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Video Coding with Motion-Compensated Temporal Transforms and Side Information

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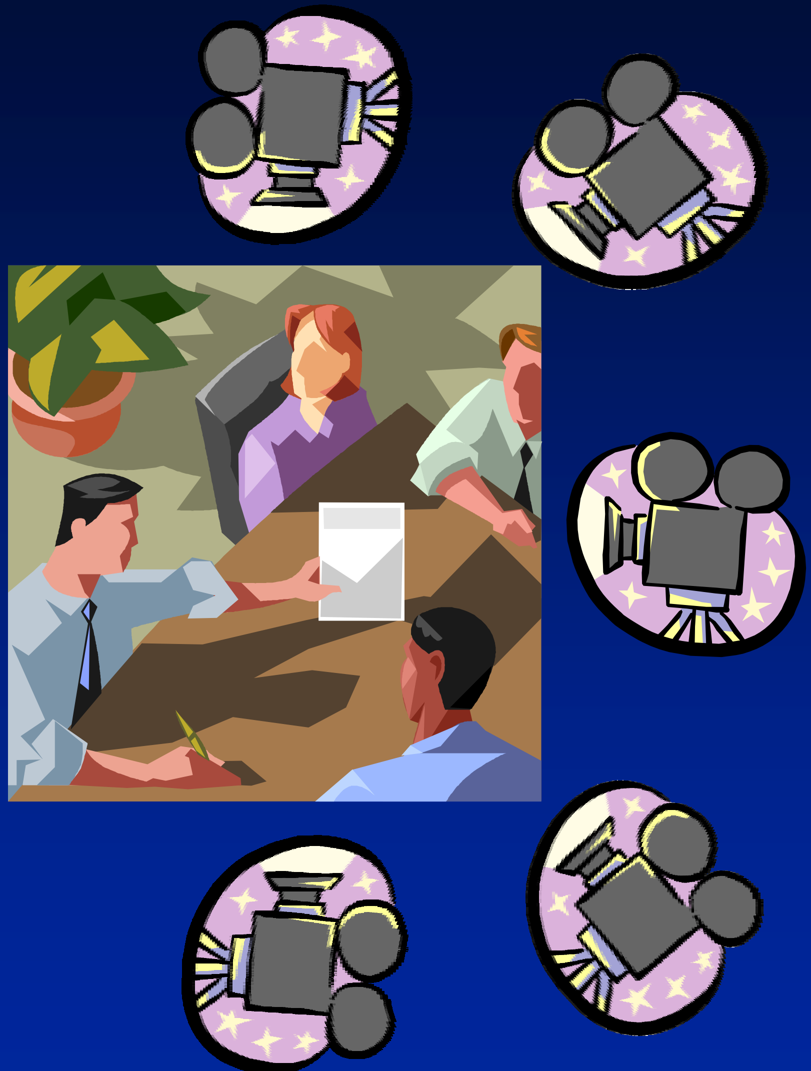
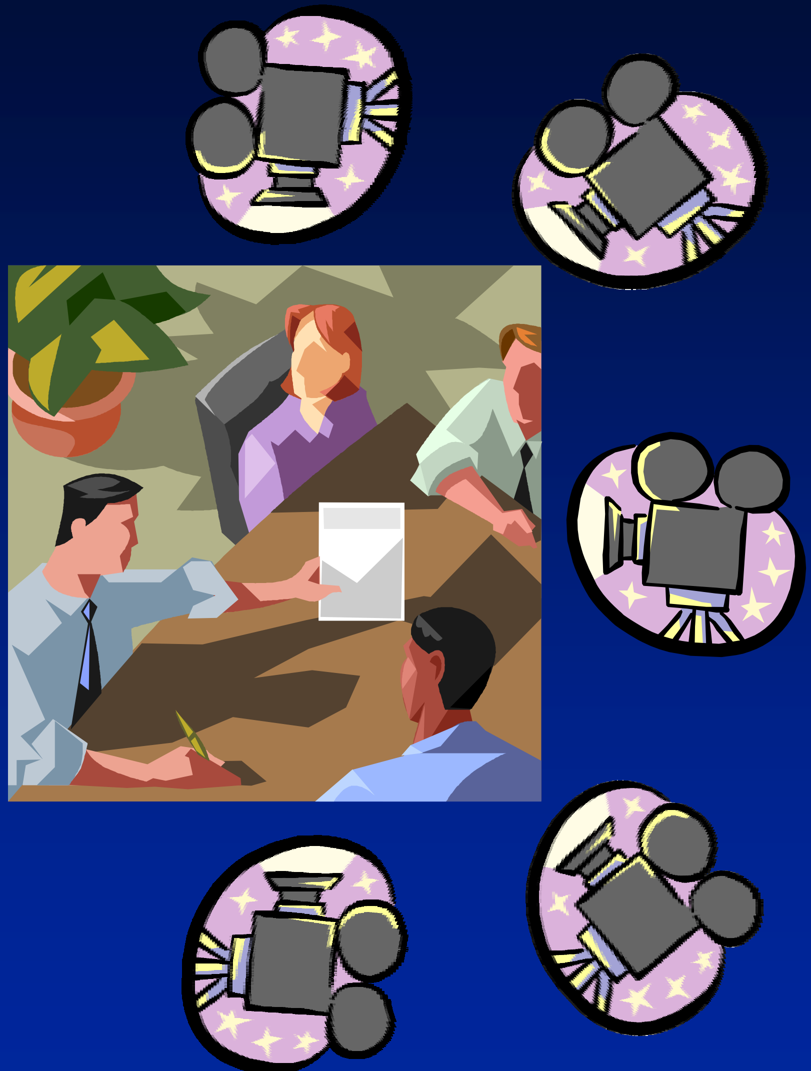
Coding Scenario I



- 3-dimensional scene that evolves in time
- Observed by multiple video cameras located at different positions
- Each camera signal is coded locally
- The cameras are connected directly to the network
- One remote decoder is able to reconstruct arbitrary views

Coding Scenario II

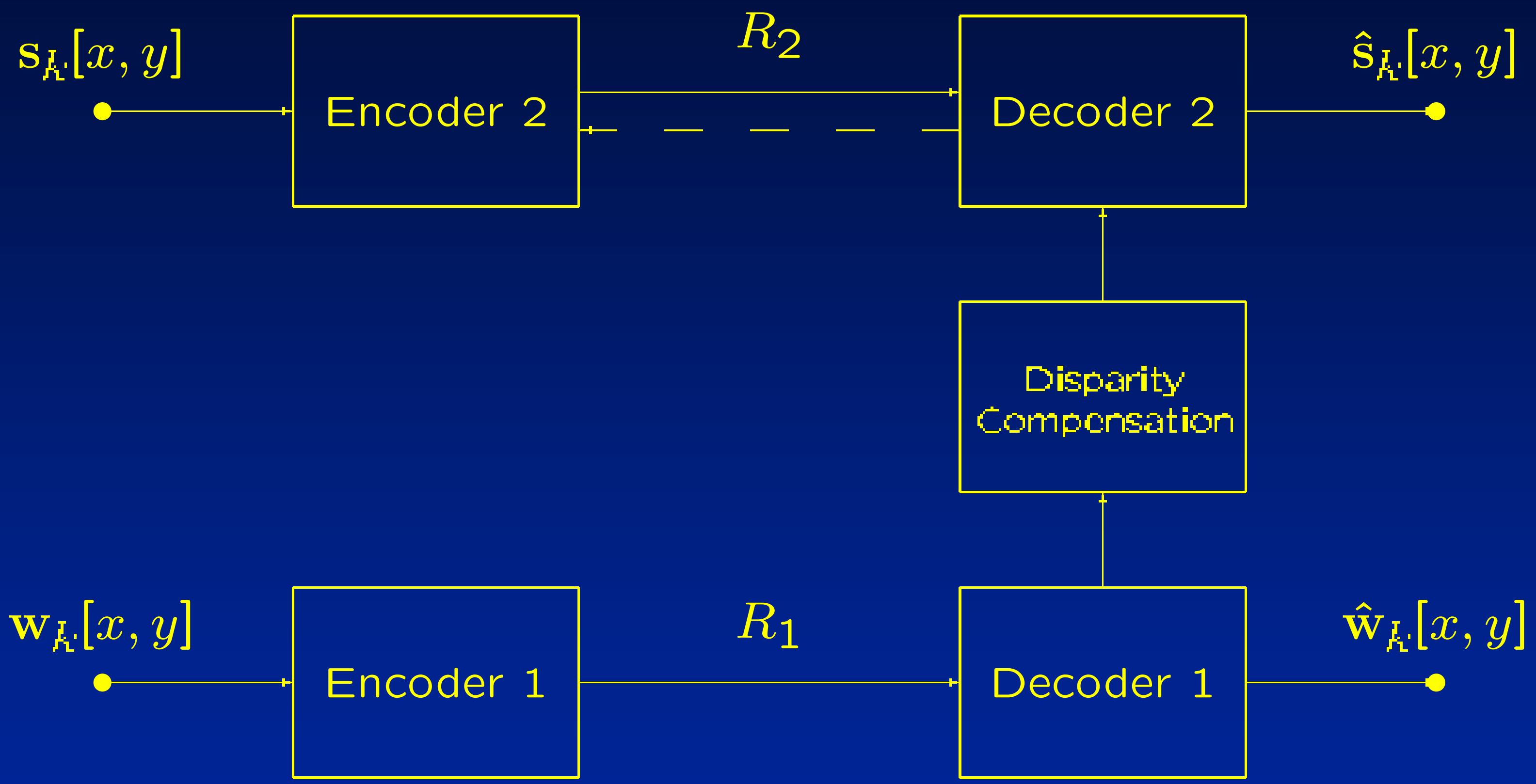


- How to use the information of neighboring cameras to improve the efficiency of the current video encoder?
- Obviously, side information can be used at encoder and decoder
- But what if the encoder do not communicate directly?
- Each encoder needs to operate independently and to transmit robustly to the central decoder!

Outline

- Coding architecture with disparity compensation at the decoder
- Rate distortion with video side information
- Signal model for subband coding of video
- Conditional Karhunen-Loeve transform
- Performance bounds
- Motion-compensated temporal Haar wavelet
- Experimental results

Coding Architecture with Disparity Compensation

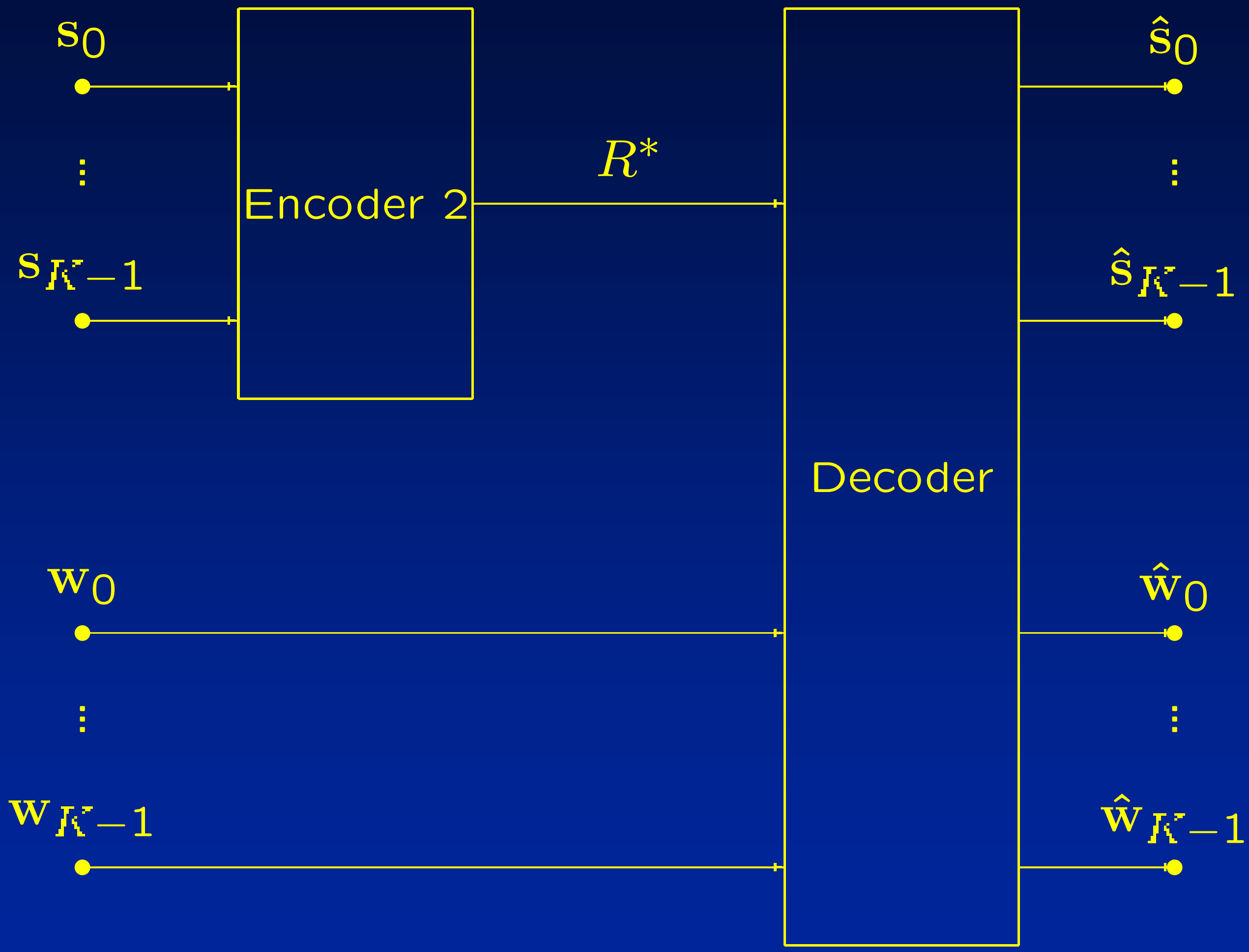


How to encode the video signal at each camera?

Rate Distortion with Video Side Information

- Vector **s** of *K* input pictures to be encoded
- Vector **w** of *K* side information pictures
- At high rates:
  - ***Reconstructed side information at the decoder approaches the original side information, i.e.,***
    $\hat{\mathbf{w}} \longrightarrow \mathbf{w}$
  - ***Wyner-Ziv coding scheme***
  - ***Rate distortion function of Encoder 2 is bounded by the conditional rate distortion function [Wyner & Ziv, 1976]***

Rate Distortion with Video Side Information



Rate Distortion with Video Side Information

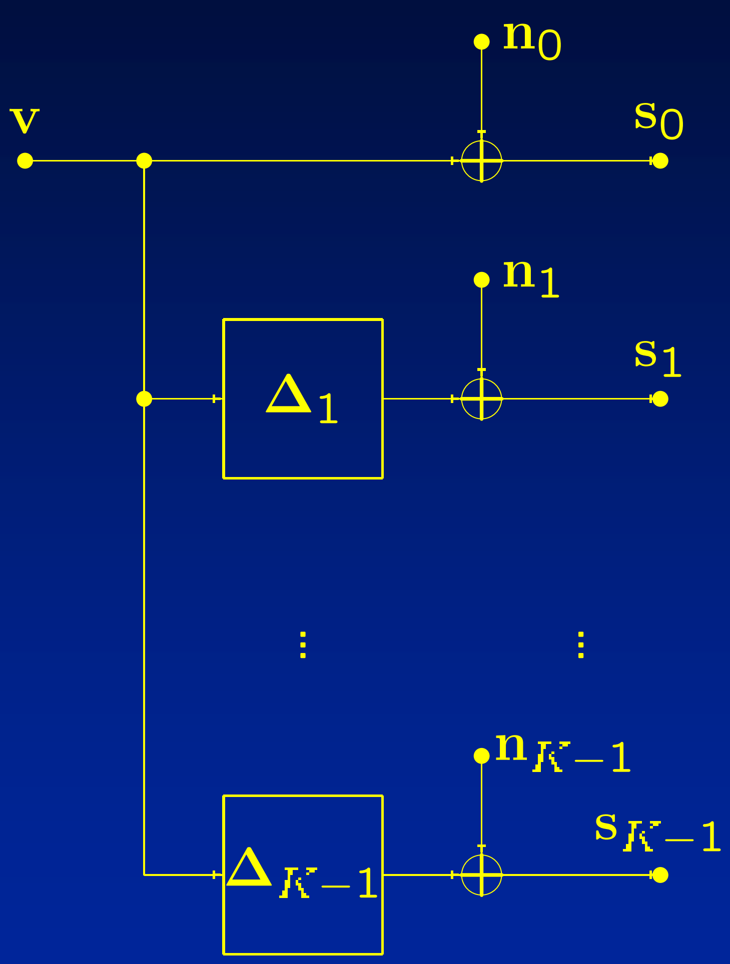
- Very accurate disparity compensation
- Consider illumination changes and occlusions
- Side information is a noisy version of the video signal to be encoded:

$$\mathbf{w} = \mathbf{s} + \mathbf{u}$$

- The vector of noisy images **u** is statistically independent of the vector of input pictures **v**.
- Matrix of conditional power spectral densities:

$$\Phi_{\mathbf{s}|\mathbf{w}}(\omega) = \Phi_{\mathbf{ss}} \left[\Phi_{\mathbf{ss}} + \Phi_{\mathbf{uu}}\right]^{-1} \Phi_{\mathbf{uu}}$$

Signal Model for Subband Coding of Video



Model for coding with motion-compensated lifted wavelets [Flierl & Girod, 2003]

$\mathbf{v}$	model picture
$\mathbf{\Delta}_k$	k-th displacement error
$\mathbf{n}_k$	k-th noise signal
$\mathbf{s}_k$	k-th motion-compensated signal

Signal Model for Subband Coding of Video

- Basic idea:
  - *Reversible true motion trajectories*
  - *Reversible estimated motion trajectories*
  - *Identical accuracy of motion compensation*
- Power spectral densities of *K* pictures:

$$\frac{\Phi_{\mathbf{ss}}(\omega)}{\Phi_{\mathbf{vv}}(\omega)} = \begin{pmatrix} 1+\alpha & P & \cdots & P \\ P & 1+\alpha & \cdots & P \\ \vdots & \vdots & \ddots & \vdots \\ P & P & \cdots & 1+\alpha \end{pmatrix}$$

$\alpha(\omega, \sigma_{\mathbf{n}}^2)$
normalized PSD
of noise

$P(\omega, \sigma_{\mathbf{\Delta}}^2)$
characteristic function
of displacement error

Conditional Karhunen-Loeve Transform

- Conditional KLT of *K* motion-compensated pictures given *K* side information pictures:
  - *First eigenvector adds all components and scales with* $1/\sqrt{K}$
  - *For the remaining eigenvectors, any orthonormal basis can be used that is orthogonal to the first eigenvector*
- Independent of side information, i.e., side information is not required at the encoder
- Motion-compensated Haar wavelet meets these requirements

Performance Bounds via Conditional Eigendensities

- Rate difference with respect to coding without video side information for each picture k

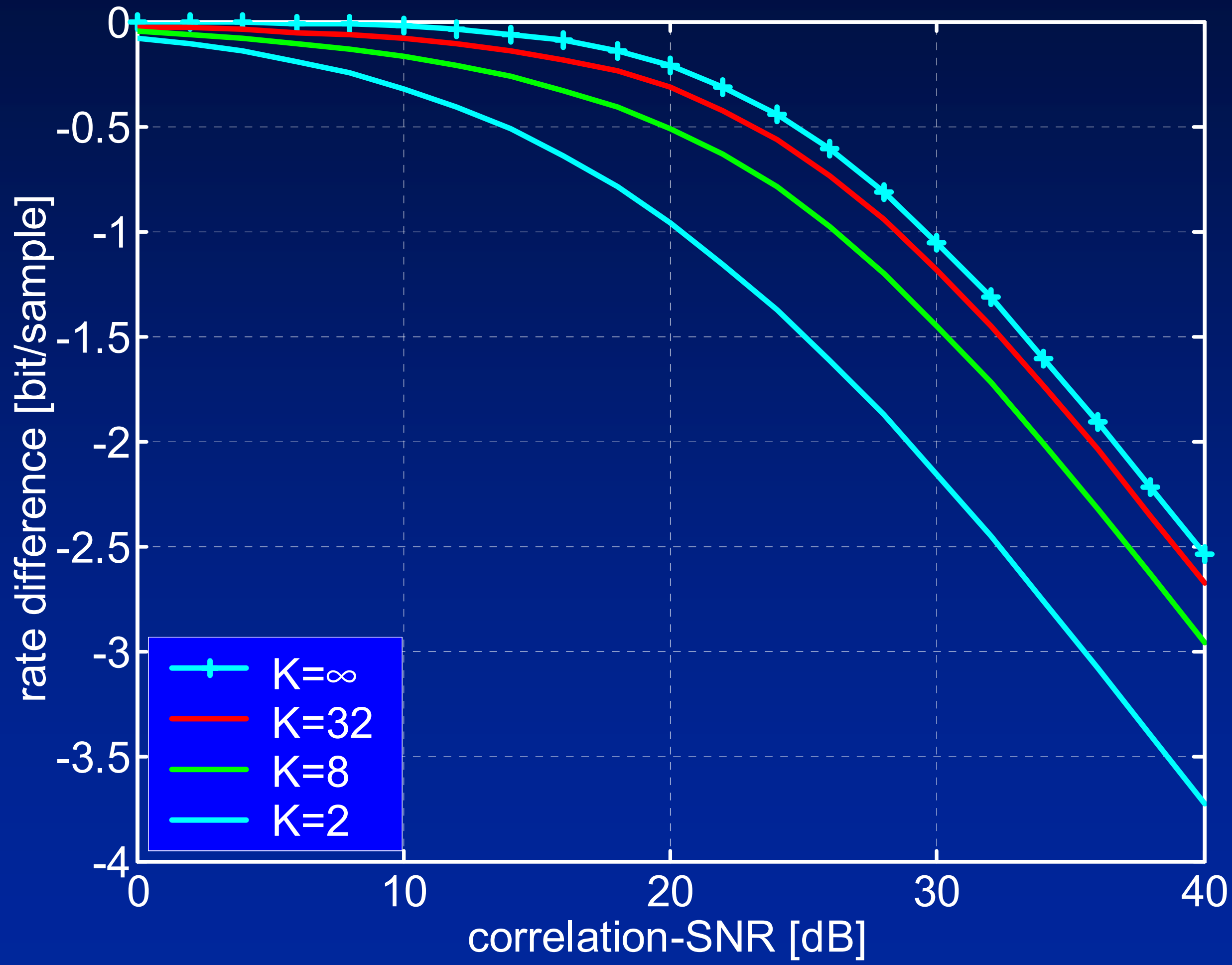
$$\Delta R_k^* = \frac{1}{4\pi^2} \int_{-\pi}^{\pi} \int_{-\pi}^{\pi} \frac{1}{2} \log_2 \left(\frac{\Lambda_k^*(\omega)}{\Lambda_k(\omega)} \right) d\omega$$

  - *Measures maximum bit-rate reduction*
  - *Compares to optimum coding without video side information*
  - *For the same mean squared reconstruction error*
  - *For Gaussian signals*

- Average rate difference for Encoder 2:

$$\Delta R^* = \frac{1}{K} \sum_{k=0}^{K-1} \Delta R_k^*$$

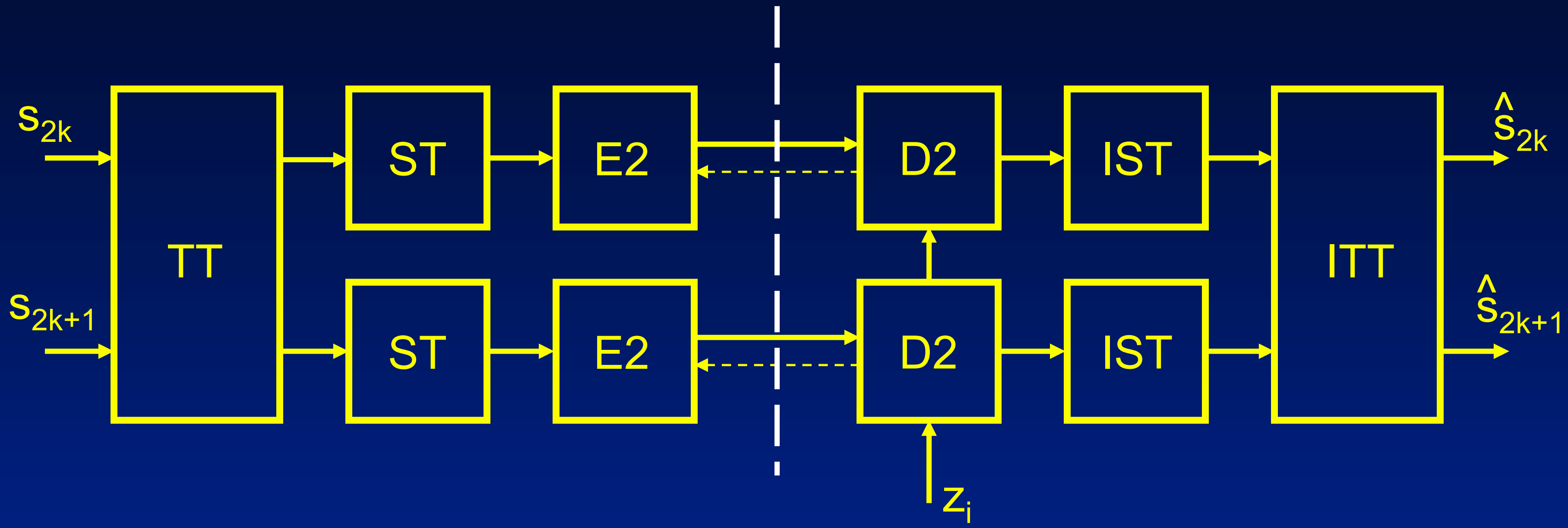
Rate Difference for High-Rate Approximation



Side information is less efficient for larger GOP sizes

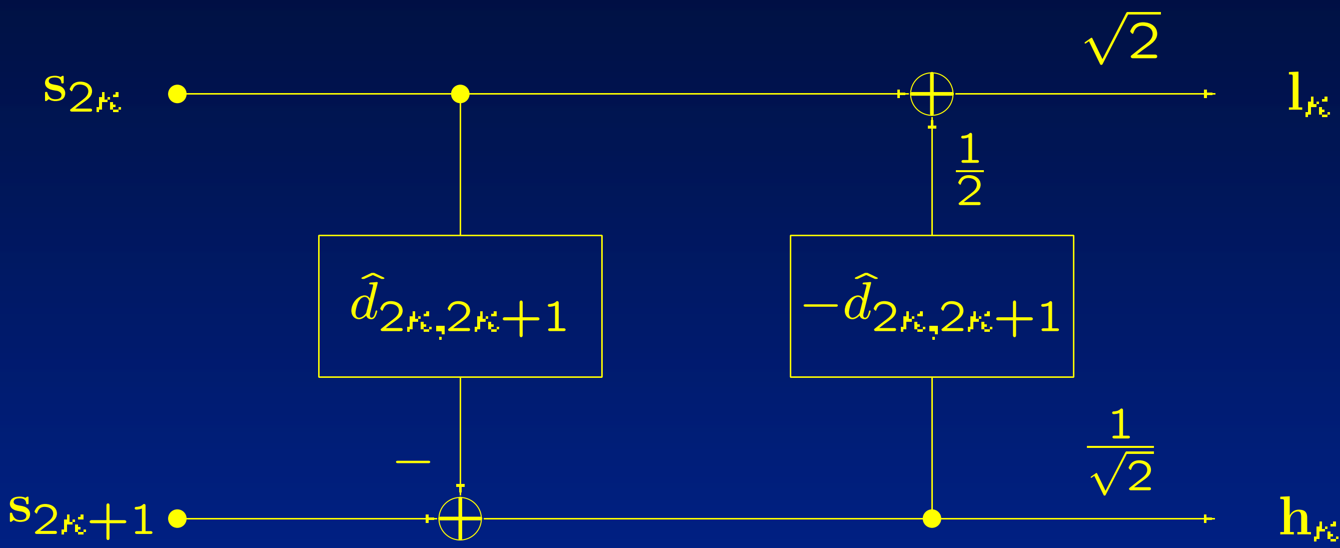
RNL = -30 dB
Half-pel accuracy

Coding Scheme



- Temporal Transform: Motion-compensated Haar wavelet
  - *Dyadic decomposition for each group of K pictures*
- Spatial Transform: 8x8 DCT
- Coefficient Coder: Nested lattice code
  - *Same minimum distance for all codes*
  - *Coefficient decoder uses side information z_i*

Motion-Compensated Temporal Haar Wavelet

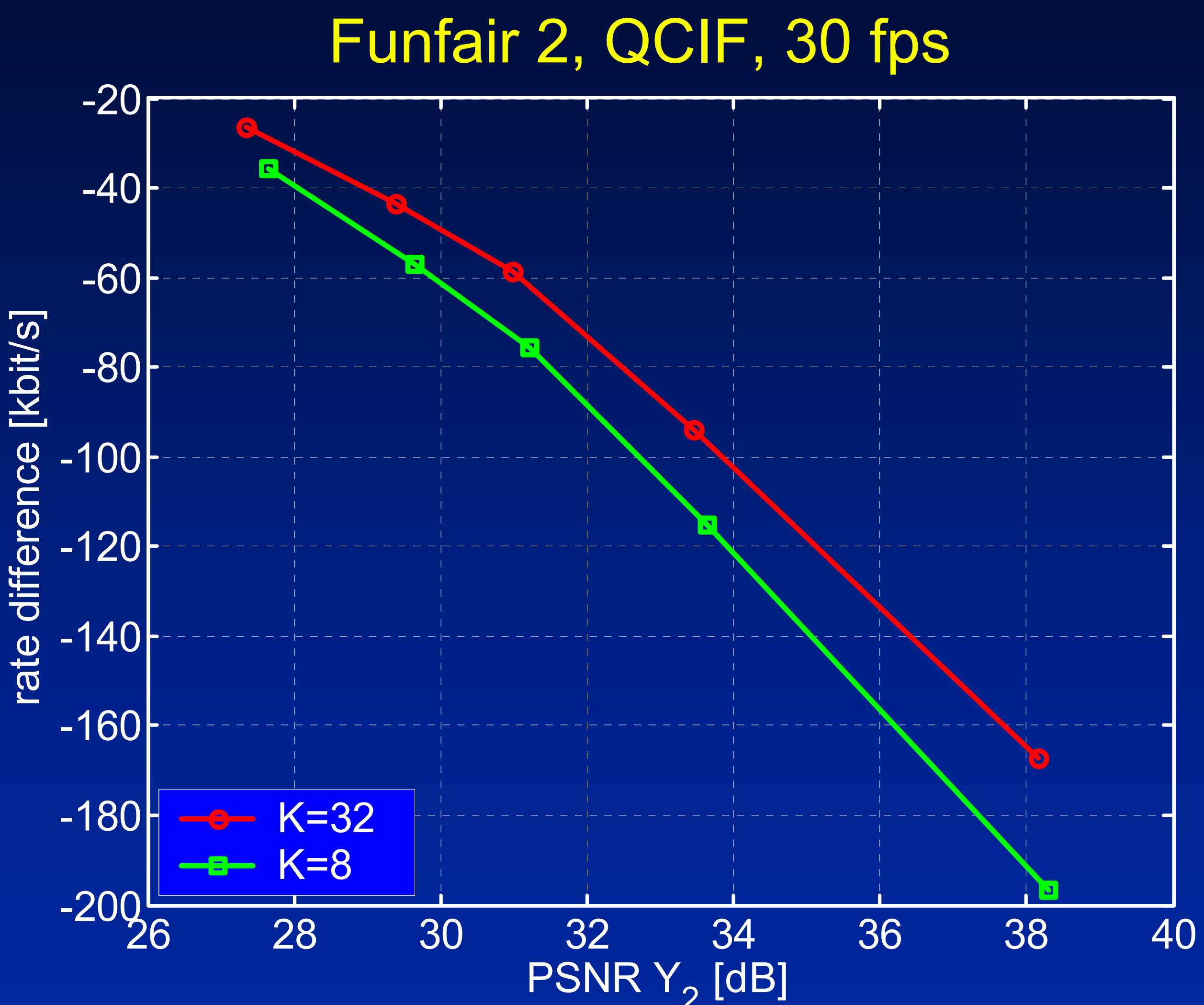


- Haar wavelet with motion-compensated lifting steps [Pesquet-Popescu & Bottreau, 2001]
- 16x16 block motion compensation with half-pel accuracy

Experimental Results

- *Encoder 1* encodes the side information (left view of a stereoscopic sequence) at high quality
- *Encoder 2* encodes the right view of a stereoscopic sequence
- The GOP sizes for *Encoder 1 & 2* are identical
- The side information is disparity compensated in the image domain
- The disparity is estimated for 24 blocks on the first frame pair
- The camera positions are unaltered in time and the disparity estimates are used for all images

Temporal Decorrelation and Video Side Information



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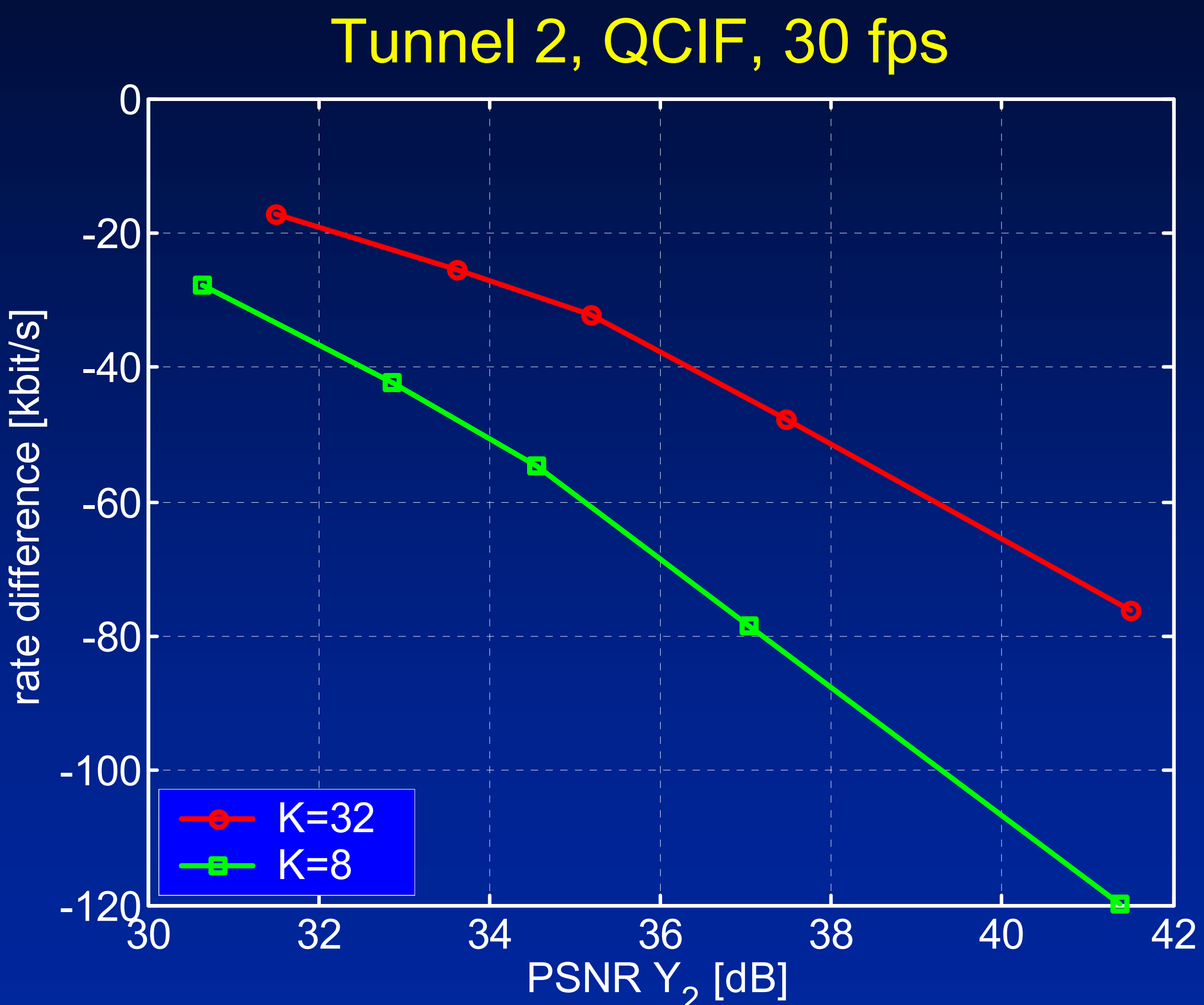

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Conclusions

- Robust coding of video signals in the presence of highly correlated video side information
- Rate distortion with video side information
- Conditional Karhunen-Loeve transform
  - *Motion-compensated lifted Haar wavelet*
  - *Provides a robust representation for each camera signal*
- Performance bounds via conditional eigendensities
- Observe a trade-off between the level of temporal decorrelation and the efficiency of multi-view side information:
  - *Efficiency of side information increases for decreasing GOP size*