Motion-Compensated Wavelet Video Coding Using Adaptive Mode Selection

Fan Zhai
Thrasyvoulos N. Pappas

Dept. Electrical & Computer Engineering
Northwestern University, USA

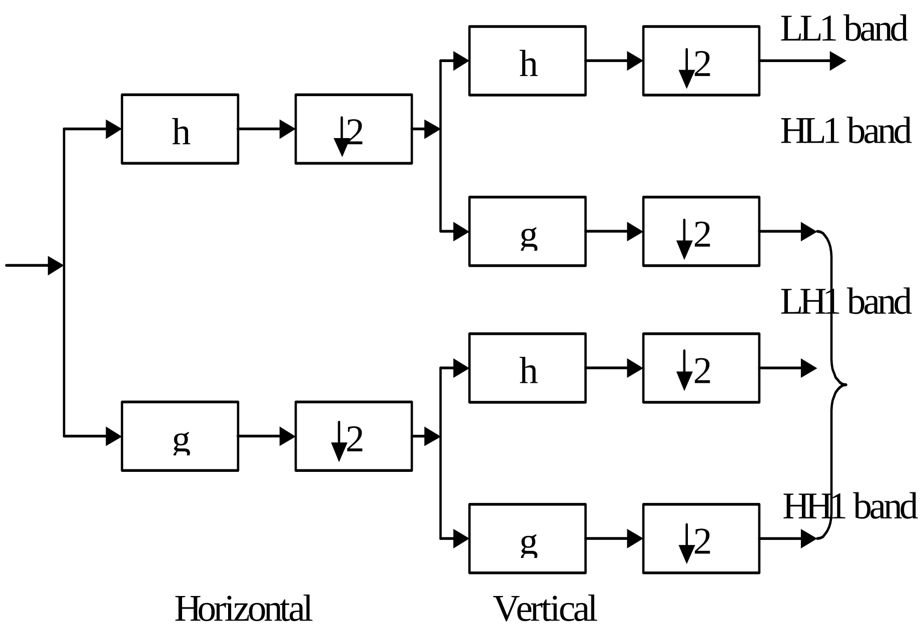
Wavelet-Based Video Coders

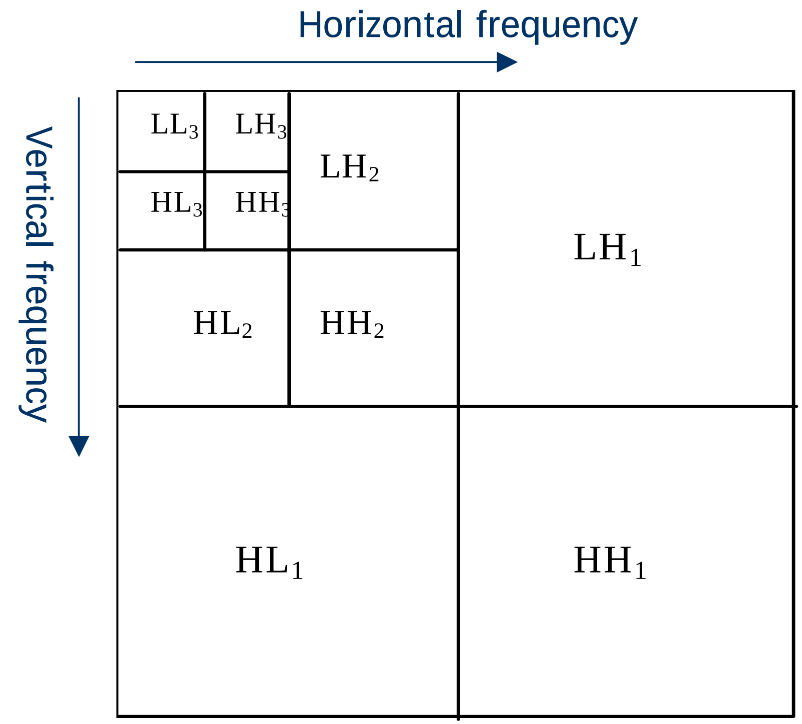
- 3D Wavelet w/o motion Compensation
  - Chen and Pearlman (VCIP'96)
  - Kim and Pearlman (3D SPIHT)(Data Compression '97)
  - Xu, Xiong, Li, and Y-Q. Zhang (3D ESCOT), (ACHA'01)
- 3D Wavelet w/ Motion Compensation
  - Frame warping: Taubman and Zakhor's work (94):
  - Local block warping/block displacement: Ohm (TIP '94) Choi and Woods (TIP '99)
  - Chen and Woods: MC-EZBC ('02)
  - Motion compensated lifting: Daubechies, Sweldens, Secker and Taubman (ICIP '01, ICIP'02), Luo etc. (ICME'01, VCIP'03)
- 2D motion-compensated wavelet coding
  - Y.-Q. Zhang and Zafar (CSVT '92)
  - Shen and Delp (SAMCoW) (CSVT '99)
  - Yang and Hemami (CSVT '00)
  - Yang and Ramchandran (TIM '00)

Overview

- **Advantages of DWT-based video coding**
  - Free of blocking artifacts
  - Support continuous data rate scalability
- **Problems**
  - The residue frames typically contain important image characteristics in the form of sharp transitions and edges, which make the DWT-based coders inefficient
- **Approaches**
  - Nonlinear wavelets: Heijmans and Goutsias, TIM'00; Pesquet-Popescu el., ICIP'03
  - Adaptive subband structure: Gerek and Cetin, TIM'00
  - Tune the characteristics of residue frames to DWT

Discrete Wavelet Transform





One level DWT decomposition

Pyramid structure of a wavelet decomposition

Adaptive Mode Selection

INTRA MB: No prediction. MB encoded with DCT. After quantization, inverse quantization, and inverse DCT, the difference from the original frame is placed in the residue frame.

INTER MB: Same as in MPEG-2 standard as far as prediction (includes SKIP mode, i.e. zero motion vectors); only nonzero motion vectors need to be transmitted; residual is not coded separately. The difference between the predicted MB and the original MB is placed in the residue frame.

INTER_ENCODE: Same prediction as in INTER MB case, but residual is coded with DCT. DCT is used to further reduce the variance of the prediction error. The refined prediction error is then placed in the residue frame.

Illustration of Prediction Error

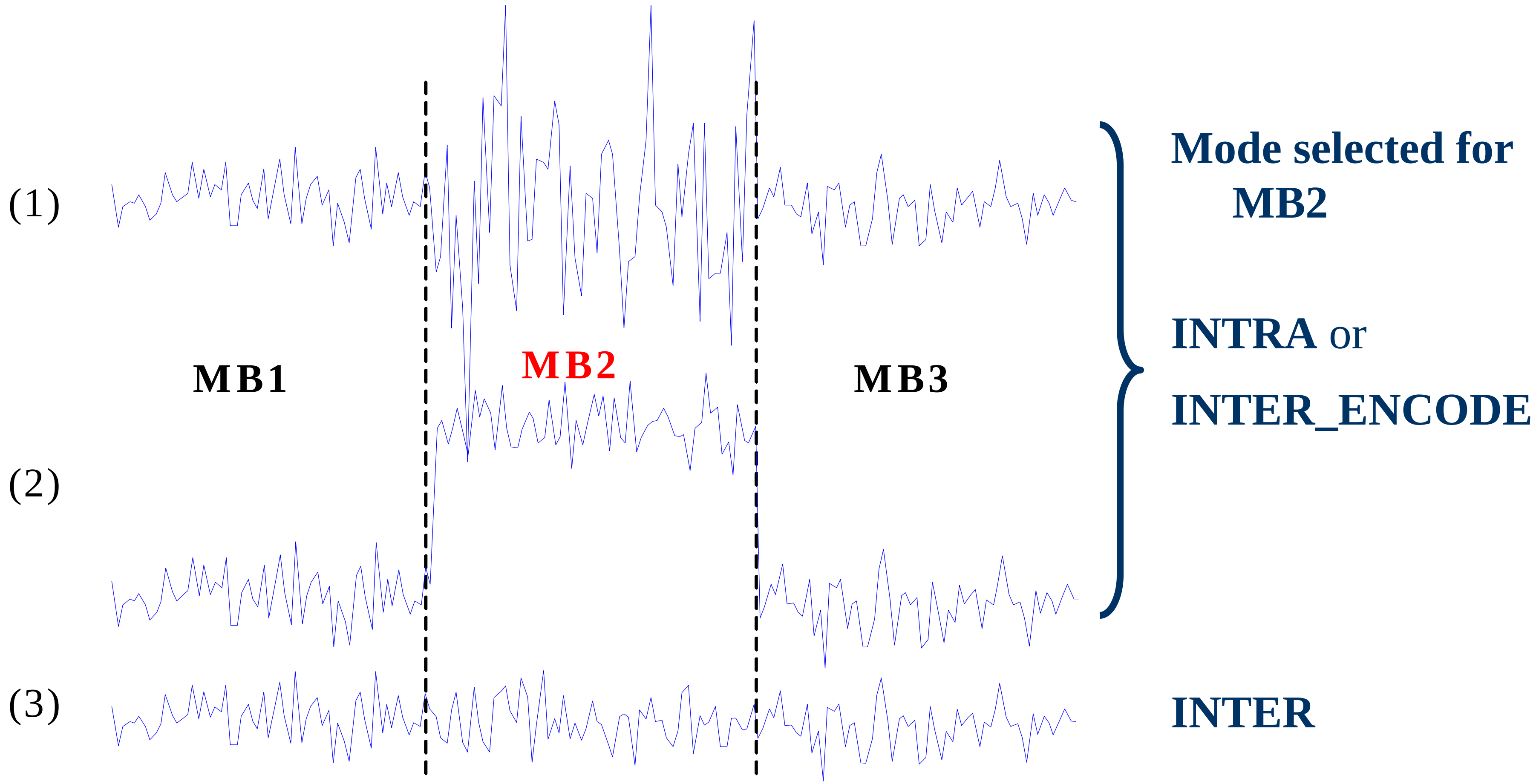


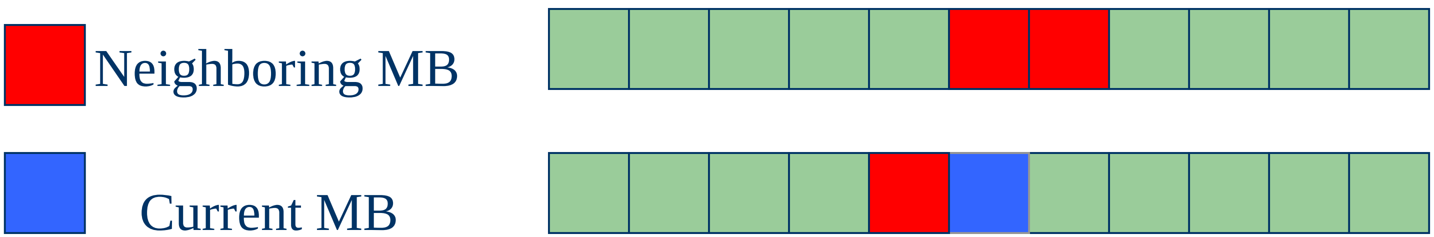
Illustration of different MB prediction errors in different cases

Adaptive Mode Selection

- Goal: Detect the local discontinuities in residue frame and smooth them by selective application of DCT coding.

- Strategy: Adaptively make the decision based on the comparison of

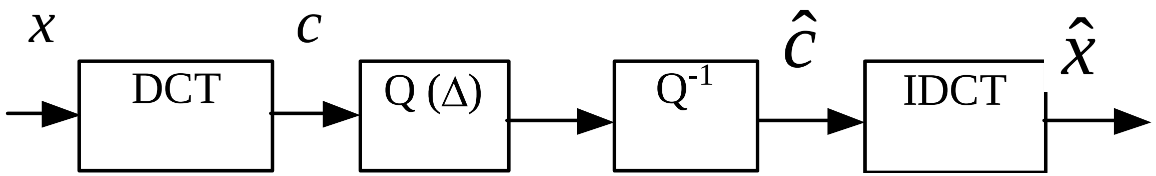
  var_intra: MB variance (no MC)
  var_inter: Lowest prediction error variance
  var_neighbor: Average of its neighboring MBs' residue variances



If (*var_inter<A*var_neighber* || *var_inter<B*var_intra* || *var_inter<C*)
        INTER MODE
elseif (*var_inter<D*var_intra*)
        INTER_ENCODE MODE
else
        INTRA MODE

IS&T/SPIE's 16th Annual Symposium
Electronic Imaging
Science and Technology

Quantization Stepsize



x: **original pixel values**

c: **DCT coefficients**

Δ: quantization stepsize

ĉ: **reconstructed coefficients**

$\hat{x}$ **: reconstructed pixel values**

- **Goal: determine Δ to achieve the desired error variance of *x*, $Var(x-\hat{x})$, which is dependent on the neighboring MBs' residue variance.**

$$c = AxA^T \quad \Rightarrow \quad |x-\hat{x}|^2 = |c-\hat{c}|^2$$

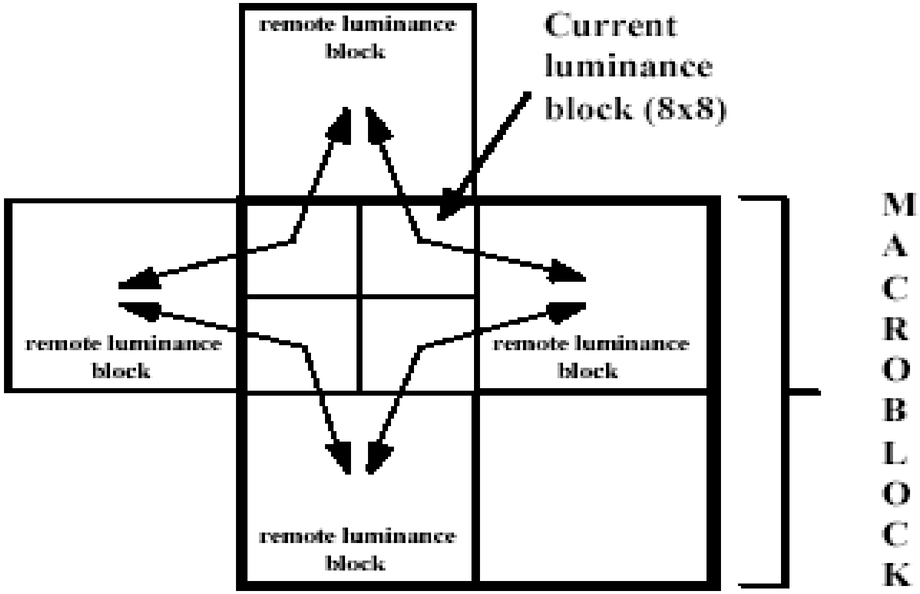
$$\Delta = (12 \times Var(x-\hat{x}))^{1/2}$$

Overlapped Block Motion Compensation

$$L(x,y)=\sum_k w_k(x,y)L_{ref}(x+m_x^k, y+m_y^k)$$

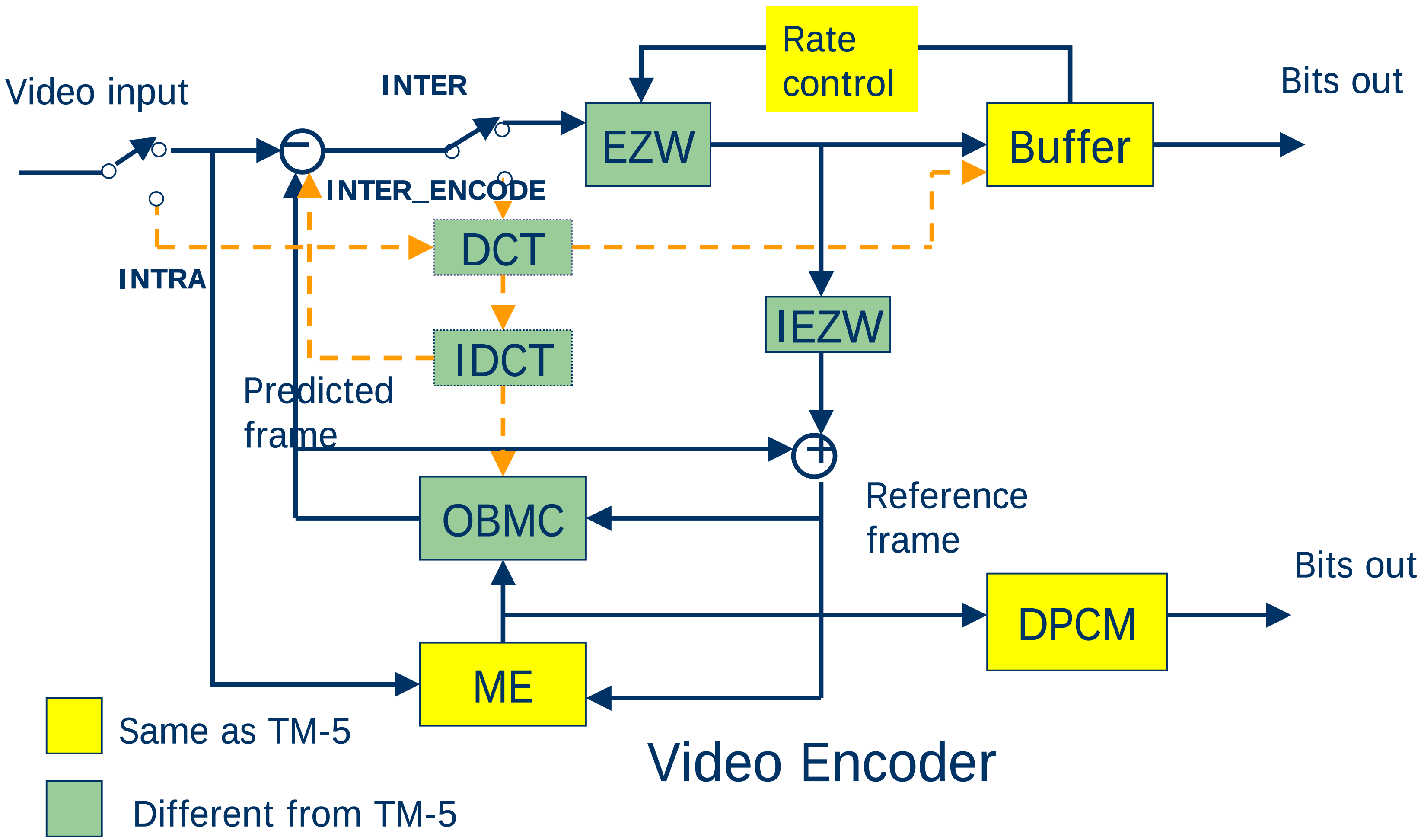
$$w_k(x,y):\ \text{Weighting matrix}\quad (m_x^k, m_y^k):\text{Motion vectors}$$

- **basic idea**: Superimpose several predictions considering motion vectors of adjacent blocks in order to reduce blocking artifacts.
- Prediction of current block is the weighted average of several corresponding blocks
- The corresponding blocks are determined by the motion vectors from adjacent blocks and current block.



IS&T/SPIE's 16th Annual Symposium Electronic Imaging Science and Technology
F. Zhai and T. N. Pappas, Motion-compensated wavelet video coding using adaptive mode selection
Northwestern University

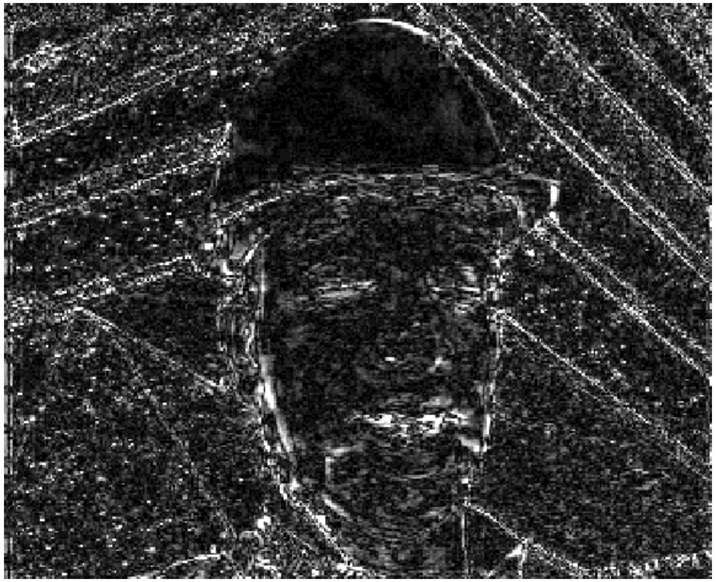
Coder Implementation



Comparison of Residue Frames

(a)

Without Adaptive Mode Selection

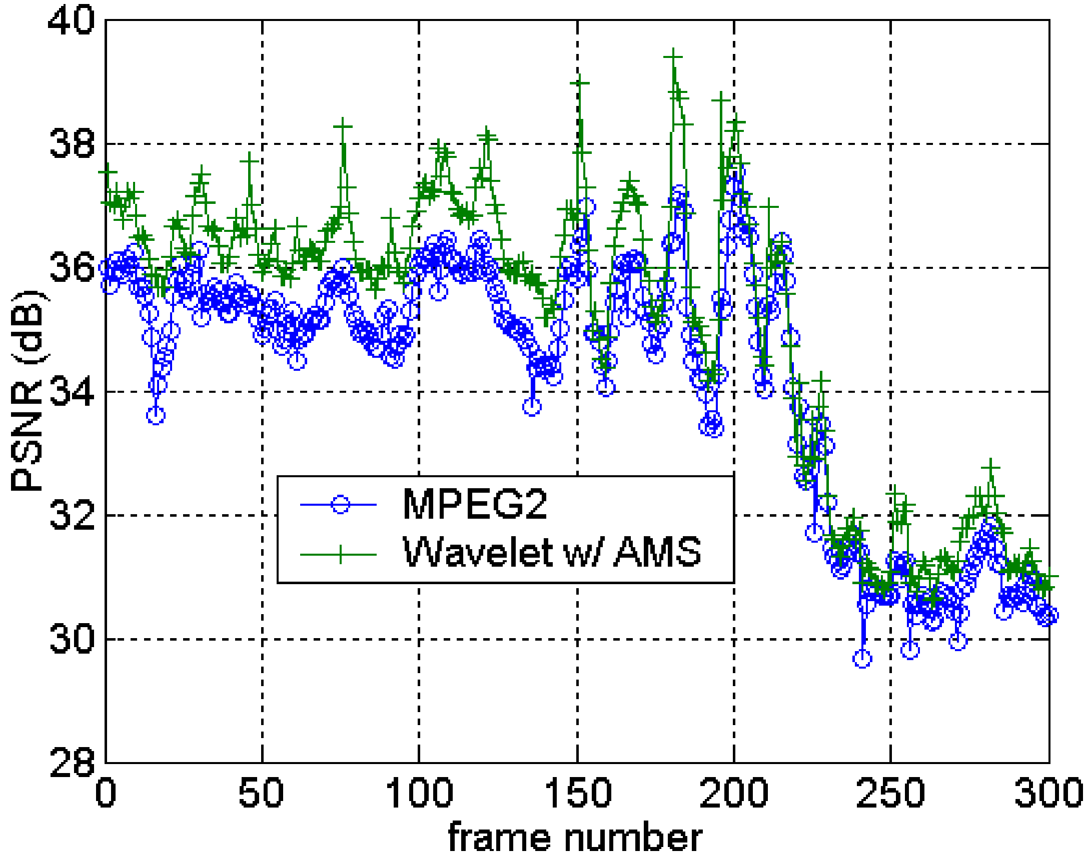


(b)

With Adaptive Mode Selection

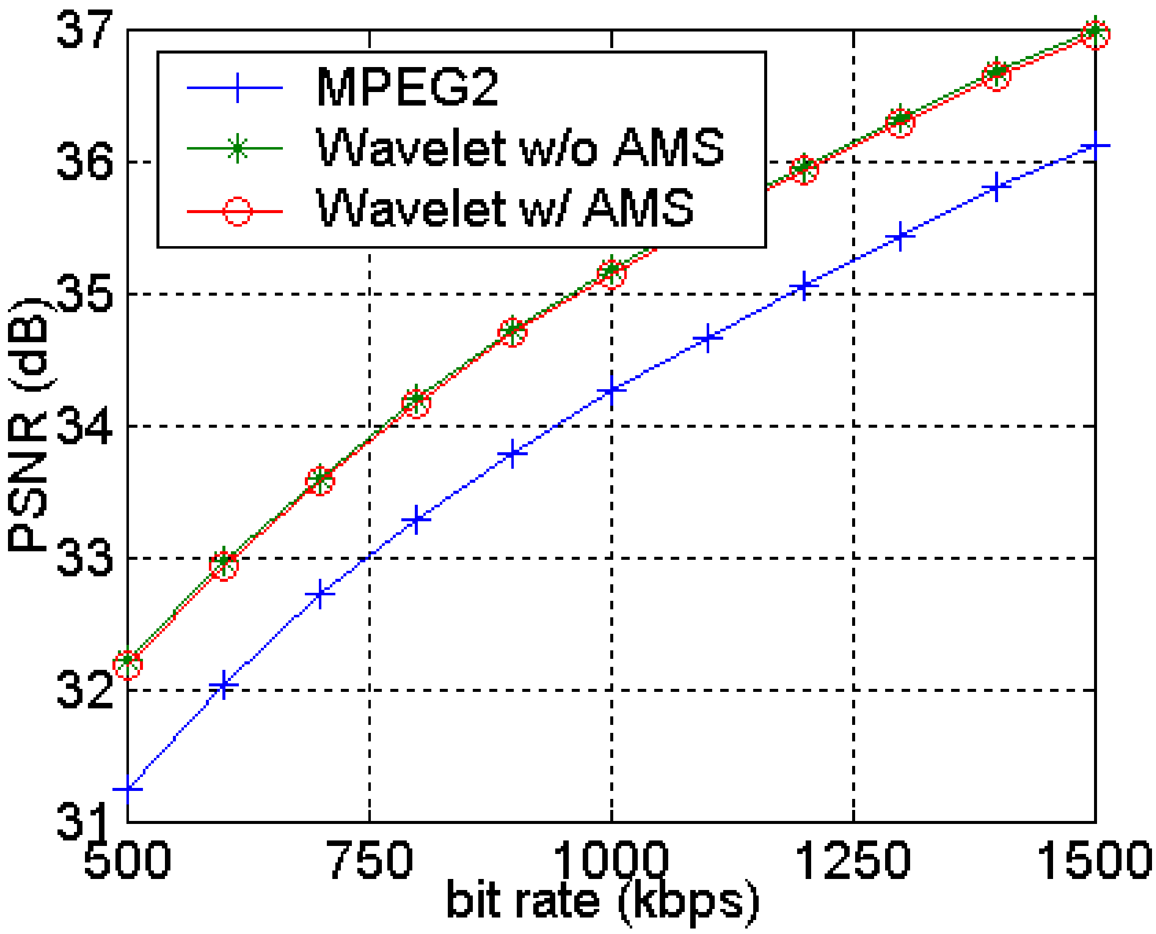
IS&T/SPIE's 16th Annual Symposium Electronic Imaging Science and Technology

Performance Comparison



- Foreman CIF resolution (1M bps, 30 fps)
- Based on TM-5 Rate control
- PSNR gain of 0.7dB obtained by DWT with AMS coder

Performance Comparison



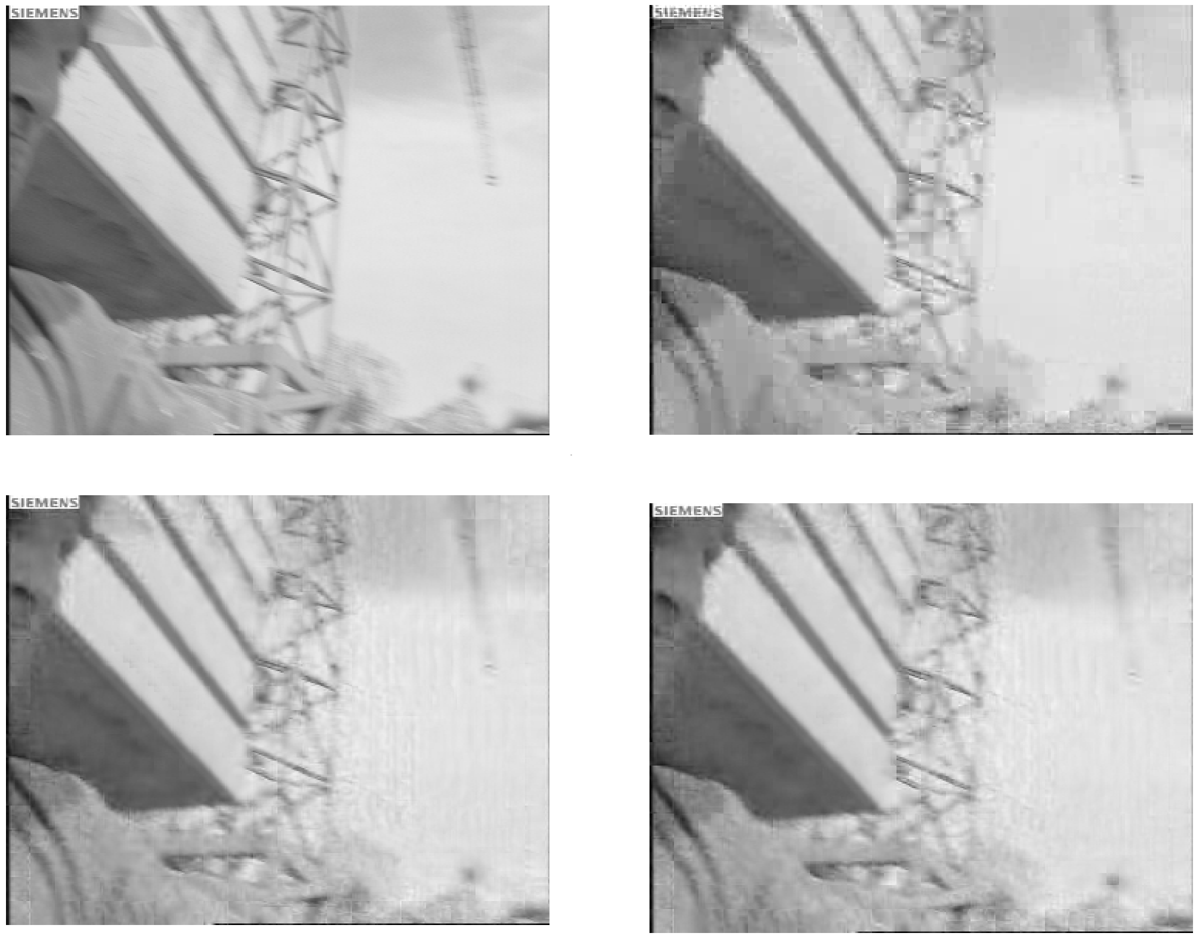
- Gains of 0.7-0.8 dB are obtained at a wide range of bit rates
- Wavelet w/ AMS is merely 0.02dB lower than Wavelet w/o AMS
- Wavelet w/ AMS can achieve better visual quality

IS&T/SPIE's 16th Annual Symposium Electronic Imaging Science and Technology

Comparison 1

(a) Original (b) DCT (c) DWT w/o AMS (d) DWT w/ AMS
Frame 16, 700kbps

Comparison 2



(a) Original (b) DCT (c) DWT w/o AMS (d) DWT w/ AMS
Frame 188, 700kbps

Conclusions

- Proposed a simple adaptive mode selection method for motion-compensated wavelet video coding, which has proved to be effective in smoothing the residue frame, and improving the reconstruction visual quality.
- Achieves 0.7-0.8 dB coding gains at wide range of bit rates (compared with MPEG-2) and visually improved quality free of blocking artifacts

Future Work

- Adaptive selection of coder parameters {*A*,*B*,*C*,*D*} based on the target bit rate.
- Adaptive enabling or disabling OBMC and optimal joint selection of OBMC weights and motion vector determination
- Rate-distortion optimization framework for incorporating mode selection in order to achieve best overall performance
- Variable-size motion compensation