed to experience slow flat Rayleigh fading.

Cross-Layer Diversity Transmission Scheme



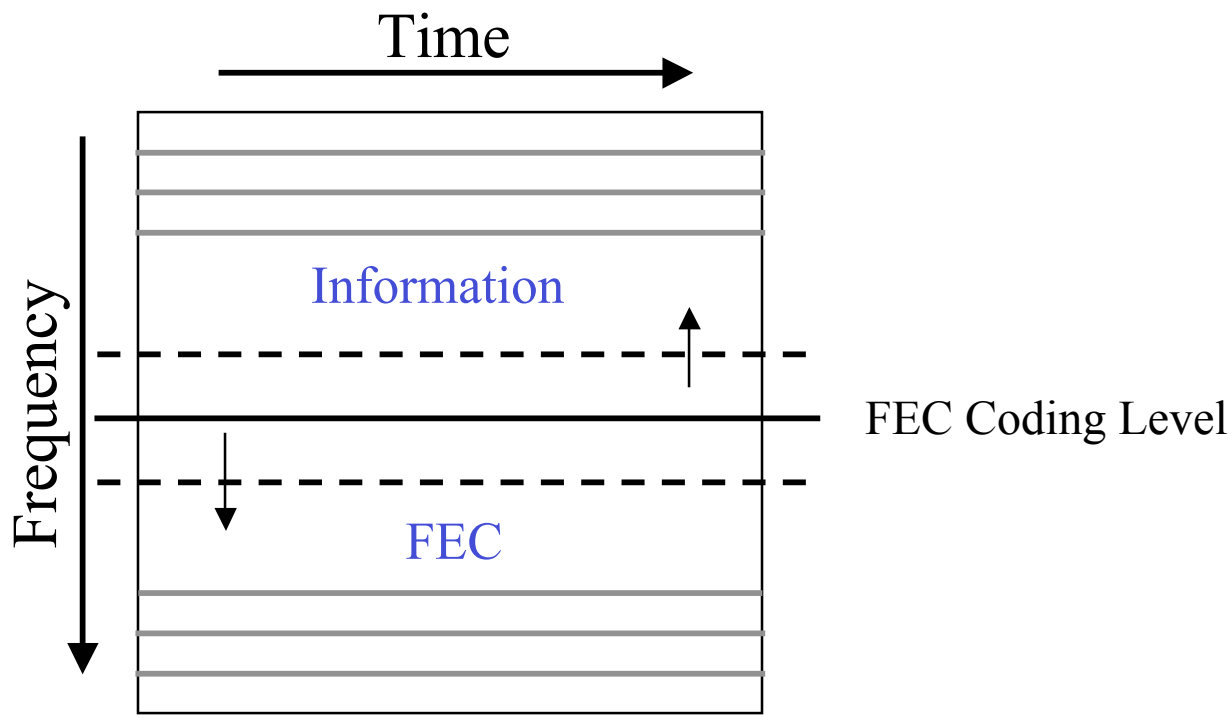
λ Choose optimal allocation of information symbols and parity symbols to minimize the expected distortion.

Proposed Cross-Layer Design

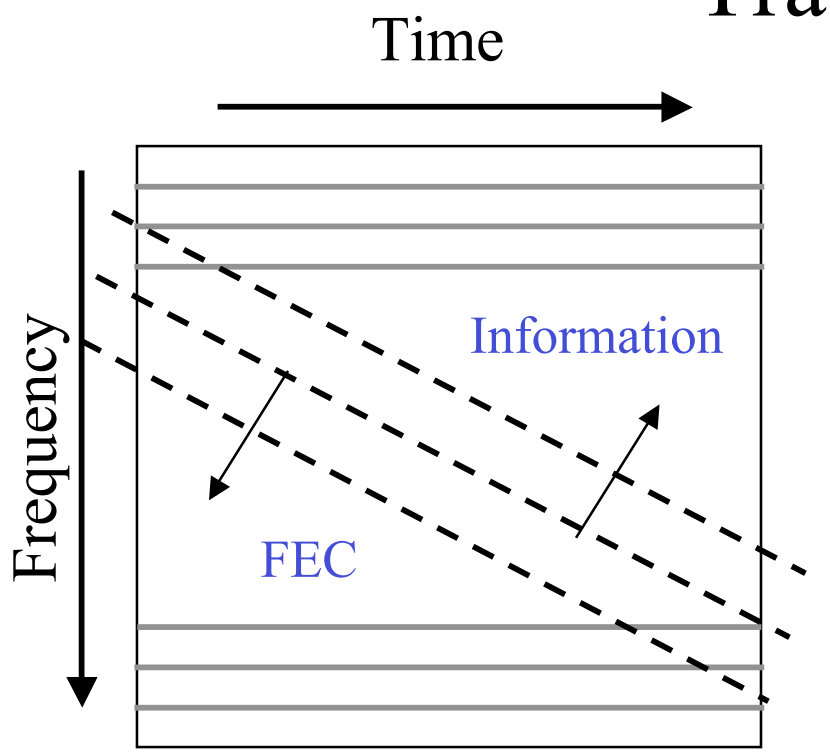


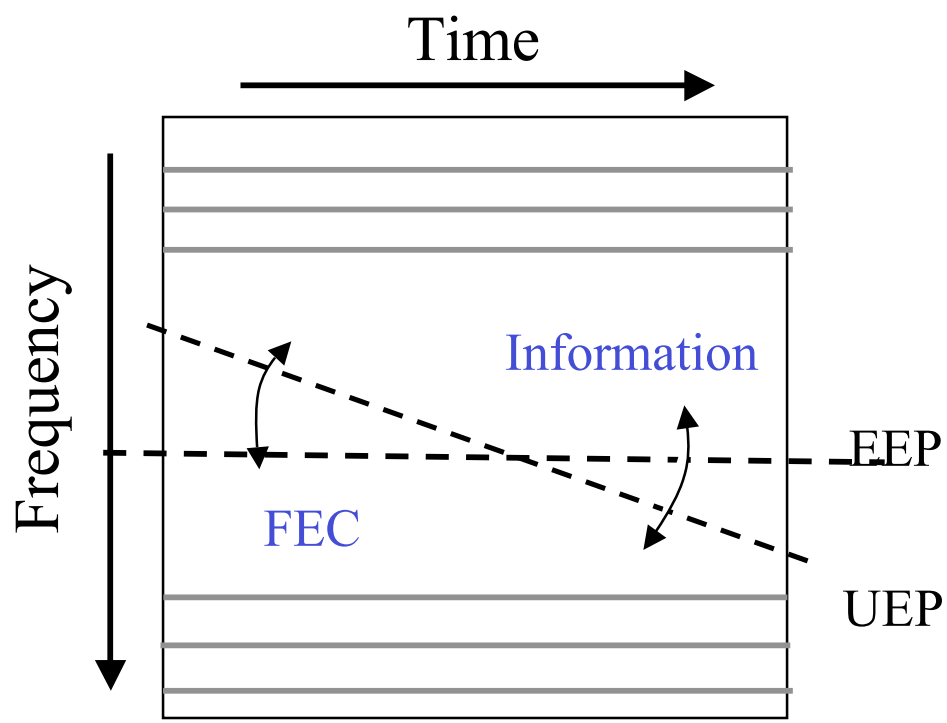
- Serial-to-parallel conversion: based on the rate distortion curve and packet loss PMF, an embedded bitstream is converted into $N_t = N \times M$ distinct descriptions using FEC-based multiple description coder.

Simple Diversity-Information Rate Tradeoff (Equal Error Protection, EEP)



Tradeoffs





- Information rate-diversity gain tradeoff
  - Higher diversity gain can be achieved at the expense of lower information rate.
  - Higher information rate can be achieved by sacrificing diversity gain (higher error rate)
- Degree of unequal error protection (UEP) vs. equal error protection (EEP)

Simulation Parameters

- Total number of subcarriers N_t=128. (128 descriptions)
- QPSK modulation and ideal coherent detection
- Each description consists of L=64 Reed-Solomon (R-S) symbols.
- Each Reed-Solomon symbol = 8 bits (4 QPSK symbols)
- Normalized Doppler spread $f_{nd} = 10^{-3}$
- Measure the performance using peak signal-to-noise ratio (PSNR), defined as

$$PSNR = 10\log\frac{255^2}{MSE_{avg}}$$

- MSE_{avg} = average mean square error

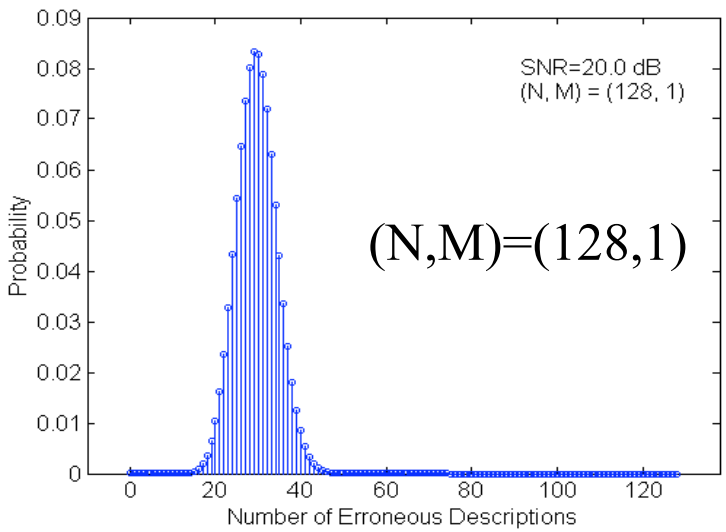
$$MSE_{avg} = E\left[\left(X - \hat{X}\right)^2\right]$$

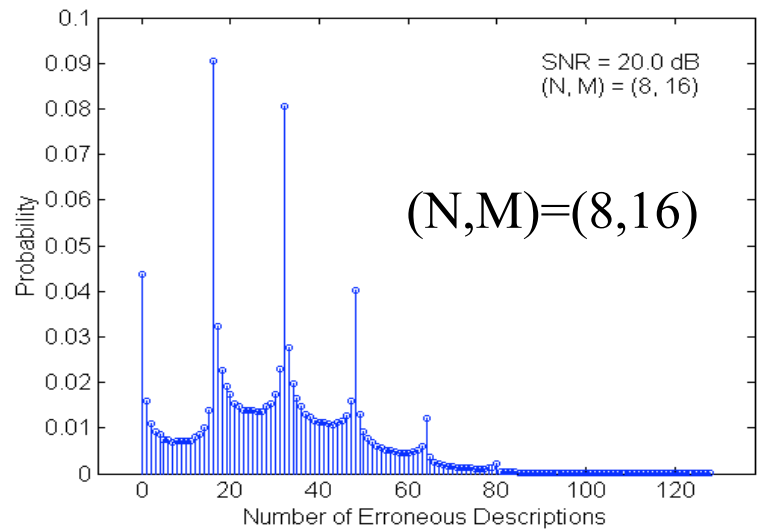
X = original image, $\hat{X}$ = reconstructed image

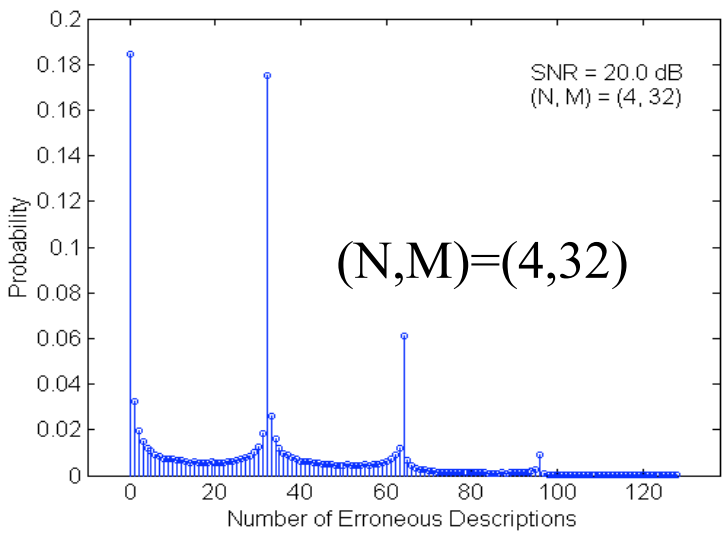
- Number of Images = 100,000

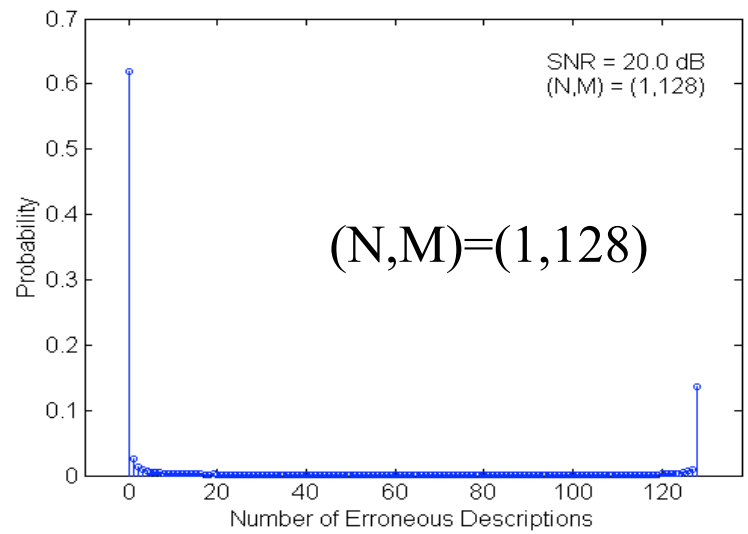
Packet Loss PMF $P_J(j)$ of the N-Band OFDM System

N = No. of Independent Bands, M = No. of Correlated Subcarriers/Band

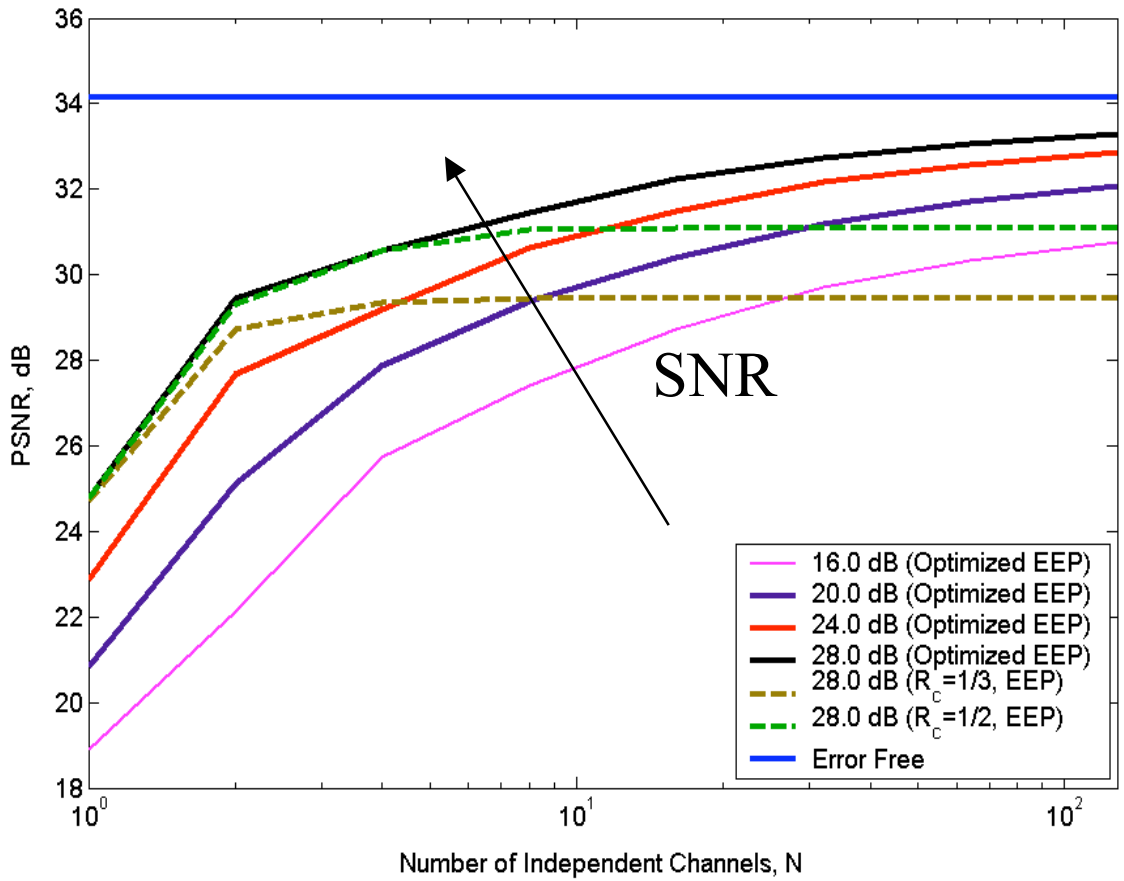






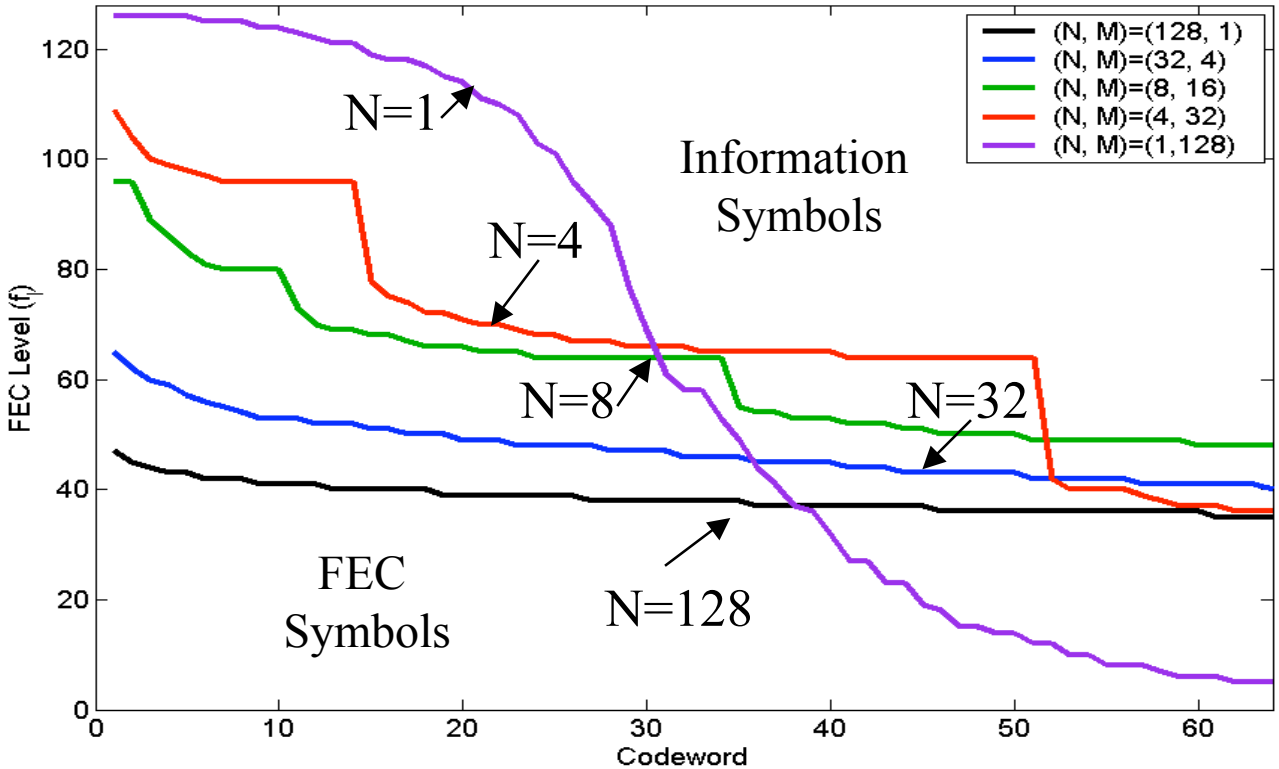


Optimized Equal Error Protection
(PSNR vs. Number of Independent Channels N)



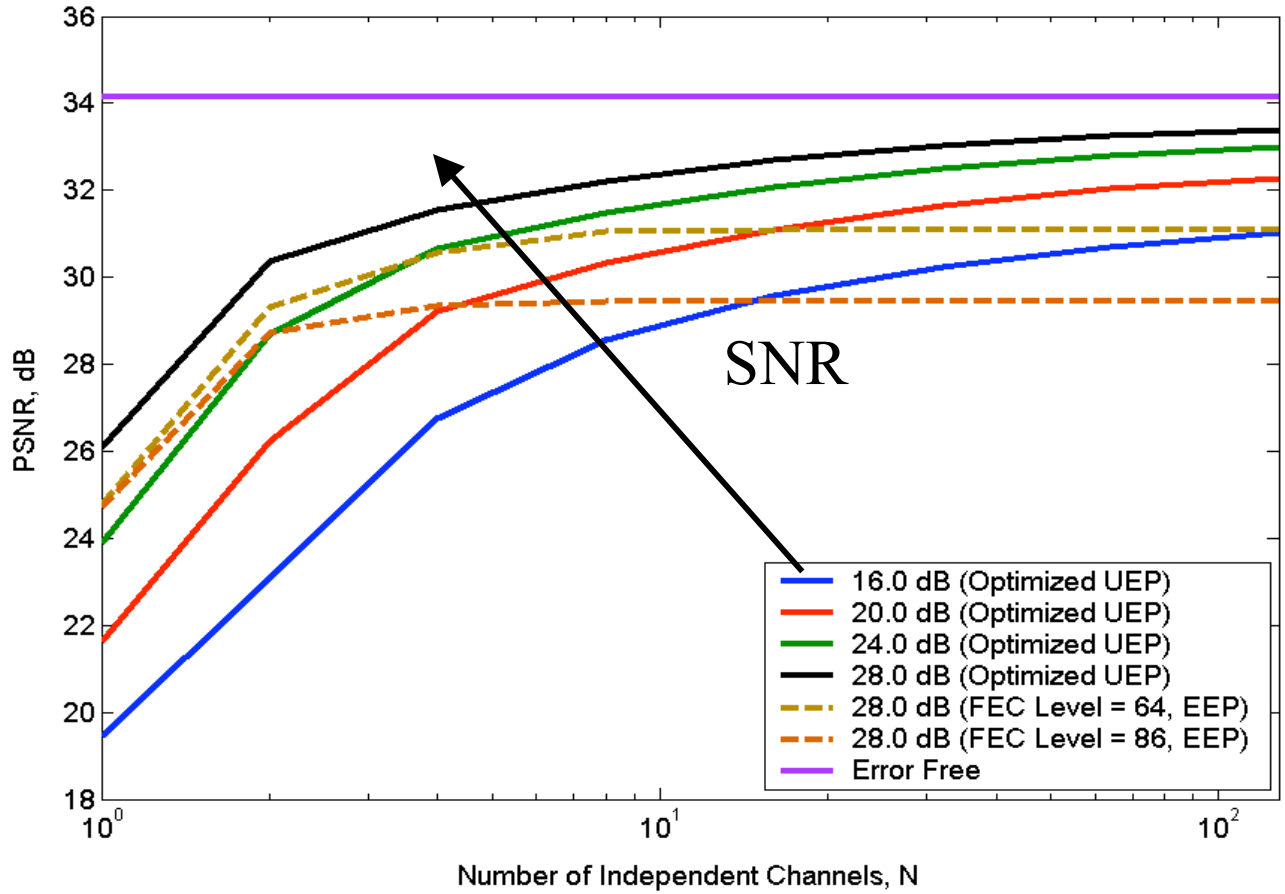
- Equal error protection: information rate and diversity gain tradeoff.
- For a fixed $N_t=128$, PSNR performance improves as N increases.
- Relatively poor performance for ($N=1$) , frequency diversity techniques become ineffective in a flat-fading environment.

Optimal Allocation



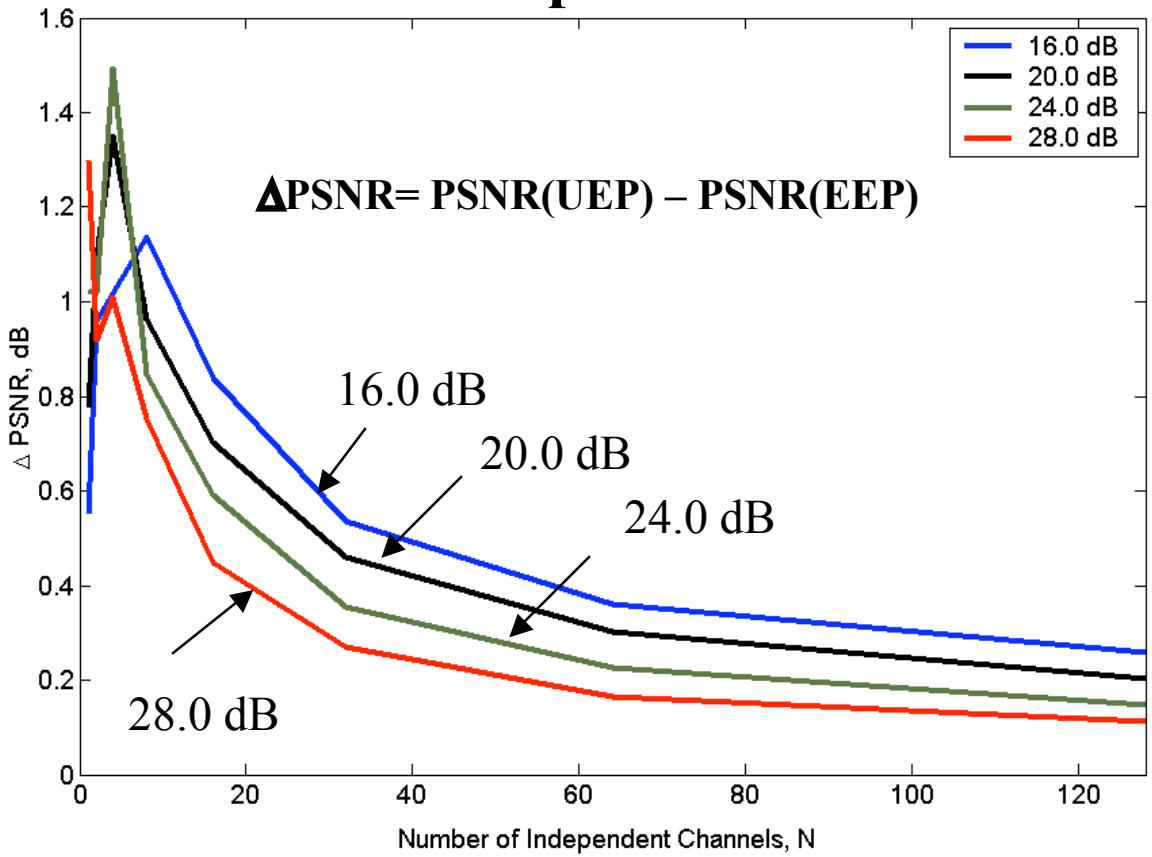
- Relative importance of an embedded bitstream is strictly decreasing, hence less redundancy is added across the subcarriers as we move to the right.
- As *N* increases, the average FEC level decreases.
  - Less redundancy needs to be added across the subcarriers for optimal system performance.
- Degree of unequal error protection (UEP) decreases as *N* increases.
  - Variance of packet loss PMF $P_j(j)$ decreases.

Optimized Unequal Error Protection (PSNR vs. Number of Independent Channels N)



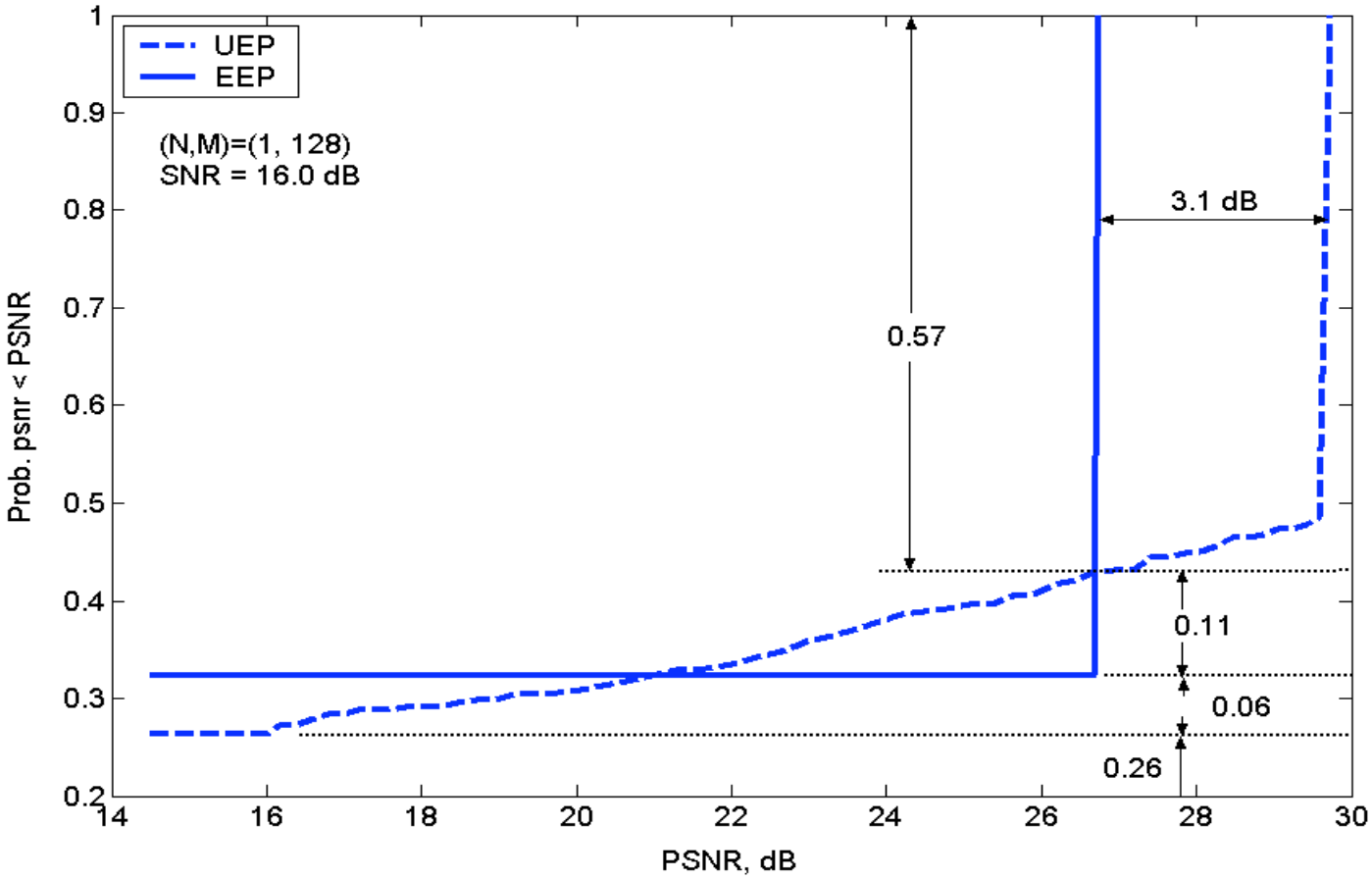
- Unequal error protection: optimal allocation of information symbols and FEC parity symbols
- For a fixed $N_t=128$, there is a significant improvement in system performance measured in terms of PSNR, as N increases.

Difference in PSNR Performance Between Optimized UEP and Optimized EEP



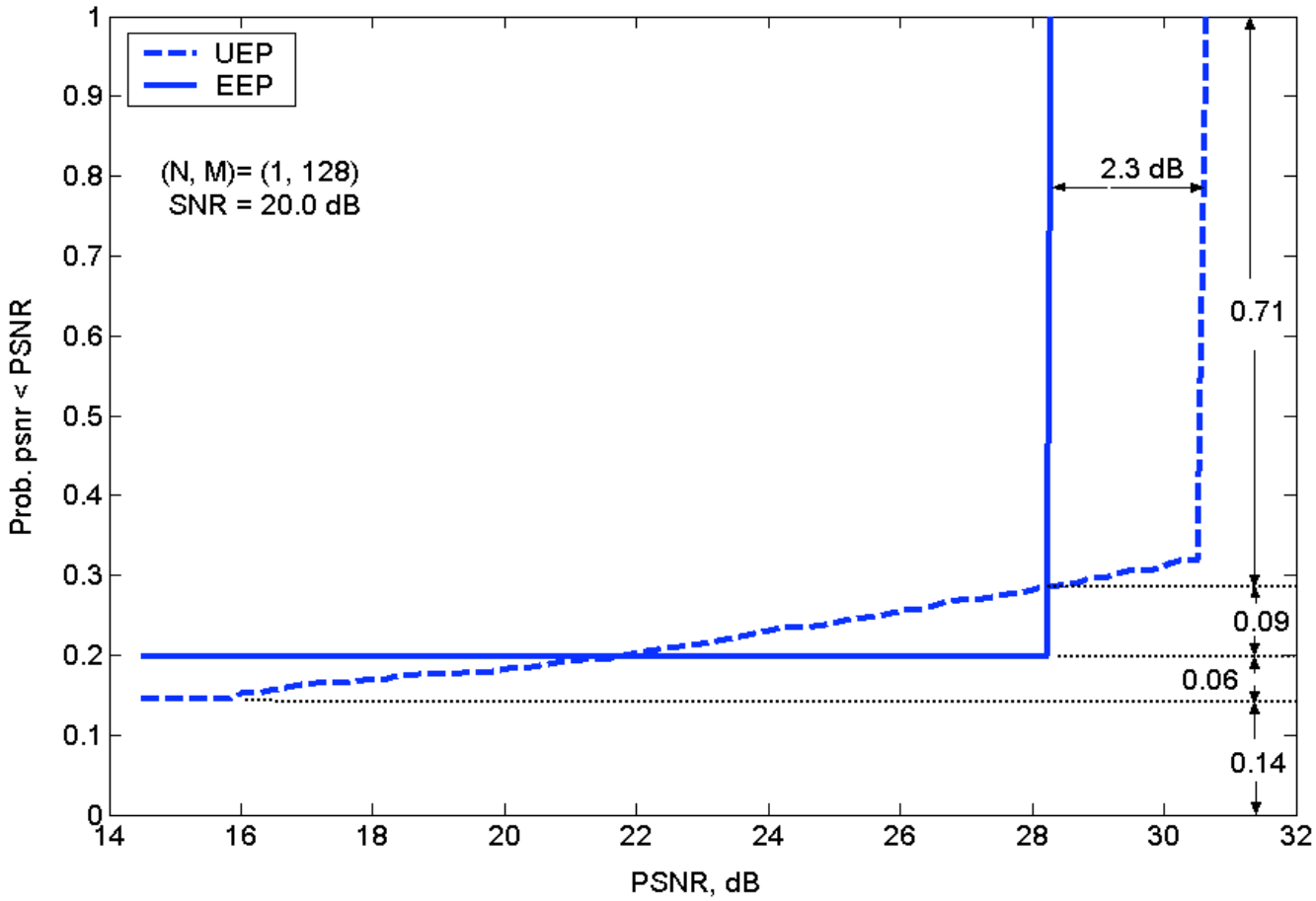
- There is an improvement in PSNR performance by utilizing the UEP technique, especially when *N* is small.
- Relative advantage of UEP to EEP diminishes with increasing *N*.
- In some OFDM systems, the number of independent channels, *N,* might be limited. Hence, there is a significant advantage in employing the cross-layer diversity and UEP techniques.

UEP vs. EEP
(Cumulative Distribution)



(N, M) = (1, 128)
SNR = 16.0 dB

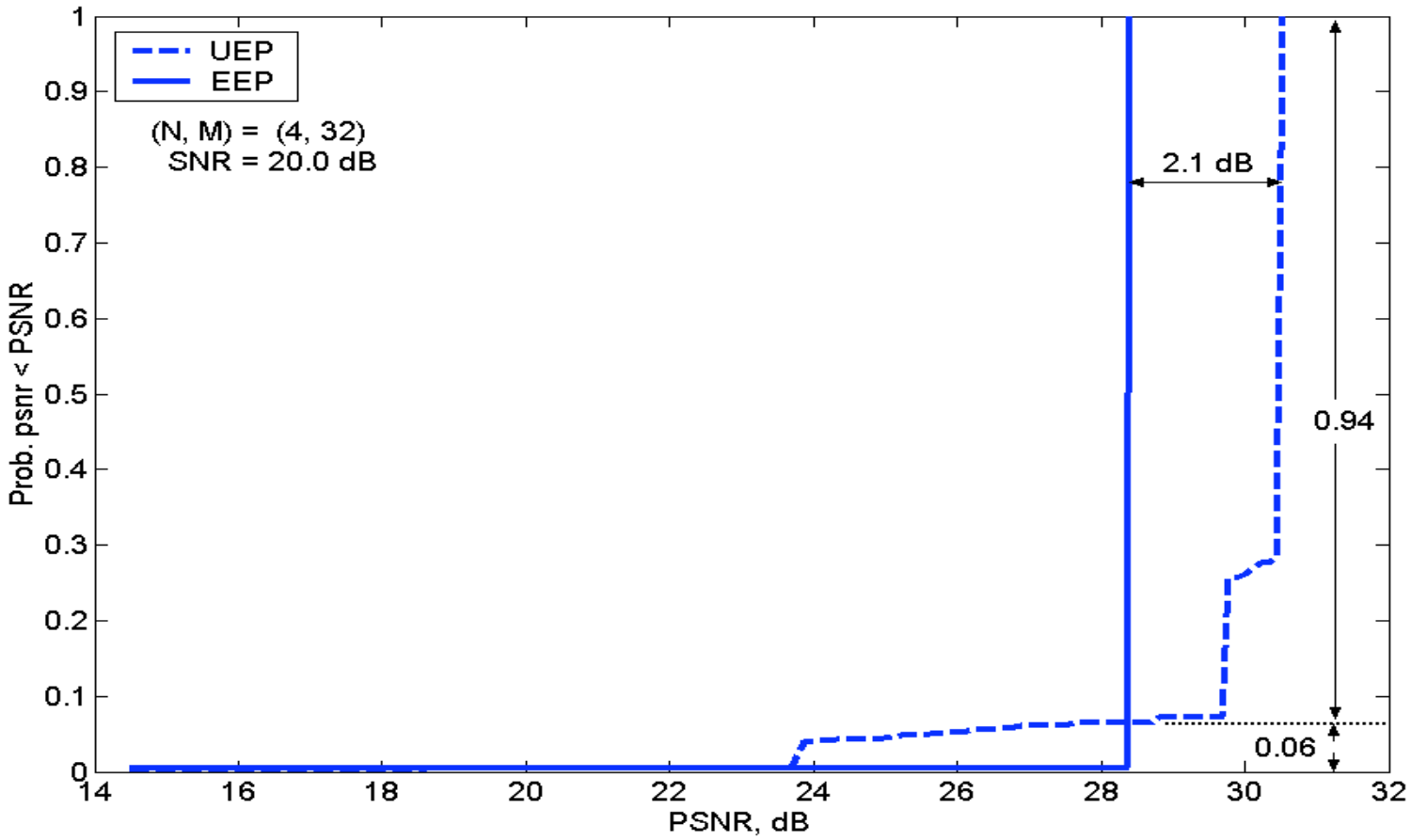
UEP vs. EEP (Cont.)
(Cumulative Distribution)



(N, M) = (1, 128)
SNR = 20.0 dB

UEP vs. EEP (Cont.)

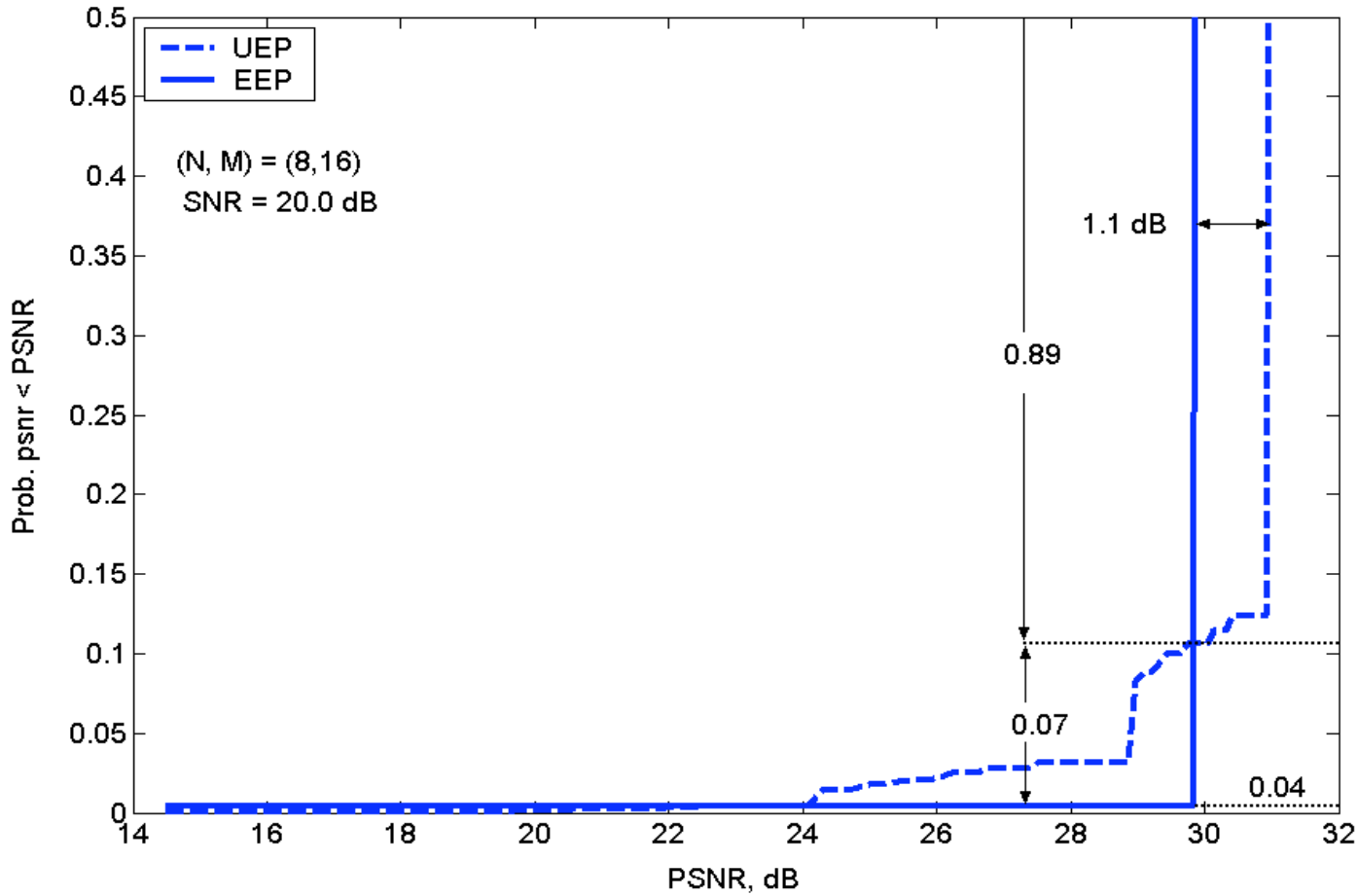
(Cumulative Distribution)



(N, M) = (4, 32)
SNR = 20.0 dB

UEP vs. EEP (Cont.)

(Cumulative Distribution)



(N, M) = (8, 16)
SNR = 20.0 dB

Summary

- Proposed a cross-layer diversity technique for multi-carrier OFDM systems jointly considering
  - Application layer diversity: FEC-based multiple description coding
  - Physical layer diversity: frequency diversity by channel coding across subcarriers
- Investigated the tradeoffs associated with the transmission strategy
  - Information rate and diversity gain tradeoff
  - Unequal error protection vs. equal error protection
  - Results indicate improved robustness and a substantial improvement in end-user QoS can be achieved