Spectrally Efficient Partitioning of MPEG Video Streams for Robust Transmission over Multiple Channels

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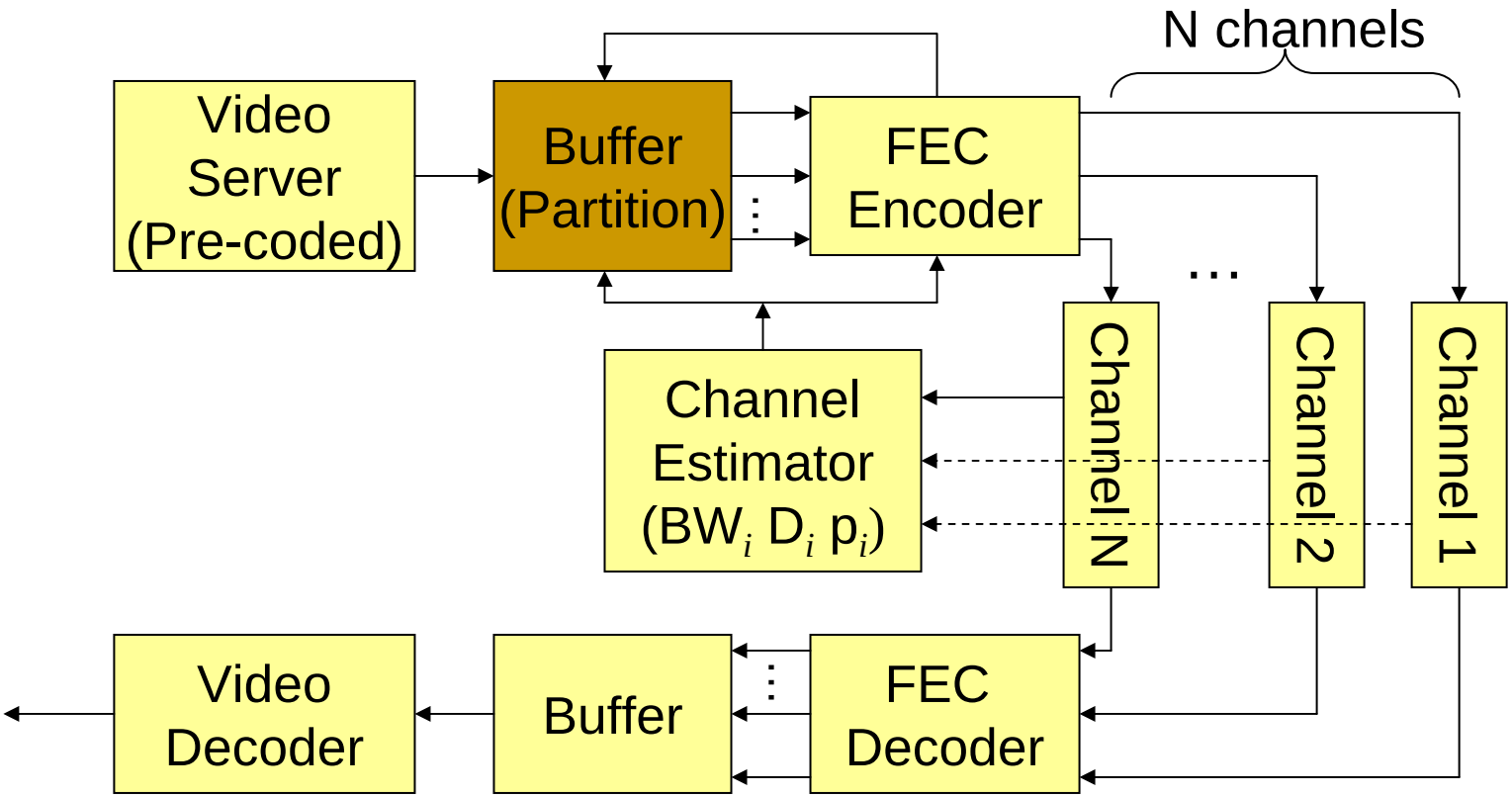
Outline

- Problem Statement
- Related Work
- Problem Formulation and Solution
- Experimental Results
- Conclusion

Transmit 1 Stream over N Channels



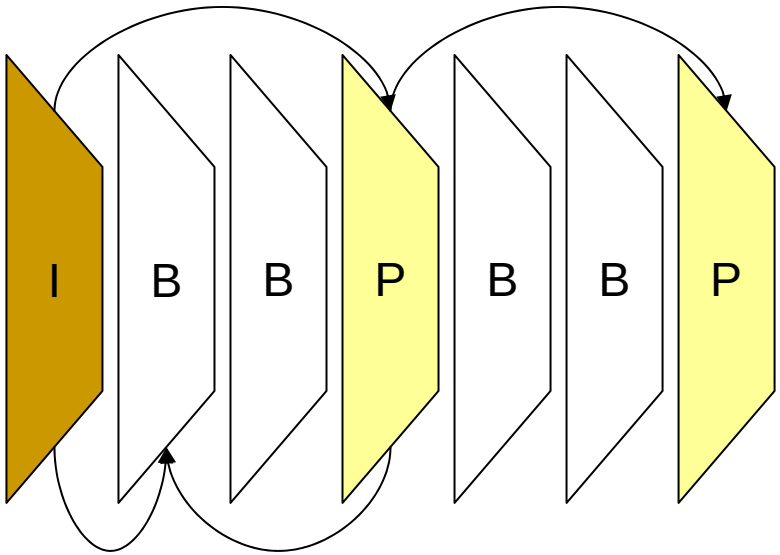
Goal: maximize decodable frame rate when the total bandwidth is too small to transmit all frames.

Related Work

- Video Partitioning
  - Unequal error protection (UEP)
  - Layered video coding
    - Partition: macroblock, slice, frame
    - Further partition: inefficient
- Multiple Channel Transmission
  - Inverse multiplexing
  - Multiple description coding

MPEG Frame Structure

- MPEG Compression



- Group-of-Pictures (GOP)
- Size ratio of I- to B- frames: roughly 1:1 ~ 10:1
- Frame priority: I > P > B

Tailoring FEC to this Problem

- Implement Unequal Error Protection (UEP) for Different Frame Types.
- Model UEP using Redundancy Factors:
  - $R_i(A, t)$ (i = channel index, A = (I, P, B)).
    - (Post-coding size) = (Pre-coding size)·(1 + R)
  - Consider frame priorities:
    - $R_i(I, t) \geq R_i(P, t) \geq R_i(B, t)$
  - Balance different channels:
    - $R_i(A, t) \geq R_j(A, t)$ if and only if $p_i(t) \geq p_j(t)$

Problem Formulation

- How to assign FEC-coded frames to channels to maximize the decodable frame rate?
- The Optimization Formulation

  max{ **number of decodable frames** }

subject to $\sum_{A \in S_i} (1 + R_i(A)) \cdot F(A) \le BW_i \cdot T$

Frames assigned to channel i

FEC-coded frame sizes

Bandwidth-time product

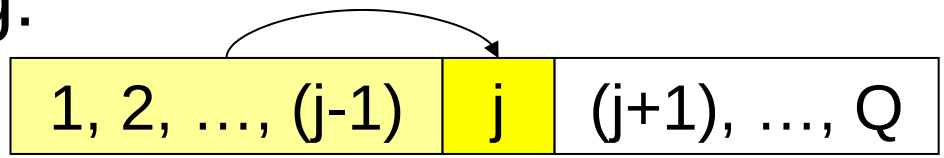
T: GOP duration

Delay Constraint

- We require low initial latency and continuous playback.
- Two Components Considered:
  - Channel delay: transmission and propagation delay
  - Processing delay: partitioning and FEC encoding
- In Constraints: $$\sum_{A \in S_i} (1 + R_i(A)) \cdot F(A) \leq BW_i \cdot T$$
- T is justified when
  - Processing delay negligible
  - Variation of propagation delay is small

Solving the Optimization Problem

- Frame Reordering:
  - Each GOP



- NP-Hard Problem
  - Search space is $O(N^{GOPsize})$
  - Polynomial-running-time algorithm is unavailable.
- Algorithms:
  - Pruned-Tree-Search (PTS) algorithm: benchmark
    - Exponential running time (in the worst case)
  - Greedy: fast approximation algorithm
    - Linear running time

Experiments: Video Sources

- Real-life MPEG video traces: *Movies* (*Star Wars*), *Sports* (*Soccer*), *News*, *MTV*
  - 384 x 288, 25 frames/sec, 40,000 frames
- Berkeley MPEG-encoder (version 1.3)*
  - YUV (4:2:0, 8 bits)
  - Quantization value (I = 10, P = 14, B = 180)
  - “Logarithmic”/ “Simple” motion vector search
  - 1 slice
  - Half pel motion estimation
  - GOP pattern: IBBPBBPBBPBB (12 frames/GOP)

*ftp-info3.informatik.uni-wuerzburg.de/pub/MPEG/

Experiment Parameters

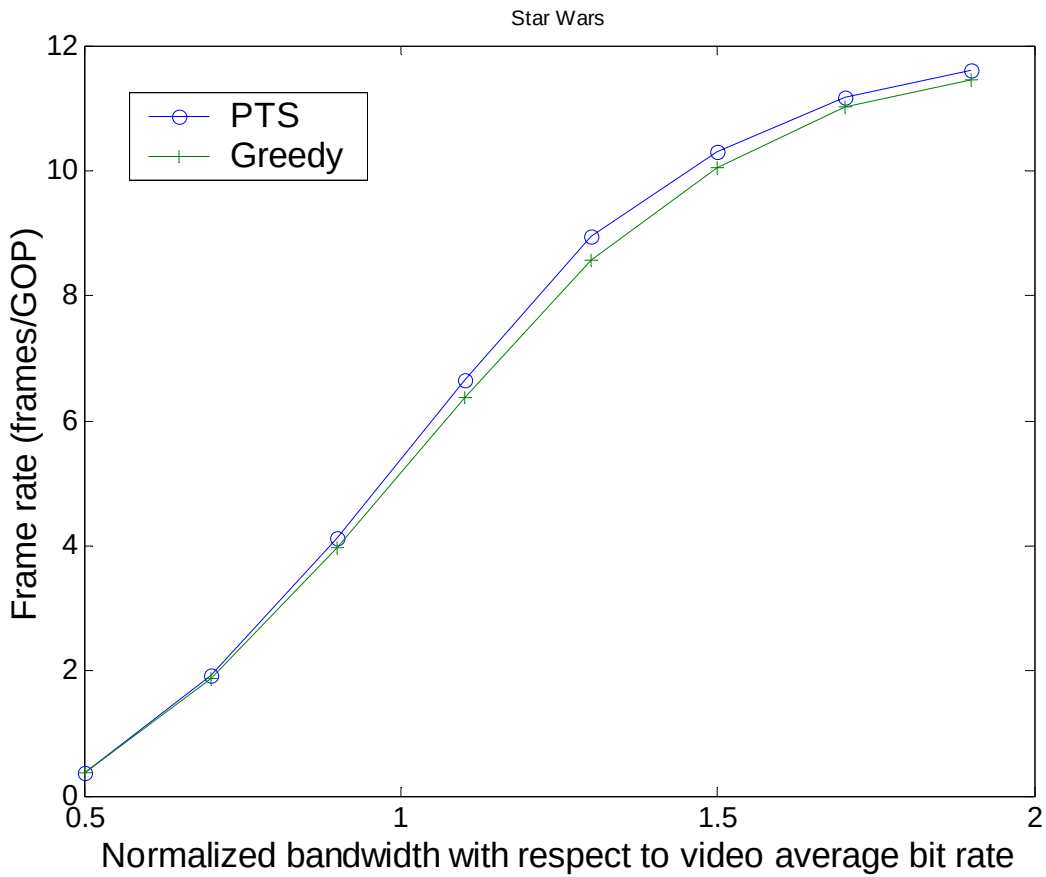
- Redundancy factors:

R factors	Channel 1 (worst)	Channel 2	Channel 3 (best)
I-frame	0.48	0.35	0.24
P-frame	0.16	0.10	0.08
B-frame	0.03	0.00	0.00

[M. Gallant 01, F. Hartanto 99]

Comparison of Algorithms

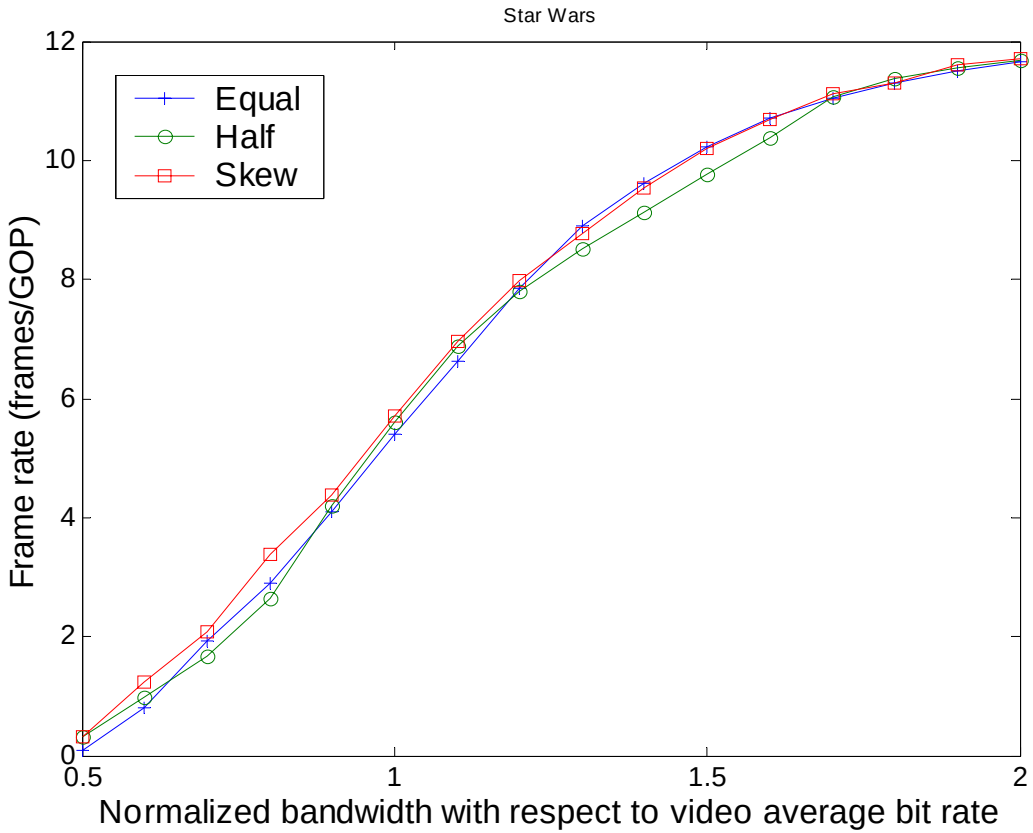
With frame reordering (*Star Wars*)



Effects of Bandwidth Distribution

BW fractions of total bandwidth for 3 channels:

Equal: 1/3, 1/3, 1/3; Half: 0.25, 0.25, 0.50; Skew: 0.1, 0.1, 0.8

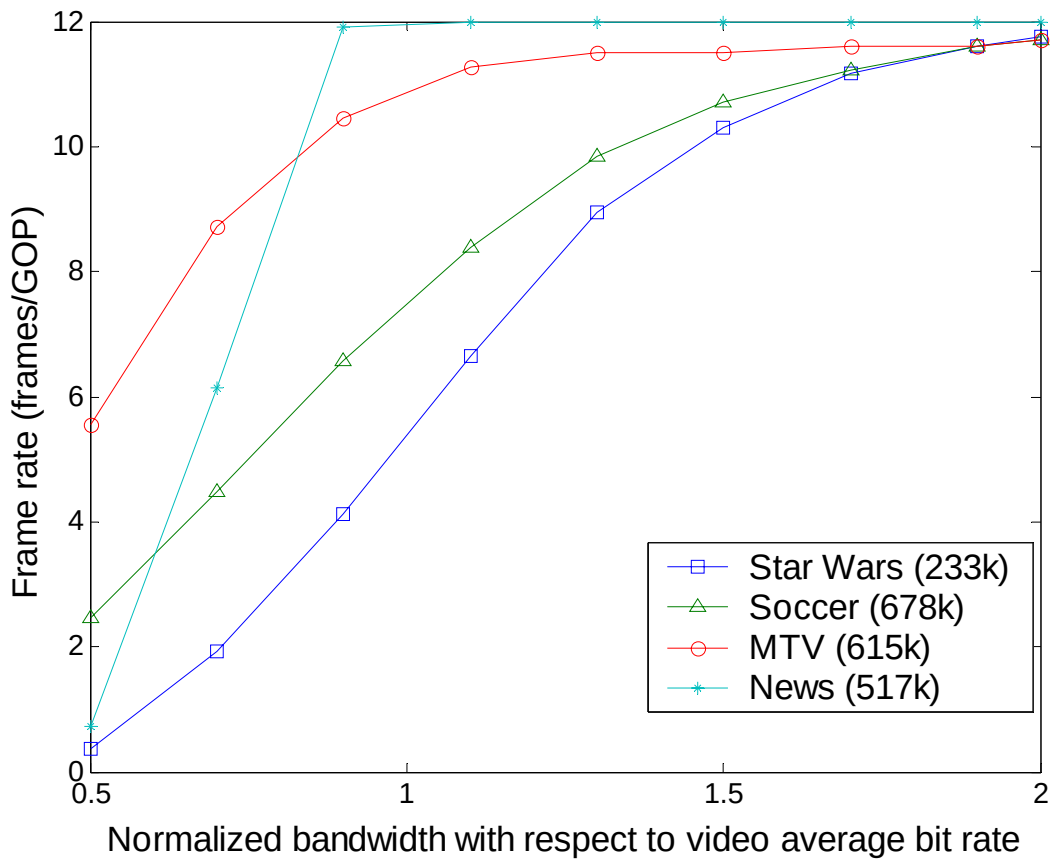


Sensitivity to Parameter Mismatch

- -5% bandwidth mismatch
- The total bandwidth is 130% of video average bit rate.
- Statistics over 100 GOPs

Video Traces (bits/s)	Frame Rate Difference (frames/GOP)		
	Average	Maximum	Std. Dev.
Star Wars (233k)	3.67	12	3.96
Soccer (678k)	2.21	12	2.97
MTV (615k)	1.26	11	2.44
News (517k)	3.28	11	4.05

Effects of Video Content



Conclusions

- An optimization formulation is provided to combine both the advantages of FEC coding and multiple channel bandwidth for robust MPEG video transmission.
- Other Optimization Problems:
  - Extension to scalable coding
  - Minimal delay
  - Minimal bandwidth

Further Improvement

- Exploit pre-encoded video source: *a priori* knowledge
- Use multiple buffers
- Pre-compute partitioning when channel state is comparatively stable
- Use parallel processing

The above can help achieve higher bandwidth utilization at the expense of increased system complexity …