Model-based Rate Allocation in Distributed Video Coding Systems

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Distributed Video Coding - Motivation

Standard Video Coders - MPEG, H.26x
- Based on hybrid of Motion Estimation and Transform Coding
- Complex encoder - due to ME
- Downlink oriented

New Video Applications - Wireless/Cellular Video, Surveillance
- Low cost
- Limited power → Low complexity encoder
- Limited computational resources
- Limited bandwidth → coding efficiency
- Uplink oriented
Slepian Wolf (SW) Coding - Lossless Case

- Switch open: $R_{X|Y}^{SW} = R_{X|Y} = H(X|Y)$, no rate loss

Wyner Ziv (WZ) Coding - Lossy Case

- RD function: $R_{X|Y}^{WZ}(D) \geq R_{X|Y}(D)$
- Equality holds if: $Y = X + N$, $X$ and $N$ independent Gaussian sources, MSE distortion
- Practical WZ coding: Quantization followed by SW coding
Slepian Wolf (SW) Coding - Lossless Case

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Need for Feedback Suppression

**Feedback Channel**
- Incurs delay → Unsuitable for real-time applications
- Not available in some apps. (e.g. storage)

**Related Work [Morbee 06, 08], [Brites 07]**
- Studied performance of a system with feedback offline or evaluated $H(X|Y)$ at bitplane level.
- Rate estimation is based on the quantized data

**Feedback Suppression**
- Proposed approach: Encoder–side rate control based on a rate distortion model
Rate Distortion Model

WZ Coding - Laplacian Sources [V. Sheinin 06]

- \( X = Y + N \), \( Y \sim \text{Laplace}(\mu_y, \sigma_y^2) \) and \( N \sim \text{Laplace}(\mu_n, \sigma_n^2) \) i.i.d., \( N \) independent of \( Y \)
- Infinite Uniform Scalar Quantizer - \( \text{IUSQ}(\Delta, \varepsilon) \)
- RD characterization assuming perfect SW coding \( H(X|Y) \)
- The RD model is given in integral form expressions

Approximation RD Model

- \( R(\Delta) = \exp[a_r \exp(-(\Delta/b_r)\gamma_r) + m_r\Delta + n_r] \)
- \( D(\Delta) = \exp[a_d \exp(-(\Delta/b_d)\gamma_d) + n_d] \)
- \( \{a_r, b_r, \gamma_r, m_r, n_r\} \) and \( \{a_d, b_d, \gamma_d, n_d\} \) are evaluated offline for a set of \( \sigma_y^2, \sigma_n^2 \) and \( \varepsilon \)
Approximation RD Model vs. Numerical Model

![Graph showing rate vs. distortion for different models](image)

- Ap. Md. $\sigma_y^2 = 2290 \sigma_n^2 = 230$
- Nm. Md. $\sigma_y^2 = 2290 \sigma_n^2 = 230$
- Ap. Md. $\sigma_y^2 = 4610 \sigma_n^2 = 720$
- Nm. Md. $\sigma_y^2 = 4610 \sigma_n^2 = 720$
- Ap. Md. $\sigma_y^2 = 6290 \sigma_n^2 = 570$
- Nm. Md. $\sigma_y^2 = 6290 \sigma_n^2 = 570$

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Once obtaining $\Delta$ that satisfies the RD constraints:

- What is the *number of IUSQ bin labels?* (Nested Quantization)
- What should be the *rate of each bitplane?*
- Both questions can be answered by evaluating the RD function

![Graph showing the relationship between Innovation SNR and Rate](attachment://graph.png)
Applications of RD Model in DVC

DVC Encoder–Side Rate Control

- Feedback suppression - evaluate RD for the whole frame
- Use frame difference to estimate 'noise' statistics (applicable only to low motion sequences)

![Graph showing PSNR vs Rate for different conditions]

Mother and Daughter

- Without Feedback
- With Feedback
- H.264 - Intra

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**Rate Allocation**

- Split WZ frames into disjoint slices, evaluate RD for each slice
- Applicable to systems **with and without** feedback

\[
\min_{(q_0, \ldots, q_{S-1})} \sum_{s=0}^{S-1} D_s, \quad \text{s.t.} \sum_{s=0}^{S-1} R_s(D_s) \leq R_{\text{max}}
\]

\[
q_i \in \{\Delta_0, \ldots, \Delta_{m-1}\}
\]

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**Coastguard (with feedback)**

![Graph showing PSNR vs Rate for Fixed Q. and Rate Allocation methods. The graph plots PSNR in dB on the y-axis and Rate in bpp on the x-axis, with a clear line indicating the performance of Fixed Q. and another showing Rate Allocation.]
Summary

- Approximation to the WZ rate distortion model for Laplacian sources
- Feedback suppression using model based encoder rate control
- Quality enhancement by applying rate allocation to disjoint slices in systems with and without feedback

Outlook
- Generalizing the feedback suppression framework for sequences with medium-high motion activity
- Testing the proposed system on more sequences