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

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 \(D_g\).
Assume a frequency selective environment.

- N independent bands, each consisting of M correlated subcarriers.
- N_t = N×M = total # of subcarriers.
- Each subcarrier is assumed to experience slow flat Rayleigh fading.
Choose optimal allocation of information symbols and parity symbols to minimize the expected distortion.
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)
• 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

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

- $MSE_{avg} = \text{average mean square error}$

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

$X$ = 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

$\text{SNR} = 20.0 \, \text{dB}$

$\text{(N,M)} = (128,1)$

$\text{(N,M)} = (8,16)$

$\text{(N,M)} = (4,32)$

$\text{(N,M)} = (1,128)$
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.
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.
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)

\[(N, M) = (1, 128)\]
\[\text{SNR} = 16.0 \text{ dB}\]
UEP vs. EEP (Cont.)
(Cumulative Distribution)

\[(N, M) = (1, 128)\]
\[\text{SNR} = 20.0 \text{ dB}\]
UEP vs. EEP (Cont.)
(Cumulative Distribution)

\[(N, M) = (4, 32)\]
\[\text{SNR} = 20.0 \text{ dB}\]
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