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

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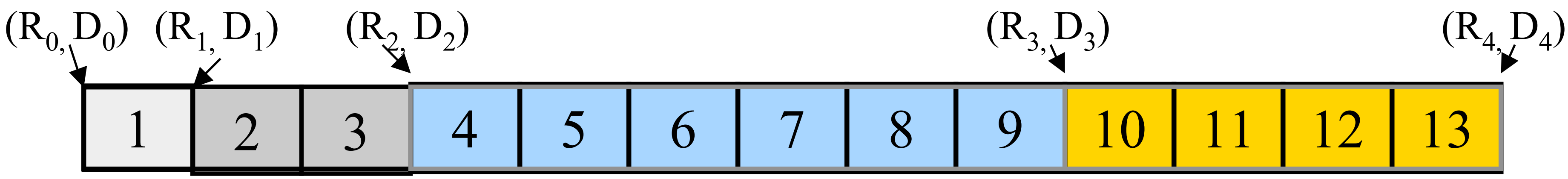
**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

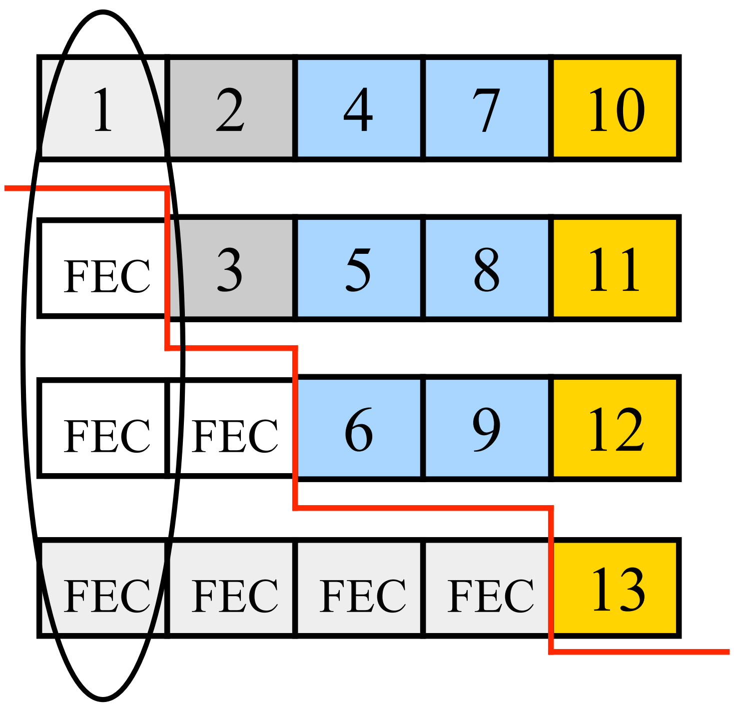
# Application Layer Diversity

- **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.

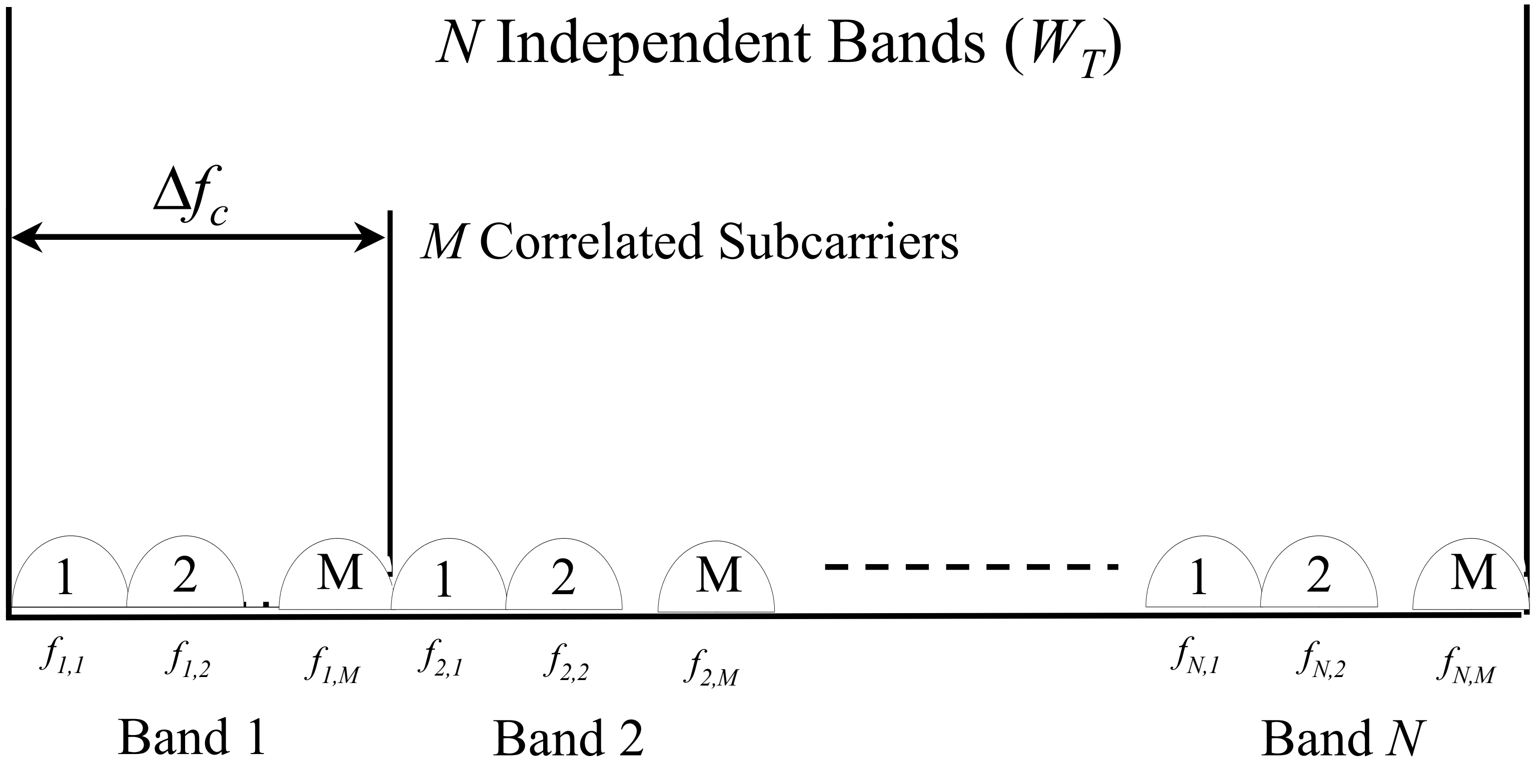
Contiguous information symbols are spread across the multiple descriptions.

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.

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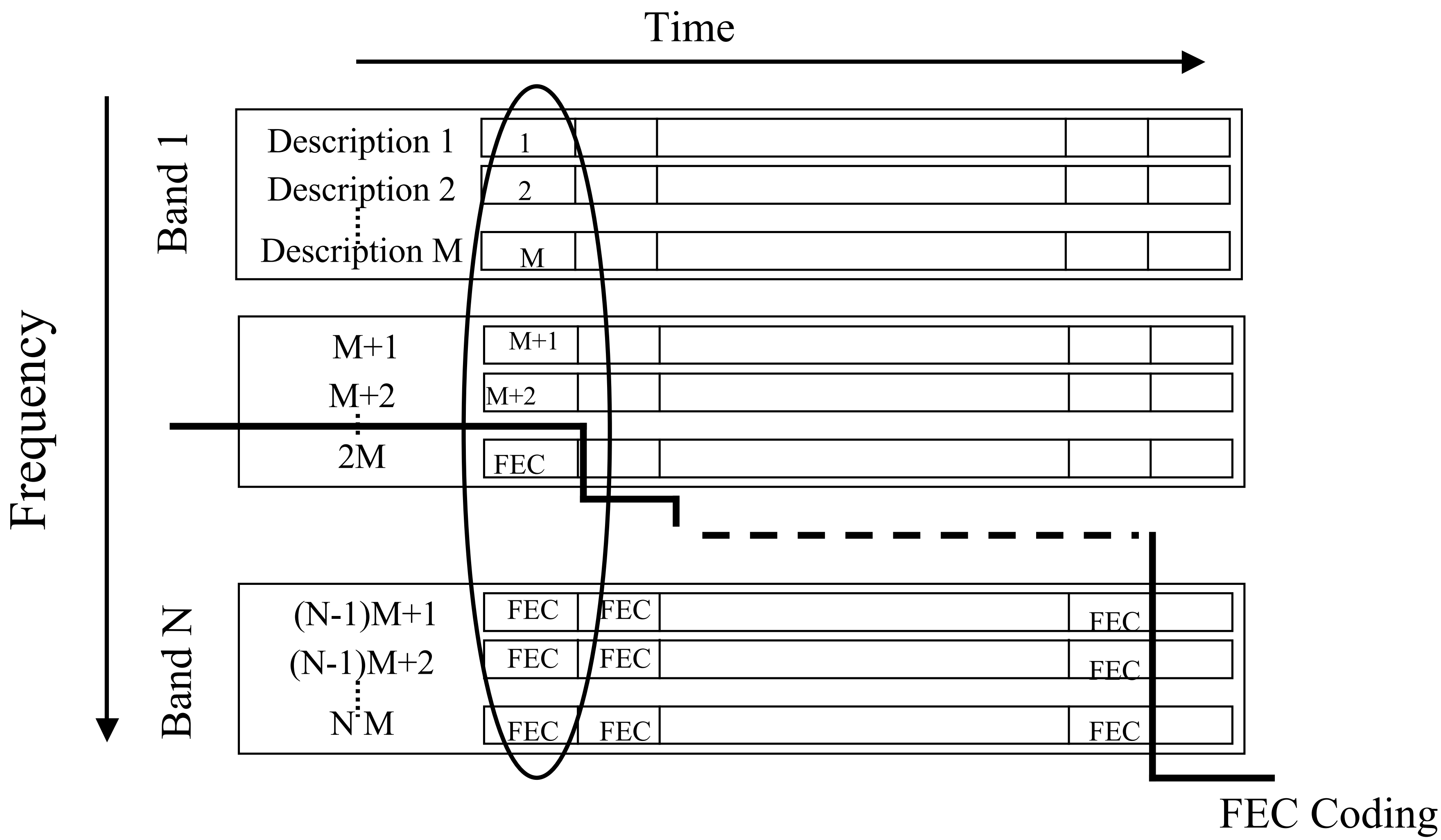
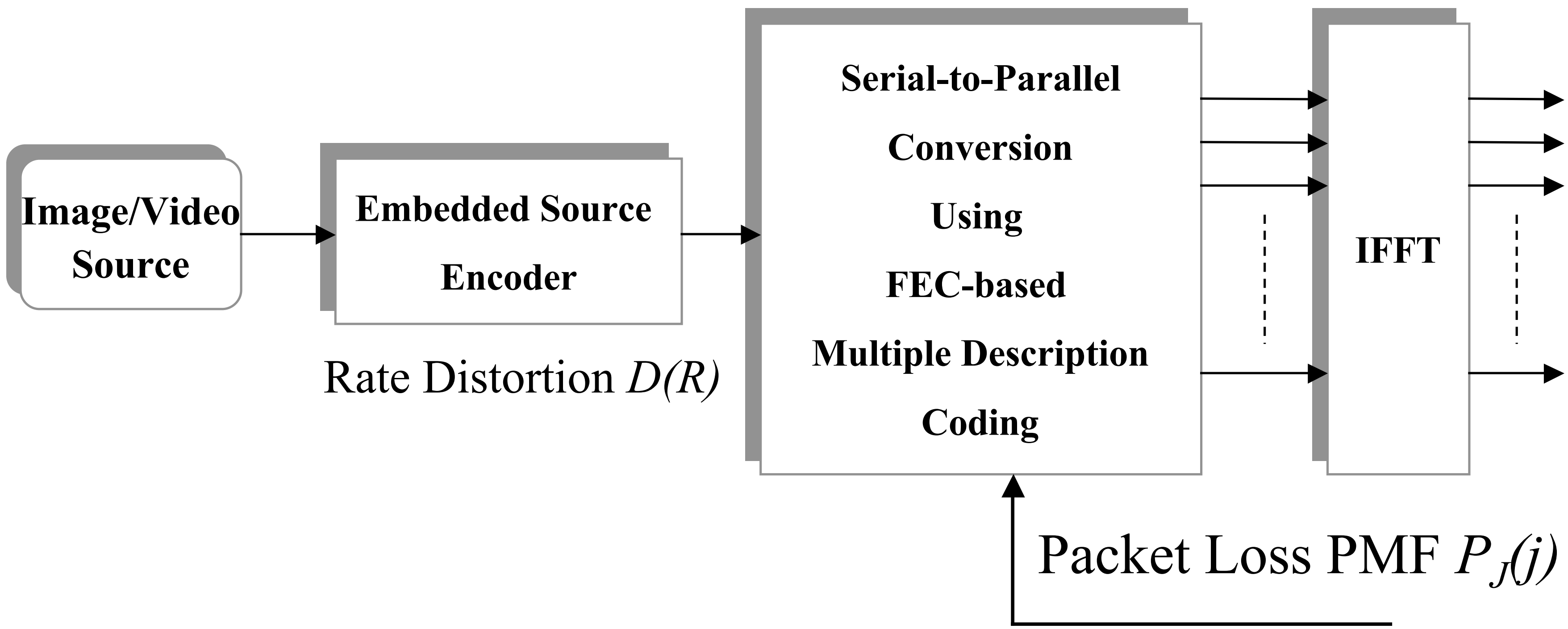
# Cross-Layer Diversity Transmission Scheme



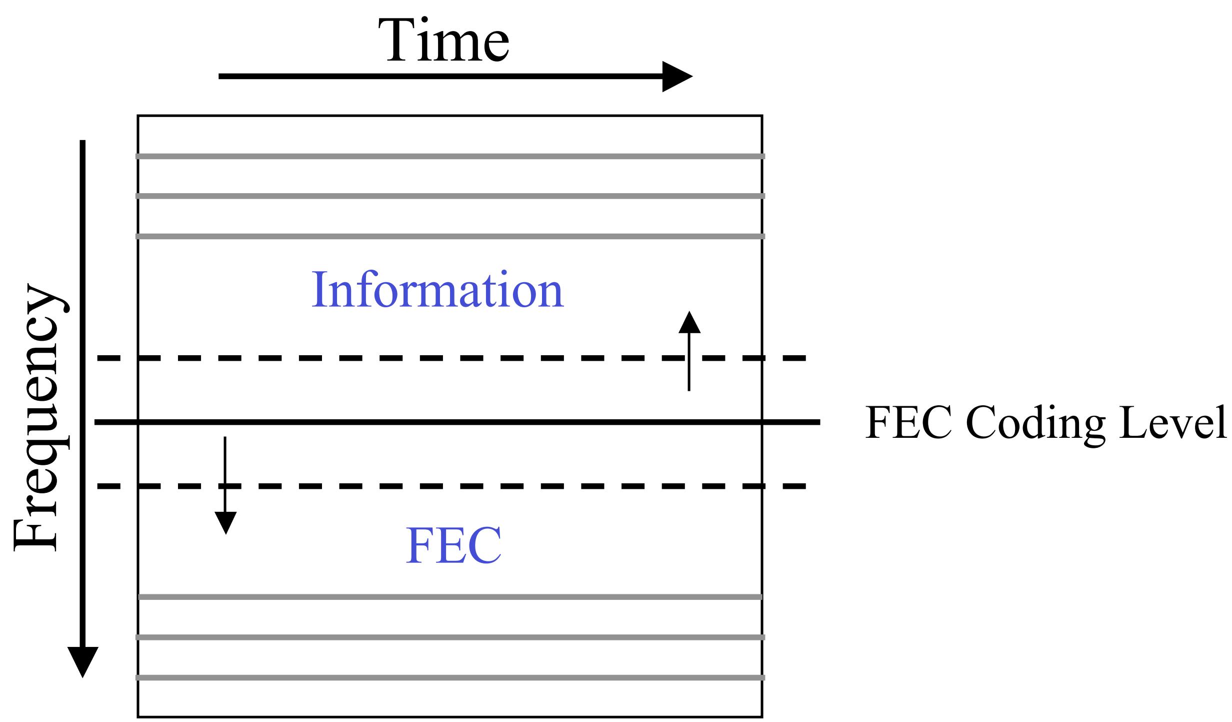

- λ Choose optimal allocation of information symbols and parity symbols to minimize the expected distortion.

# Proposed Cross-Layer Design

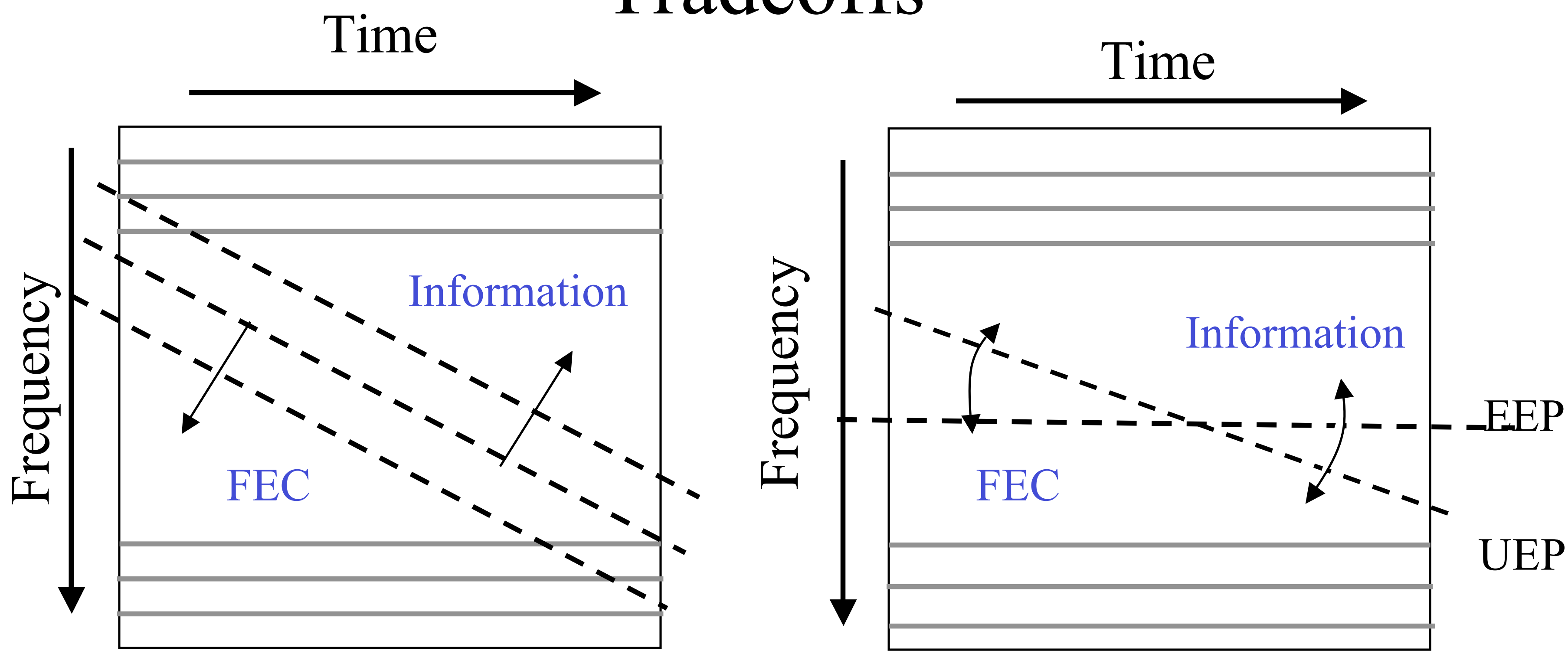



- Serial-to-parallel conversion: based on the rate distortion curve and packet loss PMF, an embedded bitstream is converted into $N_t = N \times M$ distinct descriptions using FEC-based multiple description coder.

# 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

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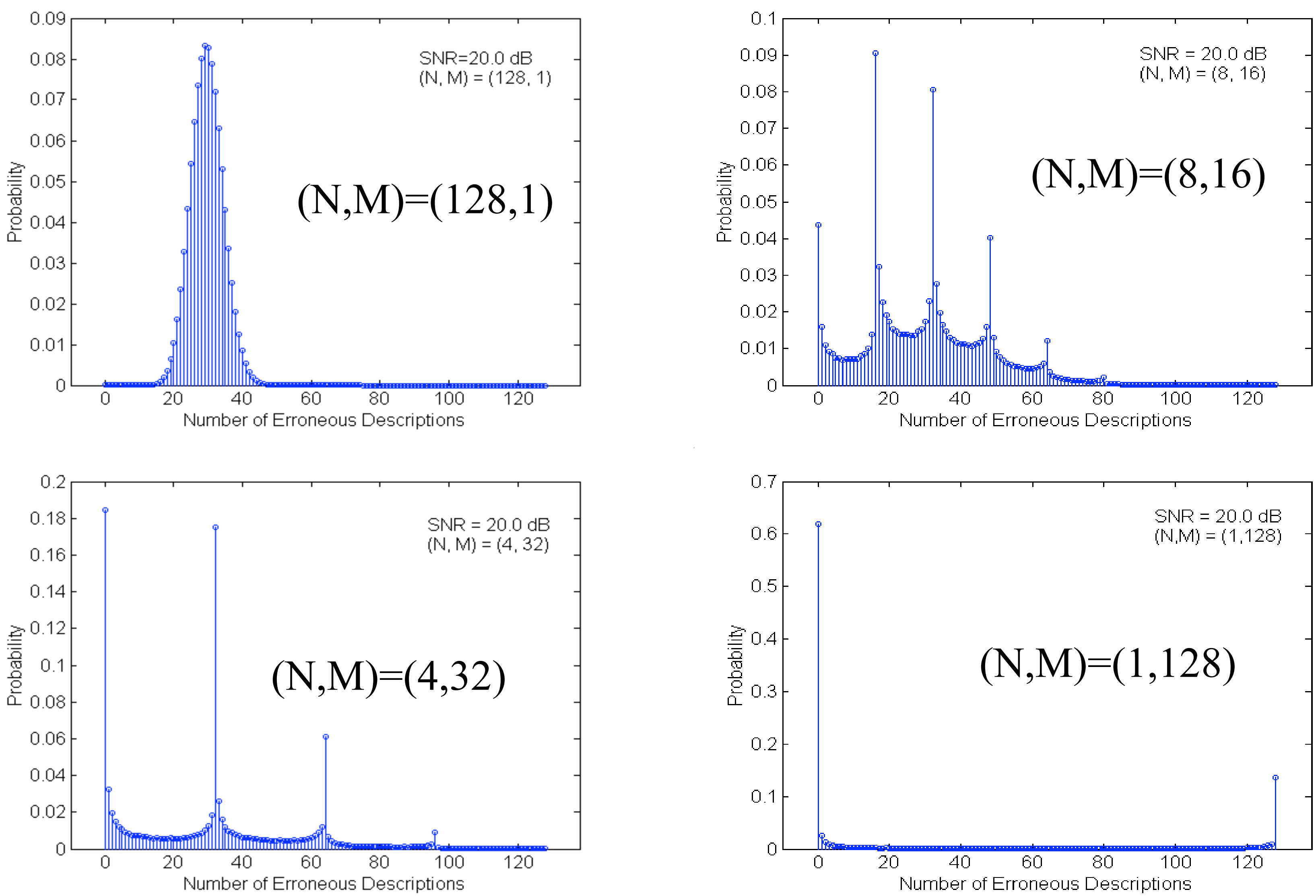
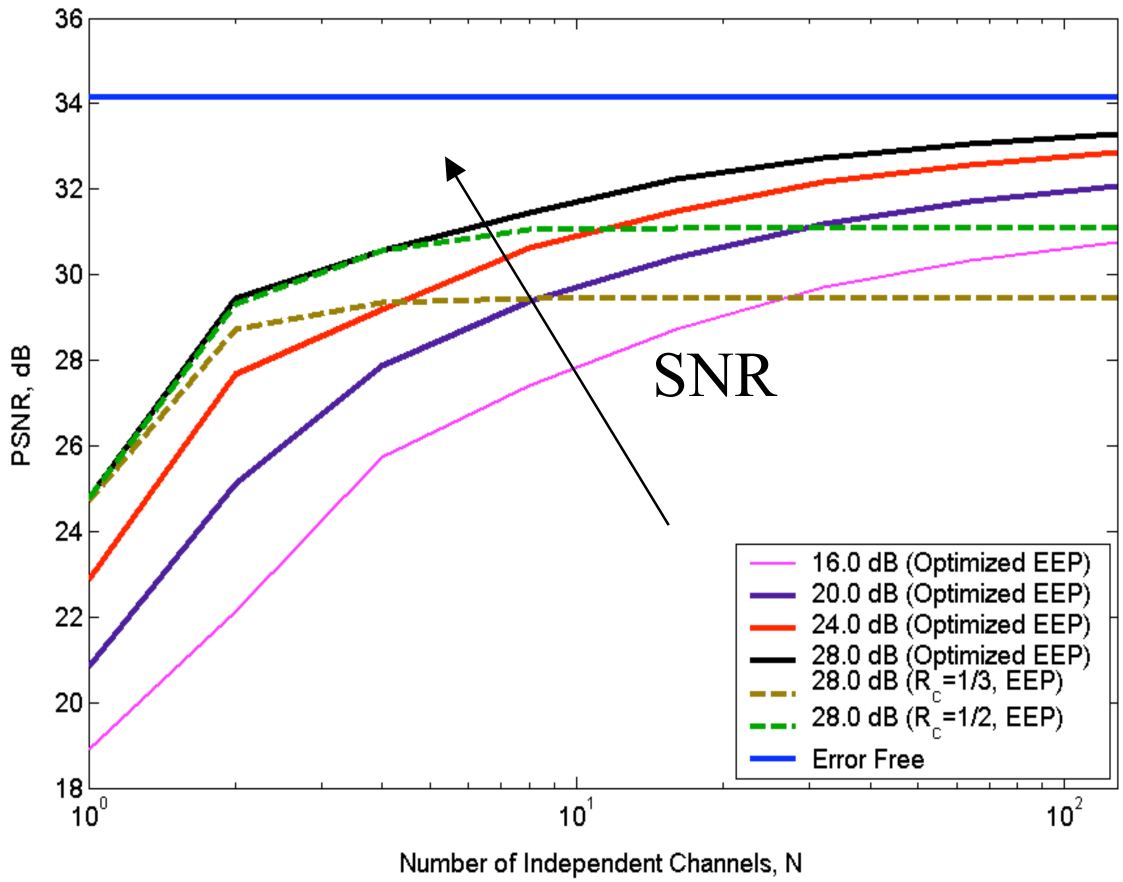
# Packet Loss PMF $P_J(j)$ of the N-Band OFDM System

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

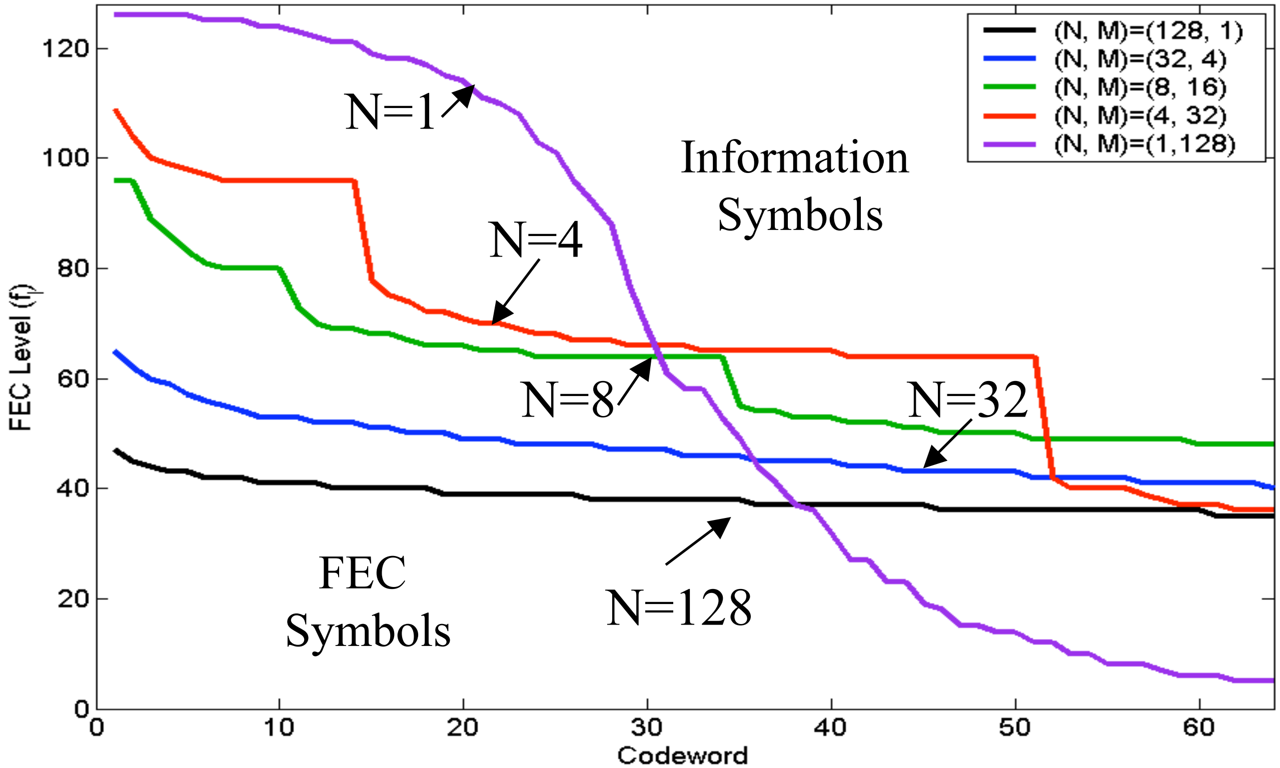


# Optimized Equal Error Protection (PSNR vs. Number of Independent Channels N)



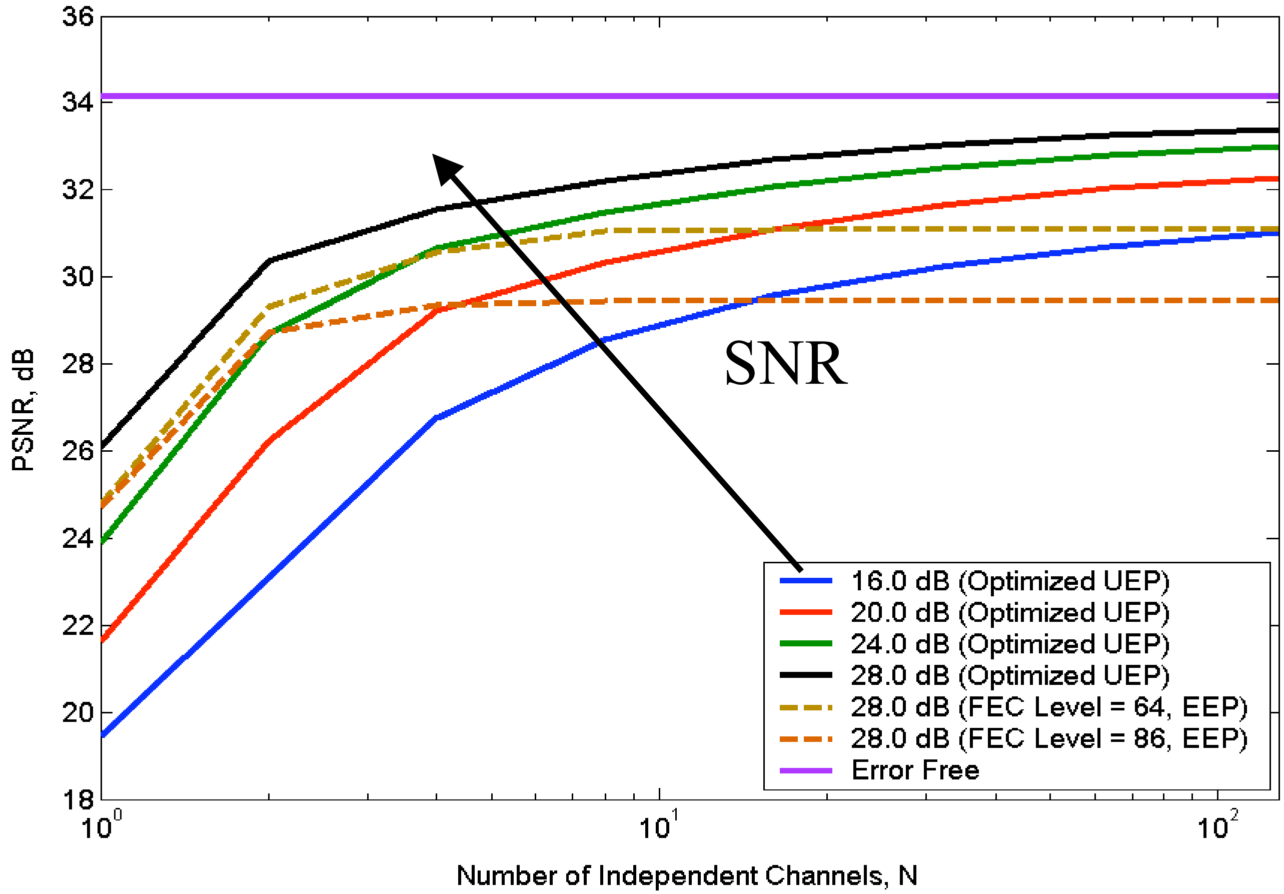

- Equal error protection: information rate and diversity gain tradeoff.
- For a fixed $N_t$=*128*, PSNR performance improves as *N* increases.
- Relatively poor performance for (*N=1*) , frequency diversity techniques become ineffective in a flat-fading environment.

# Optimal Allocation



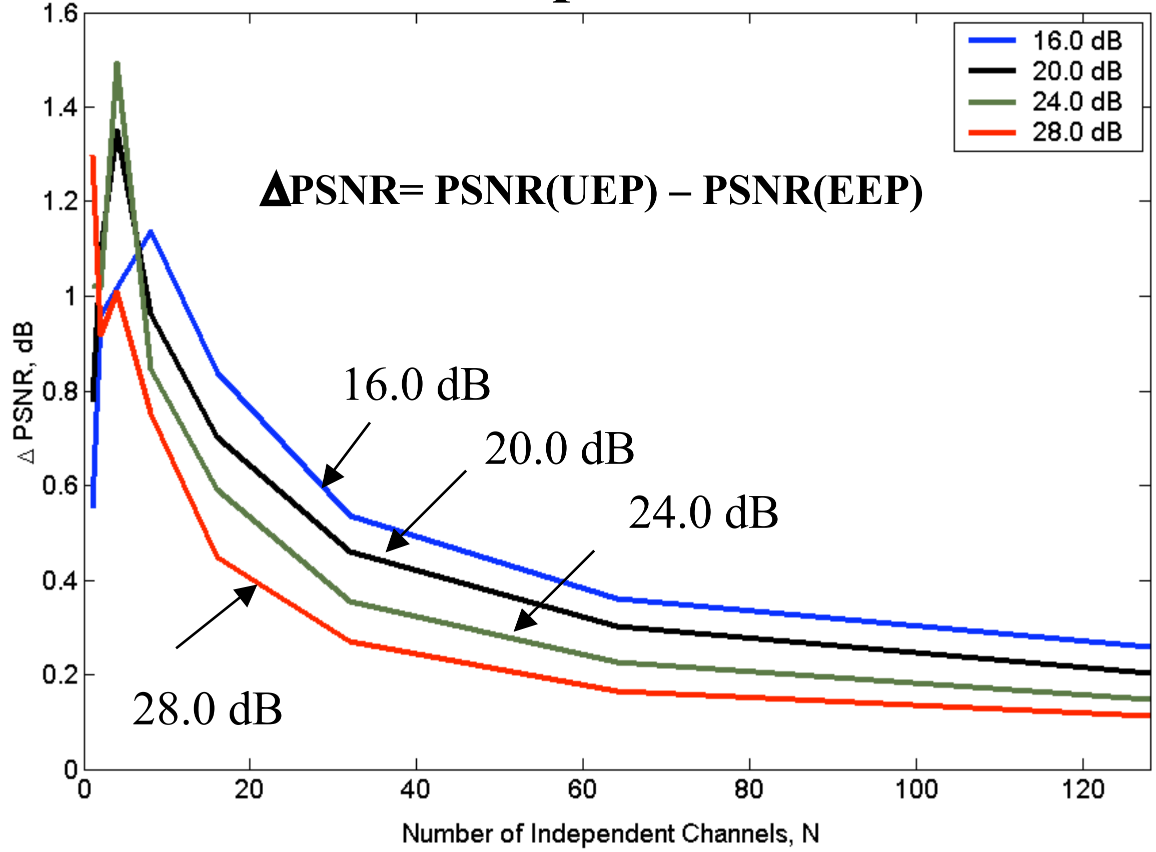

- Relative importance of an embedded bitstream is strictly decreasing, hence less redundancy is added across the subcarriers as we move to the right.
- As *N* increases, the average FEC level decreases.
  - Less redundancy needs to be added across the subcarriers for optimal system performance.
- Degree 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.

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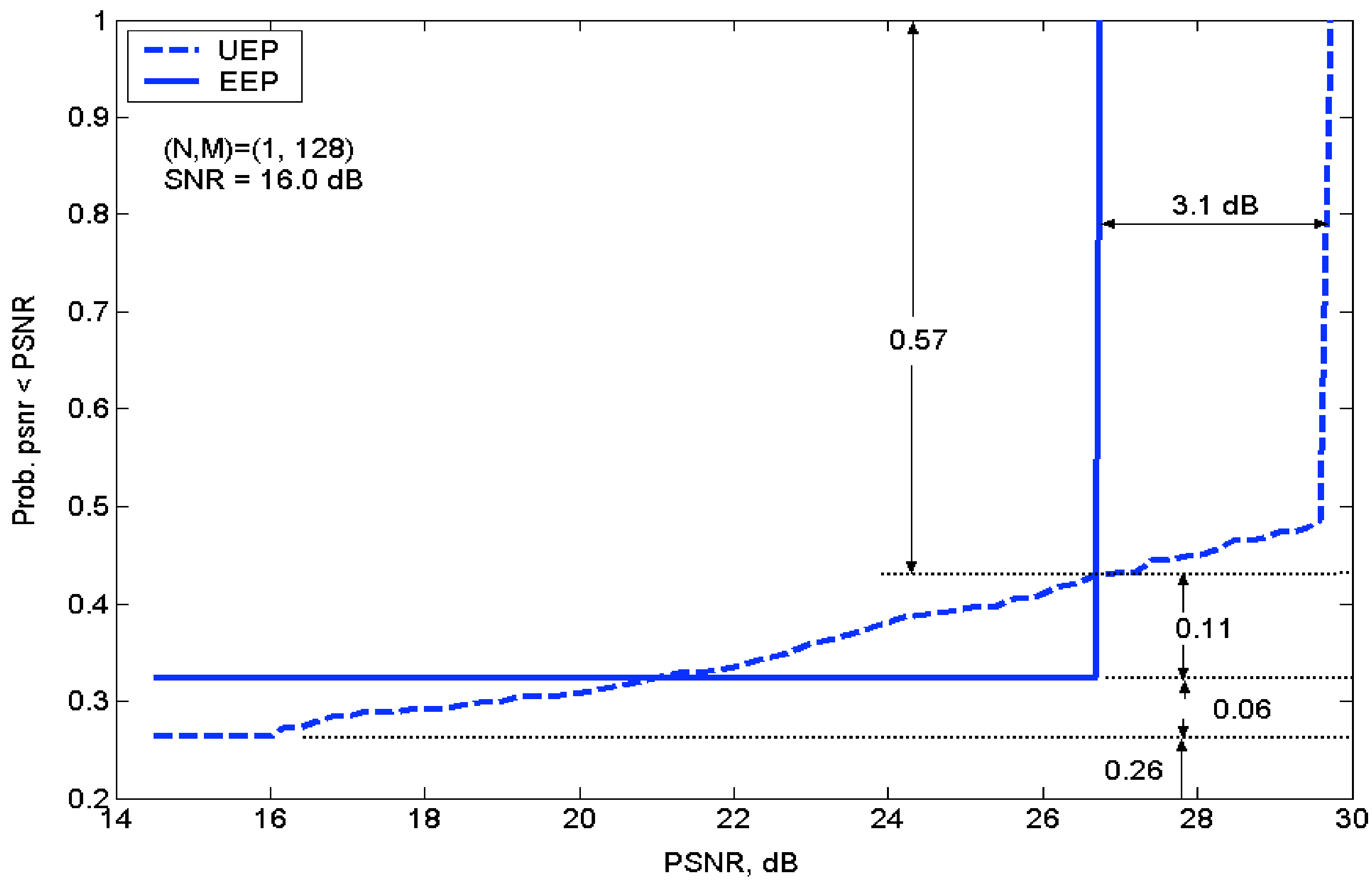
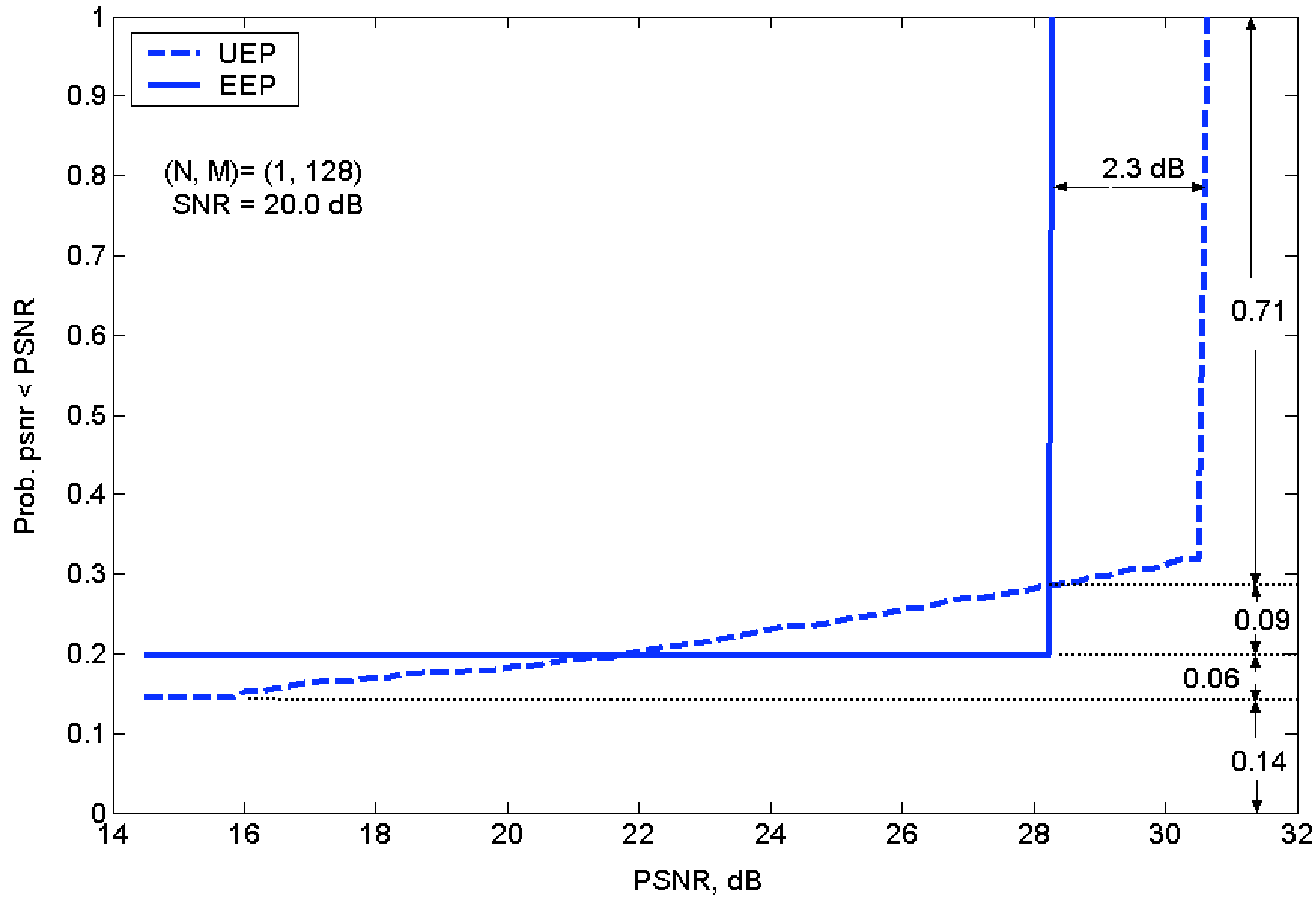
# UEP vs. EEP
# (Cumulative Distribution)




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

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




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

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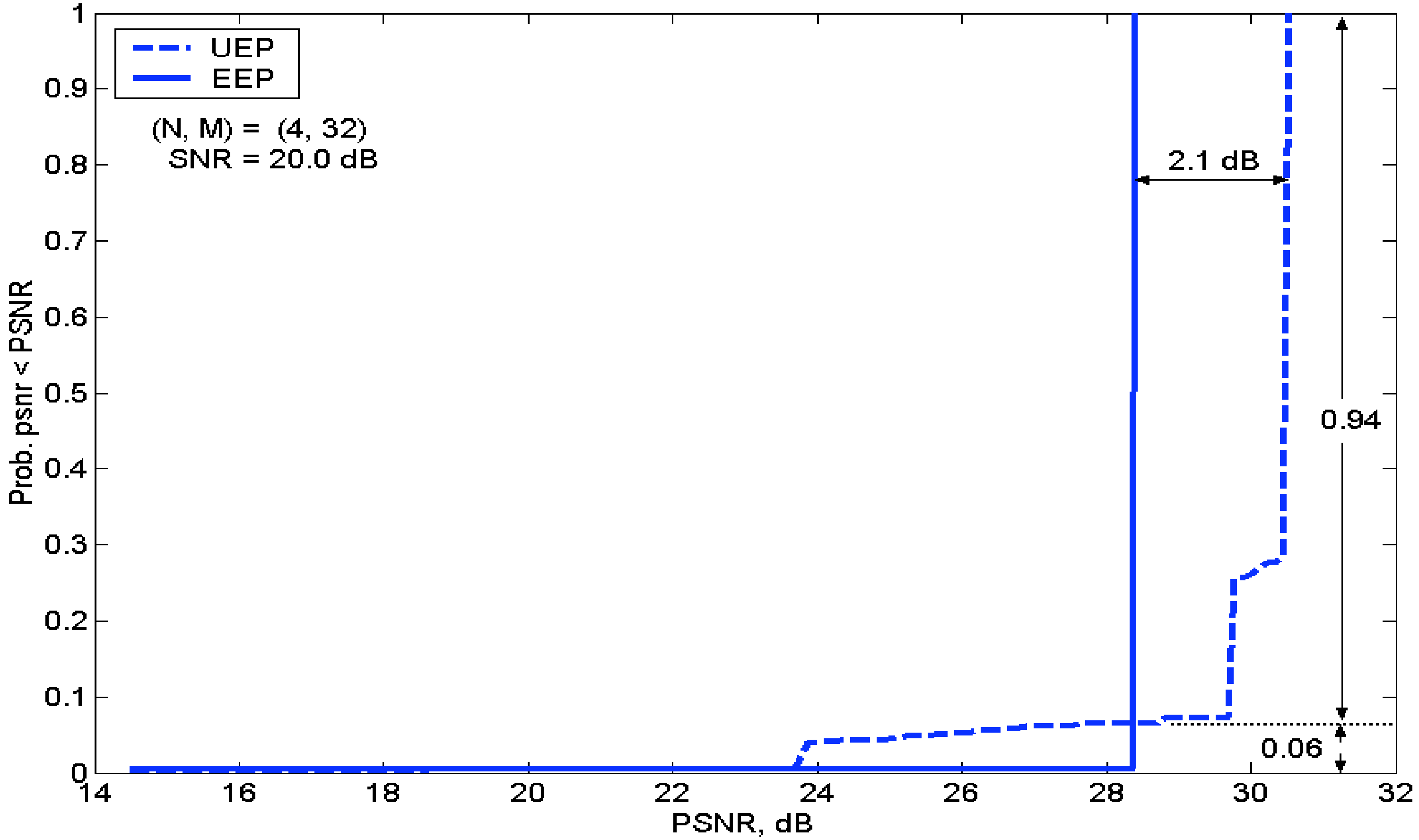
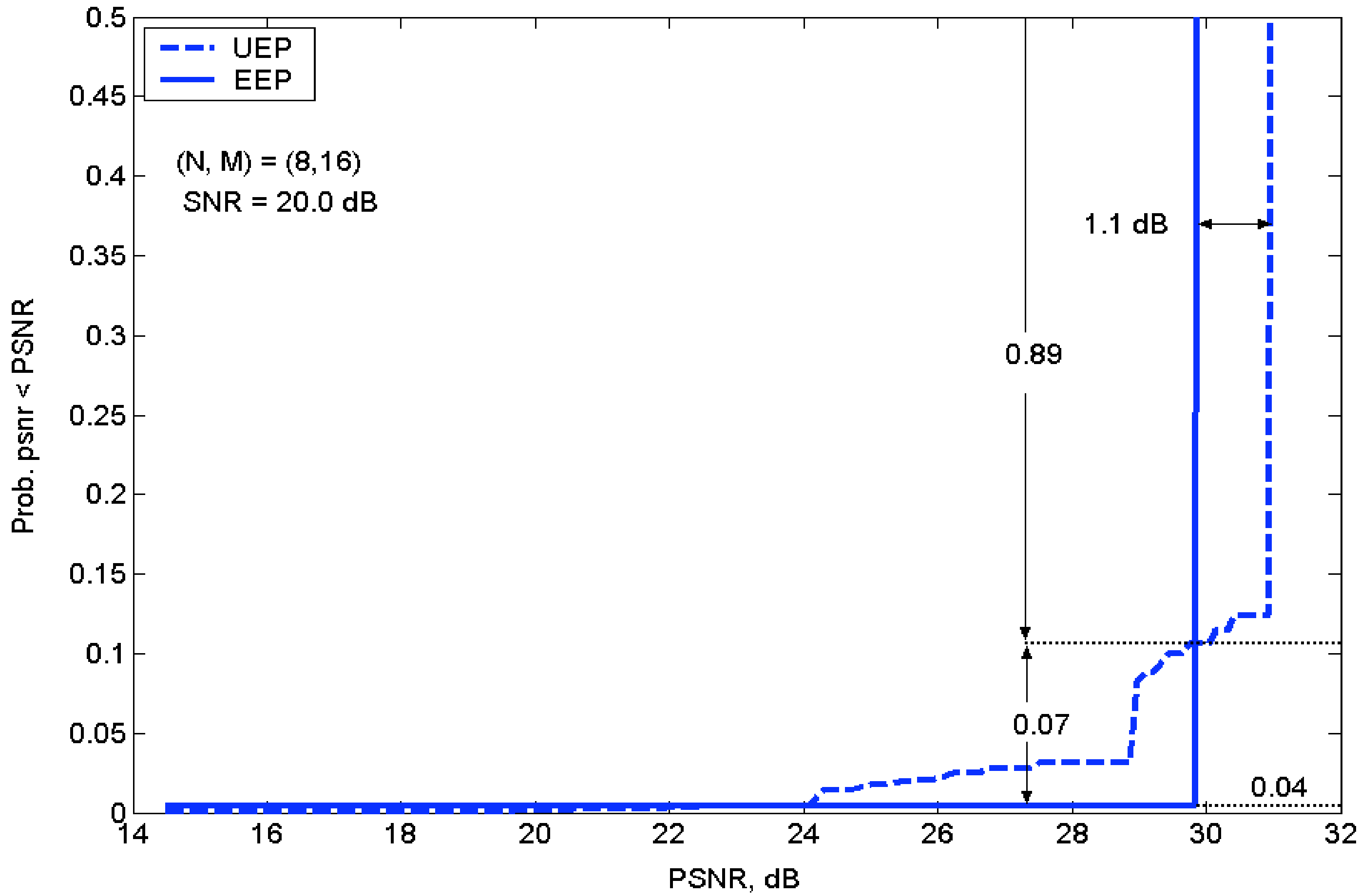
# UEP vs. EEP (Cont.)

## (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