Analysis of Error-Resilient Video Transmission based on Systematic Source-Channel Coding

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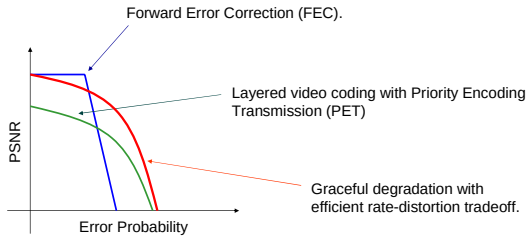
Limitations of traditional error-resilience methods

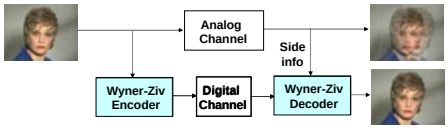


Proposed approach : Wyner-Ziv coding of the video signal
What is the end-to-end video distortion for the chosen WZ description and WZ bit-rate ?

Outline

- Systematic source-channel coding
- Systematic Lossy Error Protection using Wyner-Ziv coding
- Model for end-to-end video distortion
- Comparison of model predictions with simulation results

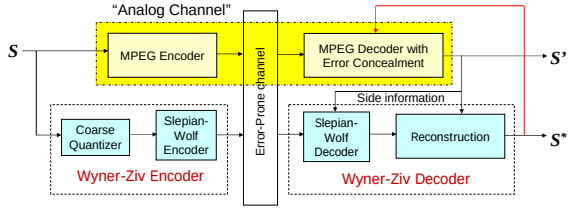
Systematic Source-Channel Coding



[Shamai, Verdu, Zamir, 1998]

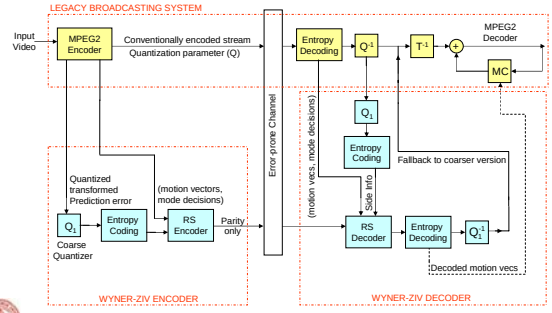
- Enhancing analog transmission systems using digital side information *[Pradhan, Ramchandran, 2001]*
- Lossy source-channel coding of video waveforms *[Aaron, Rane, Girod, 2003]*

Systematic Lossy Error Protection (SLEP)

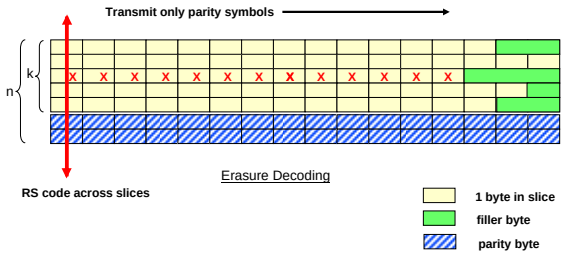


- Analogous to systematic source-channel coding
- Error corrected up to a distortion introduced by coarse WZ quantizer, hence ***lossy*** protection. ***[Rane, Aaron, Girod, 2004]***

Practical scheme for Lossy Error Protection

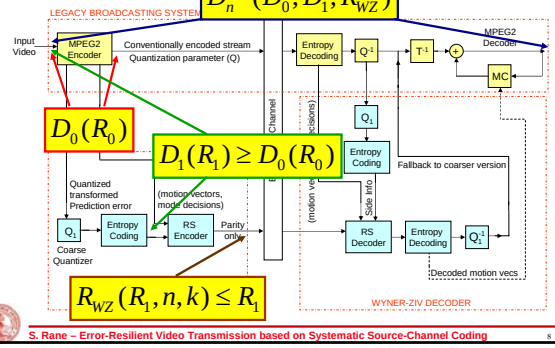


Reed-Solomon codes across slices



Essential Parameters in Video Distortion Model

$D_n^{EE}(D_0, D_1, R_{WZ})$



$D_0(R_0)$

$D_1(R_1) \geq D_0(R_0)$

$R_{WZ}(R_1, n, k) \leq R_1$

Modeling End-to-End Video Distortion (2)

- Distortion at Encoder: *[Stuhlmüller et al., 2000]*

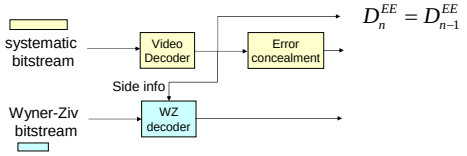
$$D = D_m + \frac{\theta}{R - R_m}$$

- Parameters θ, R_m, D_m
- Rate-distortion pair (R, D)
  - (R_0, D_0) — Main (systematic) video description
  - (R_1, D_1) — Coarse (Wyner-Ziv) video description

$$R_1 \leq R_0, D_1 \geq D_0$$

Modeling End-to-End Video Distortion (3)

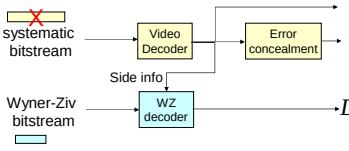
Case 1: Video bitstream correctly received



$$D_n^{EE} = D_{n-1}^{EE}$$

Modeling End-to-End Video Distortion (4)

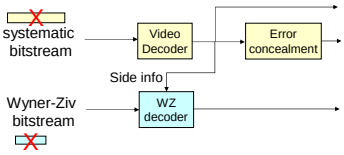
Case 2: Error in video bitstream but WZ decoding is successful



$$D_n^{EE} = D_{n-1}^{EE} + (D_1 - D_0)$$

Modeling End-to-End Video Distortion (5)

Case 3: Error in video bitstream and WZ decoding fails



$$D_n^{EE} = D_{n-1}^{EE} + MSE(n, n-1)$$

Average end-to-end distortion in the nth frame = $\mathrm{E}[D_n^{EE}]$

Simulation setup

- Codecs:
  - Main → MPEG-2 codec
  - WZ → Coarse Quantizer + RS Slepian-Wolf codec.

  [Rane, Aaron, Girod, ICIP2004]
- Settings:
  - 1 Slice = 1 GOB
  - Identical slice structure for main and WZ stream
  - Main and WZ descriptions use same motion vectors and mode-decisions
  - MPEG GOP structure : I-B-B-P-B-B-P-…
  - Previous-frame error concealment

Model vs. Simulation (Bus.CIF)

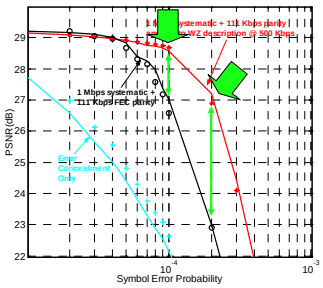
bus.cif @ 1 Mbps
111 Kbps parity

100 frames @ 30 fps

I-B-B-P-B-B-P…
Intra every 30 frames

PSNR avg. over 25 traces

$R_0 = 1\text{Mbps}$
$R_1 = 1\text{Mbps} / 500\,\text{Kbps}$
$R_{WZ} = 111\text{Kbps}$



Model vs. Simulation (Foreman.CIF)

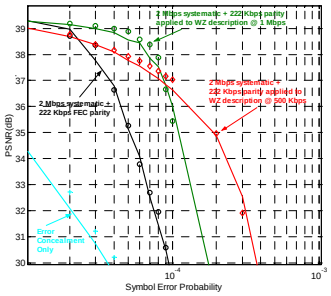
foreman.cif @ 2 Mbps
222 Kbps parity

100 frames @ 30 fps

I-B-B-P-B-B-P…
Intra every 30 frames

PSNR avg. over 25 traces

$R_0 = 2\text{Mbps}$
$R_1 = 2\text{Mbps} / 1\text{Mbps} / 500\,\text{Kbps}$
$R_{WZ} = 222\,\text{Kbps}$



Bus 100 CIF frames @ symbol error rate = 10^{-4}

With FEC
Total : 1 Mbps + 111 Kbps
(26.58 dB)

With WZ description @ 500Kbps
1 Mbps + 111 Kbps
(28.69 dB)

Bus 100 CIF frames @ symbol error rate = 2×10^{-4}

With FEC
1 Mbps + 111 Kbps
(22.90 dB)

With WZ desc. @ 500 Kbps
1 Mbps + 111 Kbps
(26.89 dB)

Conclusions

- A Wyner-Ziv bitstream provides error-resilience in a systematic source-channel setup.
- A model for the end-to-end video quality delivered by the SLEP system. Accounts for:
  - Small degradation from Wyner-Ziv decoding at low error rates
  - Large degradation from error concealment at high error rates
  - Propagation of the above.
- Model suggests an optimization scheme to find the best Wyner-Ziv description and the best Wyner-Ziv bit-rate for given channel condition.