Multimedia in Satellites:
Achieving Reliable Interactive Video Transmission over Broadband Satellite Channels

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Outline

- Motivation and Objectives
- Lossy source and channel coding
- Error concealment techniques for video transmission
- Transmitter-Receive-Identical-Reference-Frame concept
- Results based on software codec simulation

Objectives

- Design of terrestrial terminal for fixed satellite link
- Geostationary satellite current focus
- Small home office LAN application
- Data and stream traffic with focus on interactive video
- Transmission system partially defined
    - Ka-band
    - FDMA / TDMA
    - 256 Kbit / sec to 2 Mbit / sec
    - MPEG-2 transport layer for downlink:
        - -- packetization of video

Problem Areas

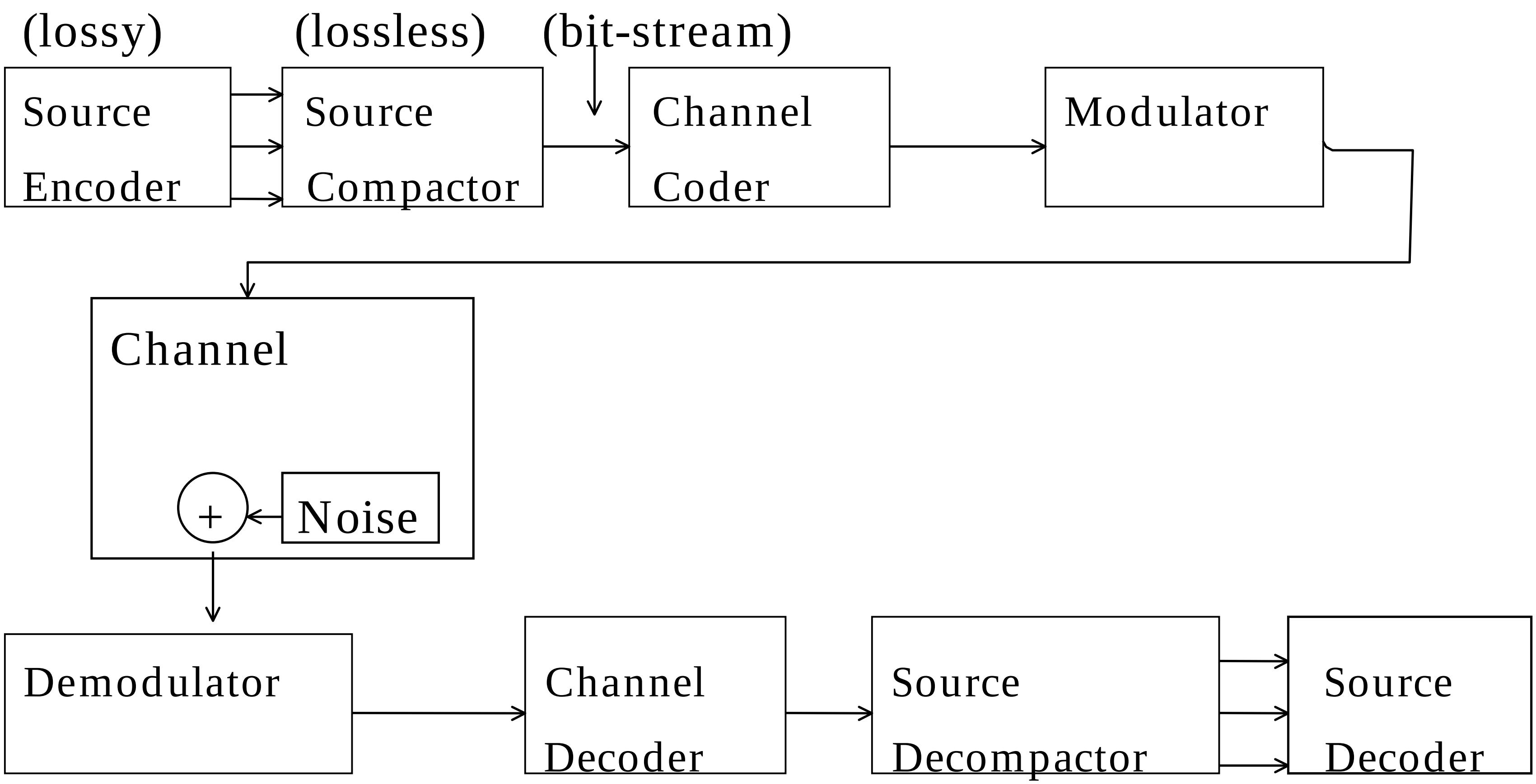
The Channel

- 1/4 sec. roundtrip delay
- Fading attenuation due to weather effects
- Large free-space propagation loss
- Large noise bandwidth

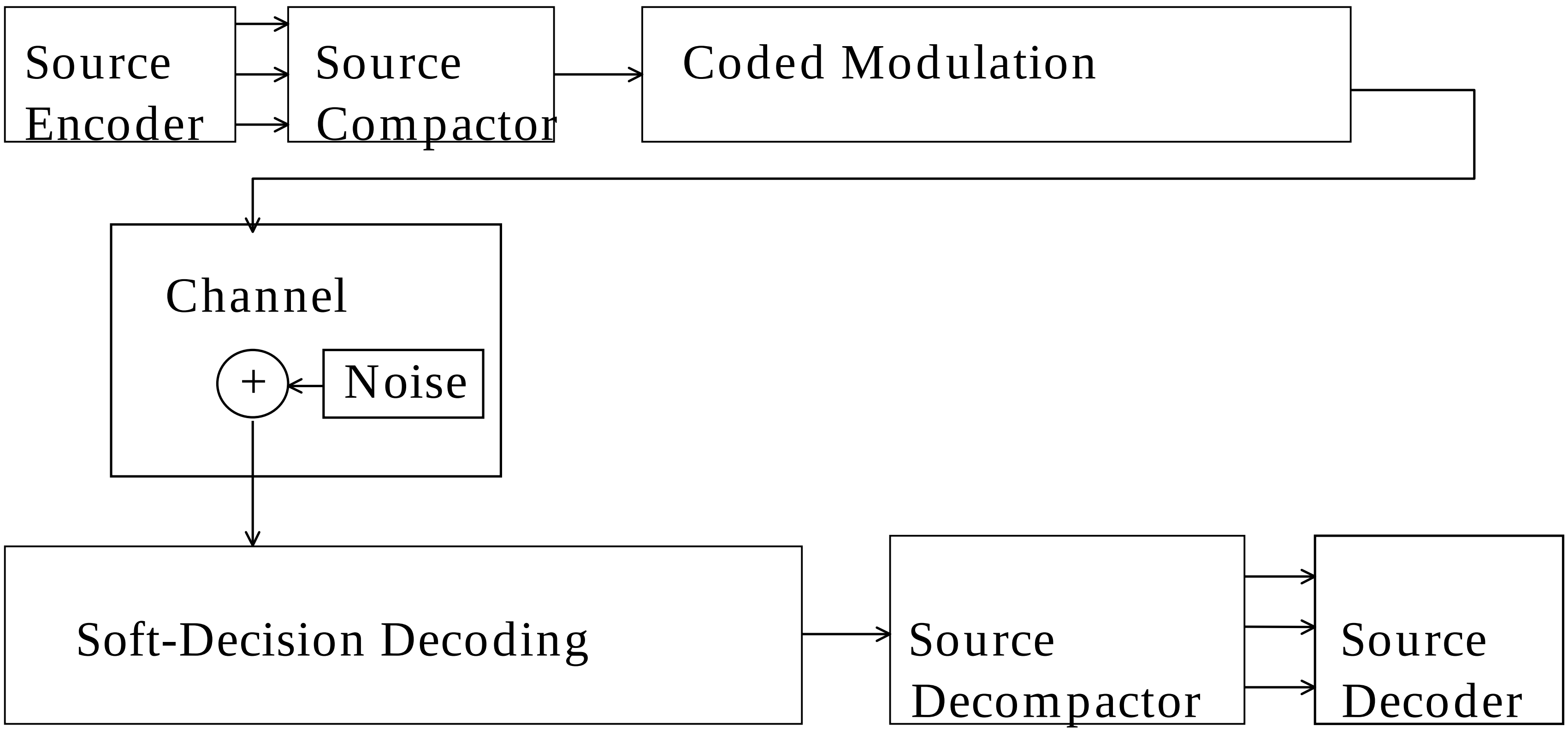
The Video Source

- Lossy compression
- Statistical redundancy
- Human visual system assesses quality of service (not BER,PSNR)
- Multi-stream data: motion, prediction error, sync., speech, etc.

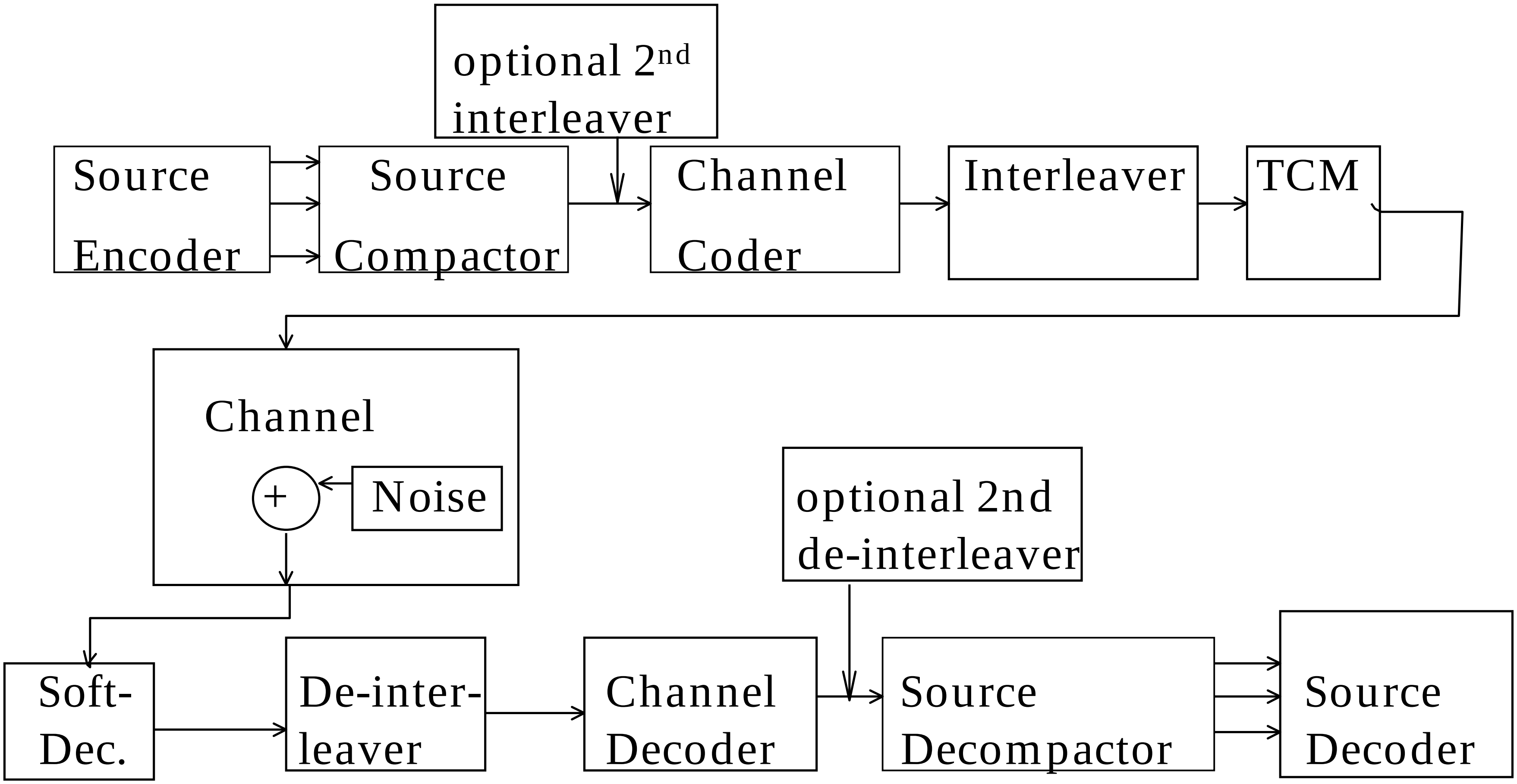
Classical Transmission Approach for Stream Traffic



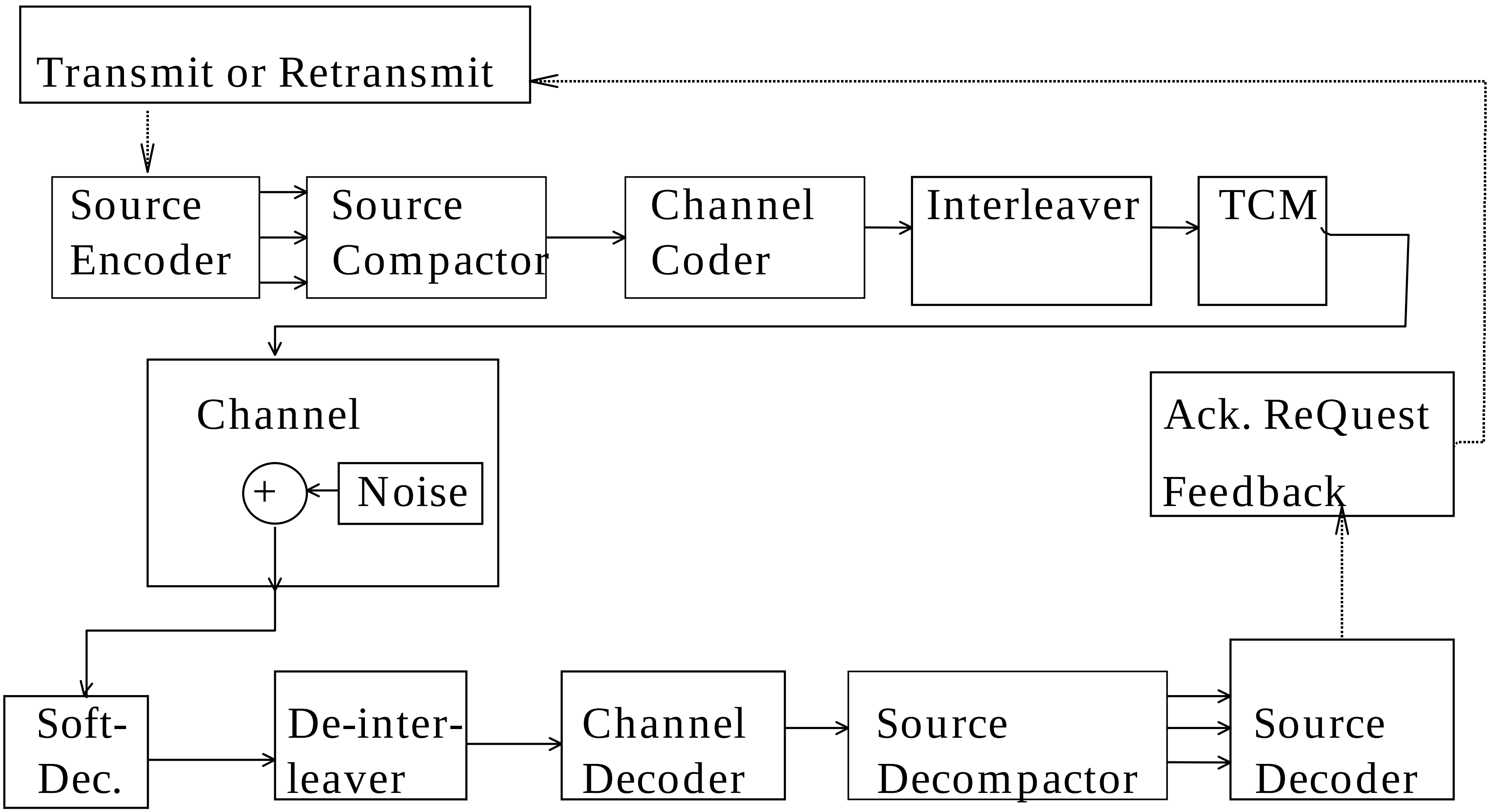
Coded-Modulation Stream Transmission System



Tandem-Coded Stream Transmission System



Packet Transmission System



Lossy Source and Channel Coding Methods

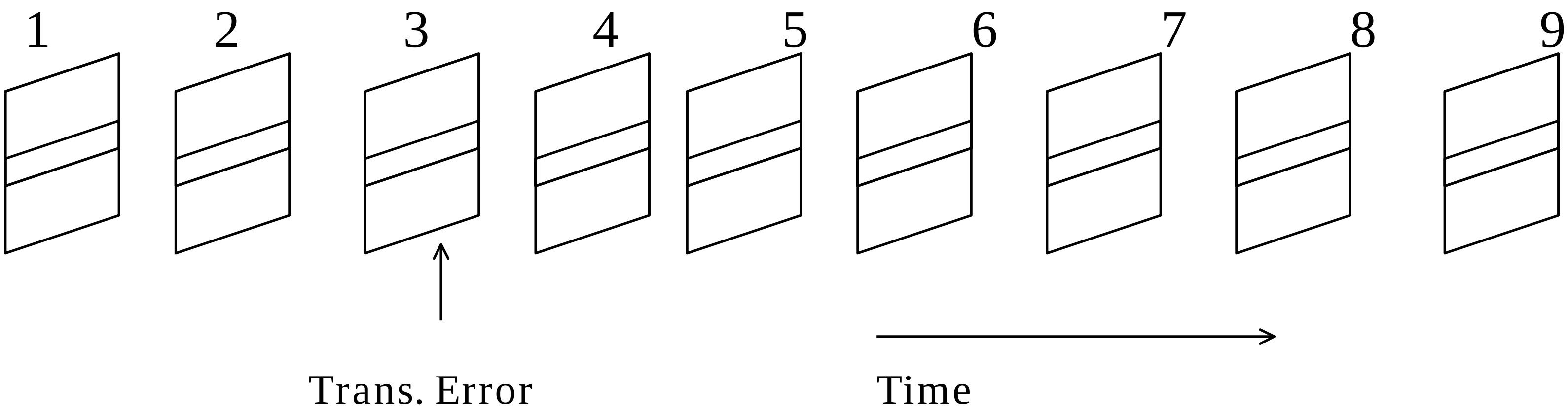
Approach	*Advantages*	*Disadvantages*
Tandem channel coding Reed-Solomon +TCM	• Separation Theorem • High compression	• Applicability of Thm. • Delay • Complexity
Turbo channel coding	• Low SNR performance near Shannon capacity	• Delay • Complexity • Lower compression
Error-resilient source Compaction	• Simplicity • Low-delay	• Ad-hoc • Lower compression
Error detection and concealment at receiver	• Low delay • HVS based, adaptive	• Hard to optimize • May be complex
Channel-Optimized VQ of source (COVQ)	• Simplicity • App. to bursty channels	• Low compression
Channel-optimized MAP decoding	• For bursty channels	• Low compression • Complexity

Research Areas

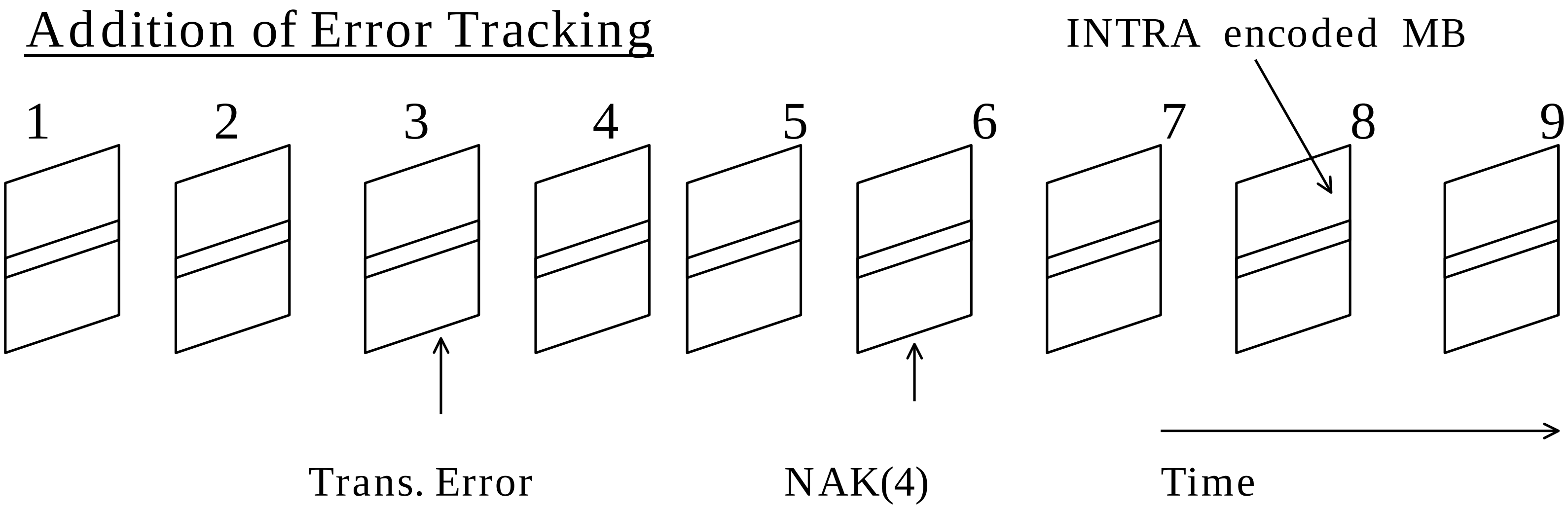
- Channel modelling for Broadband satcom
  - Motivation: performance assessment of video transmission
  - Discrete -state Ka-band transmission (Markov chain) model
  - Model that includes channel+modulation+inner code
  - Turbo coding system error characteristics to be determined
- Source coding
  - Motivation: improved robustness / efficiency / services
  - Region-based approaches to video source coding.
  - Tradeoff bit allocation among parallel coder outputs.
  - Joint source and channel coding: channel-optimized VQ

Application of Error Concealment Through Error Tracking

Error Propagation Effects



Addition of Error Tracking



Recommendations

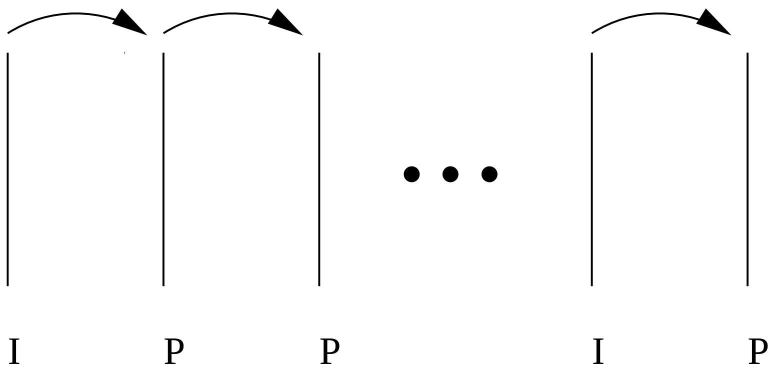
To obtain high compression efficiency over the satellite channel while maintaining interactivity and low complexity, we must

- Maintain high compression ratios by carefully exploiting rate distortion characteristics of the video source and assess the results using HVS.
- Explore minimum network feedback solutions to minimize delay and overhead.
- Design the system to perform adequately over the wide variety of Ka-band channel conditions.

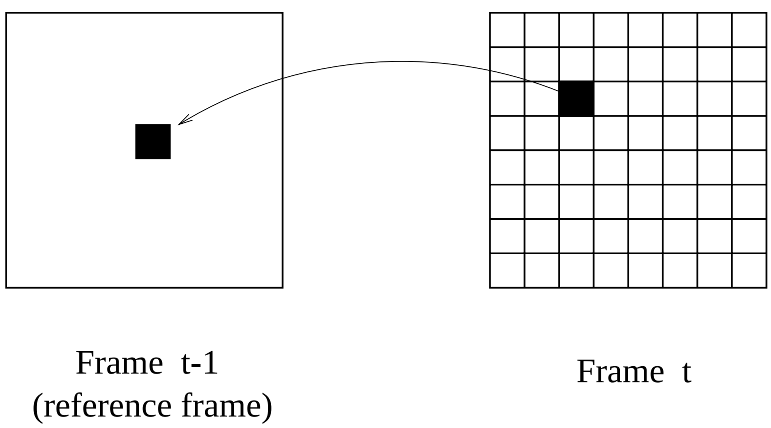
Error Concealment Background

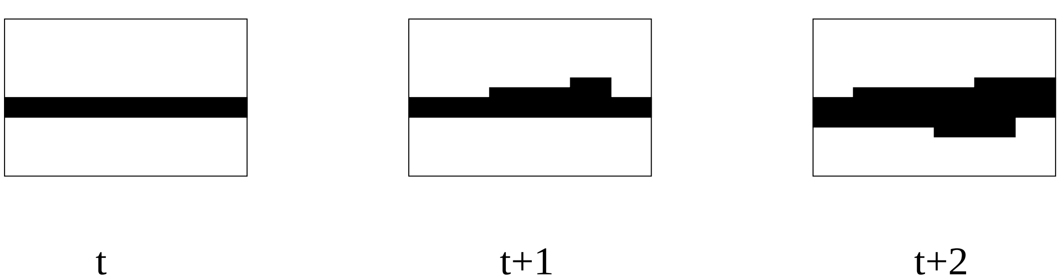
- Error-sensitive characteristics in present-day video coding schemes
  - At the bit level
    - Variable-length coding $\Rightarrow$ loss of synchronization
  - At the image level
    - Motion-compensated predictive coding $\Rightarrow$ Temporal and spatial distortion propagation and accumulation

Error Concealment Background (Cont'd)



$$\tilde{I}_t = \tilde{I}_{t-1} + Error$$



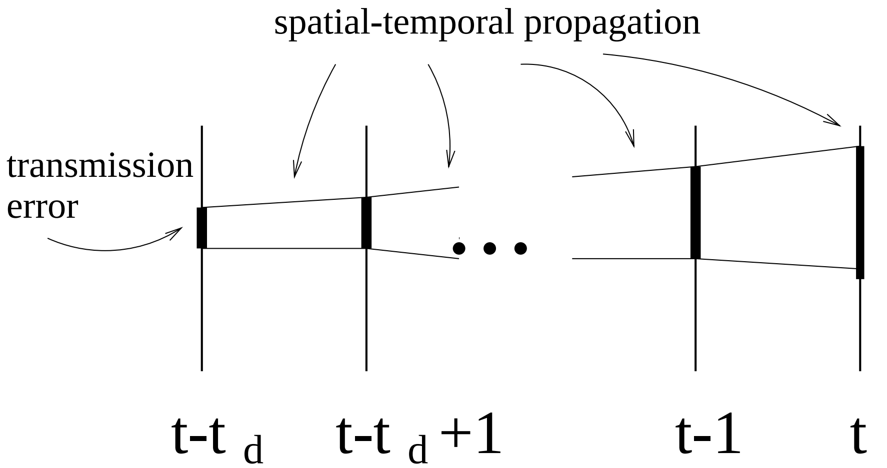


Previous Approaches

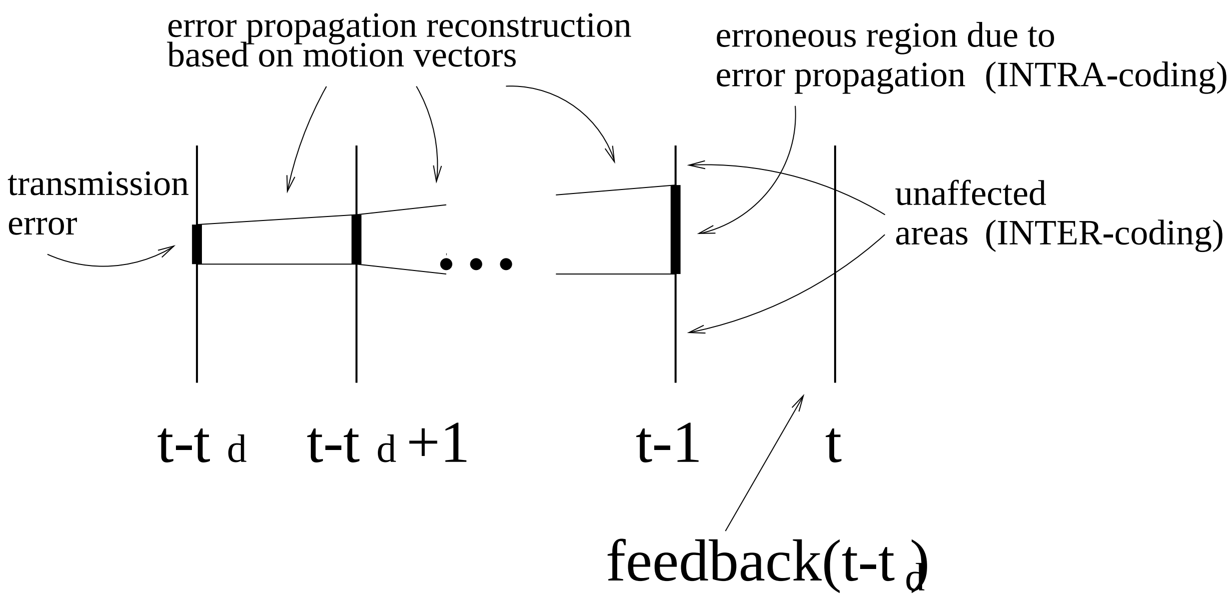
- Periodic INTRA-frame refreshing (MPEG2)
  - high cost
- Retransmission
  - additional delay
- Partial INTRA-frame refreshing based on error propagation reconstruction at the transmitter

  Steinbach et al, "Standard Compatible Extension of H.263 for Robust Video Transmission in Mobile Environments", IEEE Trans. Cir. & Sys. Video Tech., 1997

Previous Approaches (Cont'd)



Spatial-temporal error propagation at the receiver



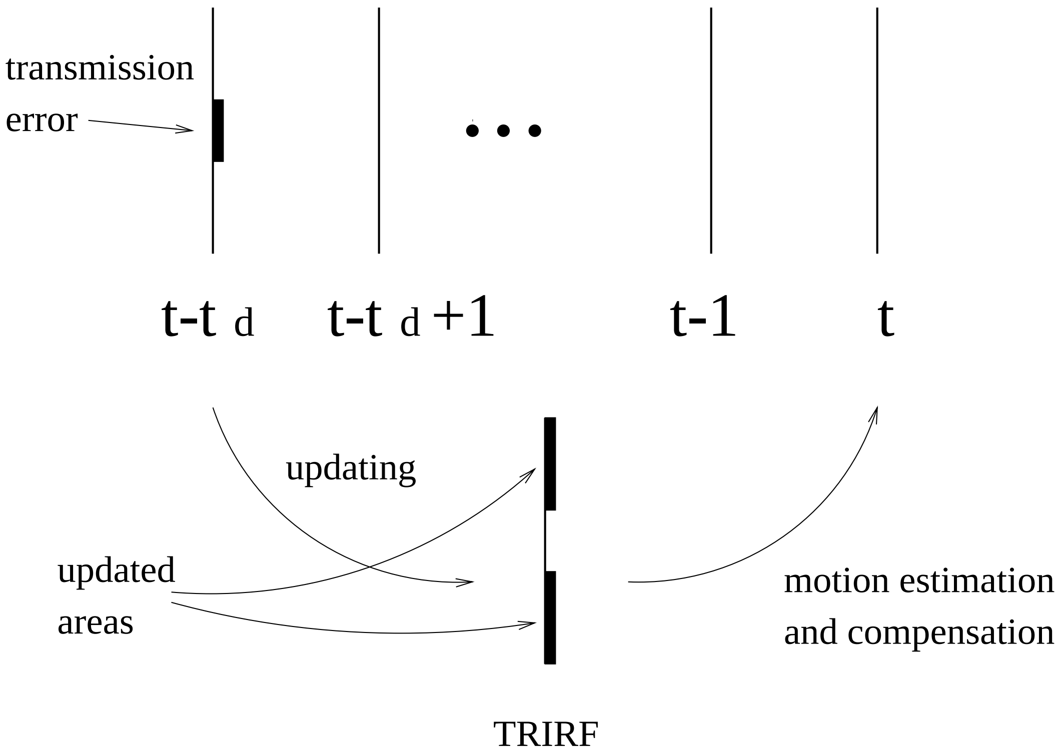
Reconstruction of error propagation at the transmitter and partial INTRA-coding (Steinbach'97)

Transmitter Receiver Identical Reference Frame (TRIRF) Coding

- Assumptions
  - Error detection capability at the receiver
  - Locations of error are sent back by a feedback channel error free
  - Feedback channel has delay
- Basic Idea of TRIRF
  - Construct the IDENTICAL reference frame for motion compensated prediction at the transmitter and the receiver *even when channel errors occur*
  - Maximize temporal correlation by constantly updating the reference frame

TRIRF-frame Coding (Cont'd)

- TRIRF-frame construction



At time t, feedback information about frame $t - t_d$ arrives at the transmitter.

TRIRF-frame Coding (Cont'd)

- Factors Affecting Coding Performance
  - transmission delay (t_d)
  - channel conditions
  - video content

- Comparisons between video coding modes

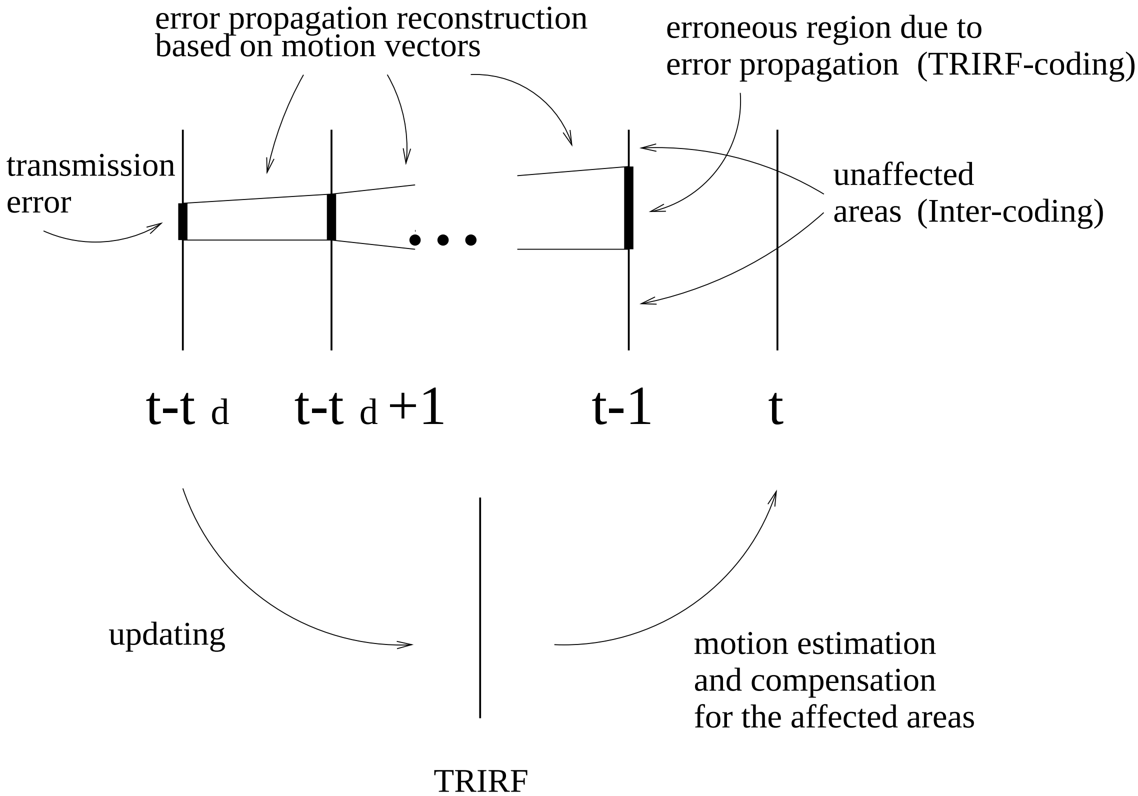
coding mode	compression efficiency	propagation prevention
INTER	usually high	no
INTRA	usually low	yes
TRIRF	moderate	yes

Increasing Compression Efficiency by Using Multi-Mode Coding

- Feedback channel enables error propagation reconstruction at the transmitter to locate damaged areas where INTRA is applied (*(Steinbach et al, 1997)*

- We propose hybrid INTER/TRIRF coding
  - Conventional INTER-frame coding on undamaged areas
  - TRIRF-frame coding on damaged areas only

Increasing Compression Efficiency by Using Multi-Mode Coding (Cont'd)



Hybrid INTER-frame/TRIRF-frame coding

Bitstream Video Codec Simulations

- We have developed a custom software codec similar to video coding standard H.263
- Comparison between (Steinbach et al, 1997) and TRIRF coding
- Test sequences in CCIR 601 QCIF (177x144) format at 10 frame/sec
- Memoryless binary symmetric channel (BSC) with BER ϵ comparisons:
  - $$y_n = x_n \oplus e_n, \qquad n = 1, 2, \cdots$$
  - Feedback information – errors are located to within a row of blocks
- Packet data transmission with given packet loss rate (PLR) and round-trip delay.
  - Variable length coding with packetization of macroblocks
  - Header contains macroblock location as re-sync information

Results on Stream-Based Video

Sequence	Lum-PSNR(dB)		Bitrate (kb ps)	
	TRIRF	ST'97	TRIRF	ST'97
Carphone	27.8	27.3	63.0	94.0
Foreman	24.3	23.6	84.7	115.7
Miss-Amer	35.3	35.4	19.5	31.2
Mthr-Dotr	31.5	31.4	29.1	51.8
Salesman	30.7	30.7	25.6	58.9
Suzie	30.0	30.0	42.0	52.9

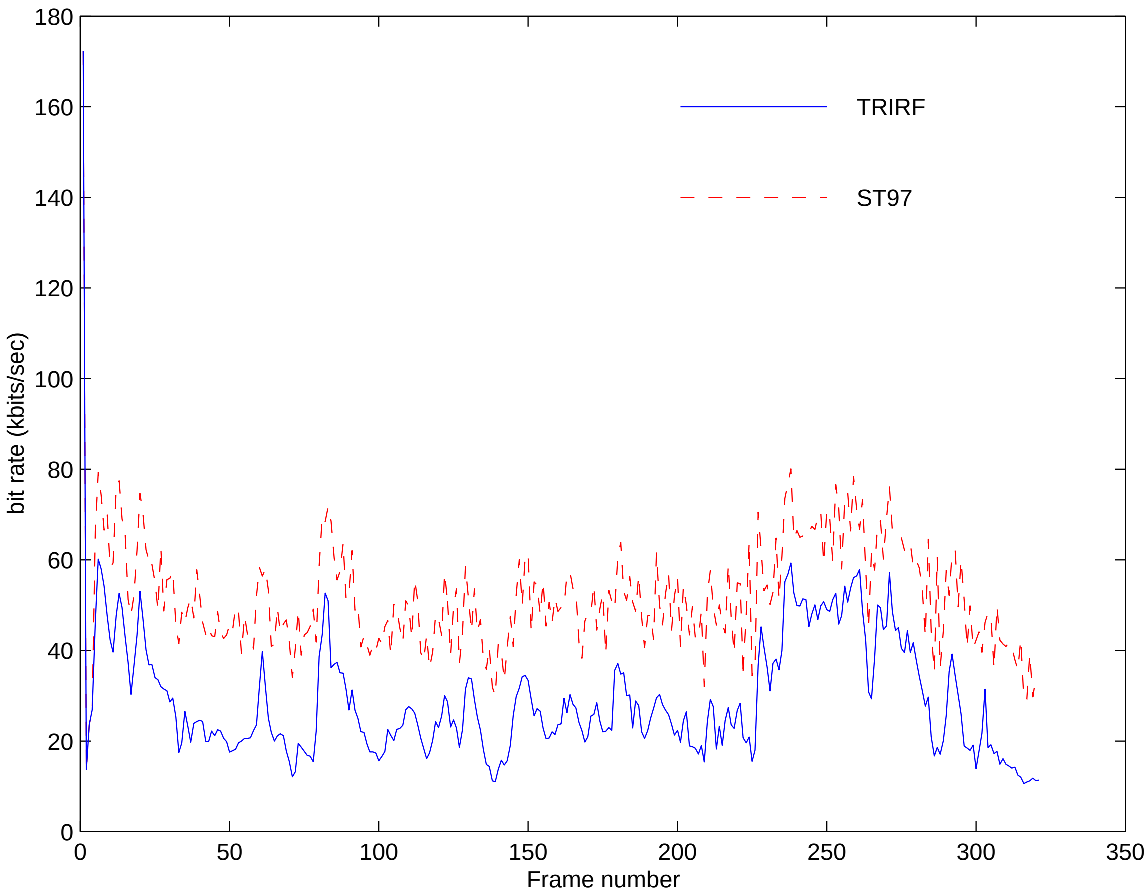
PSNR and bitrate comparisons averaged over 25 runs of the entire sequence. $\epsilon = 10^{-3}, n_{rd} = 3$.

Results on Stream-Based Video (Cont'd)

Sequence	Lum-PSNR(dB)		Bitrate (kb ps)	
	TRIRF	ST'97	TRIRF	ST'97
Carphone	31.8	31.9	57.6	63.0
Foreman	30.3	30.3	73.7	79.6
Miss-Amer	36.9	36.9	18.4	19.7
Mthr-Dotr	32.7	32.7	26.4	29.2
Salesman	31.5	31.6	23.4	27.2
Suzie	33.4	33.6	37.5	38.7

PSNR and bitrate comparisons averaged over 25 runs of the entire sequence. $\epsilon = 10^{-4}, n_{rd} = 3$.

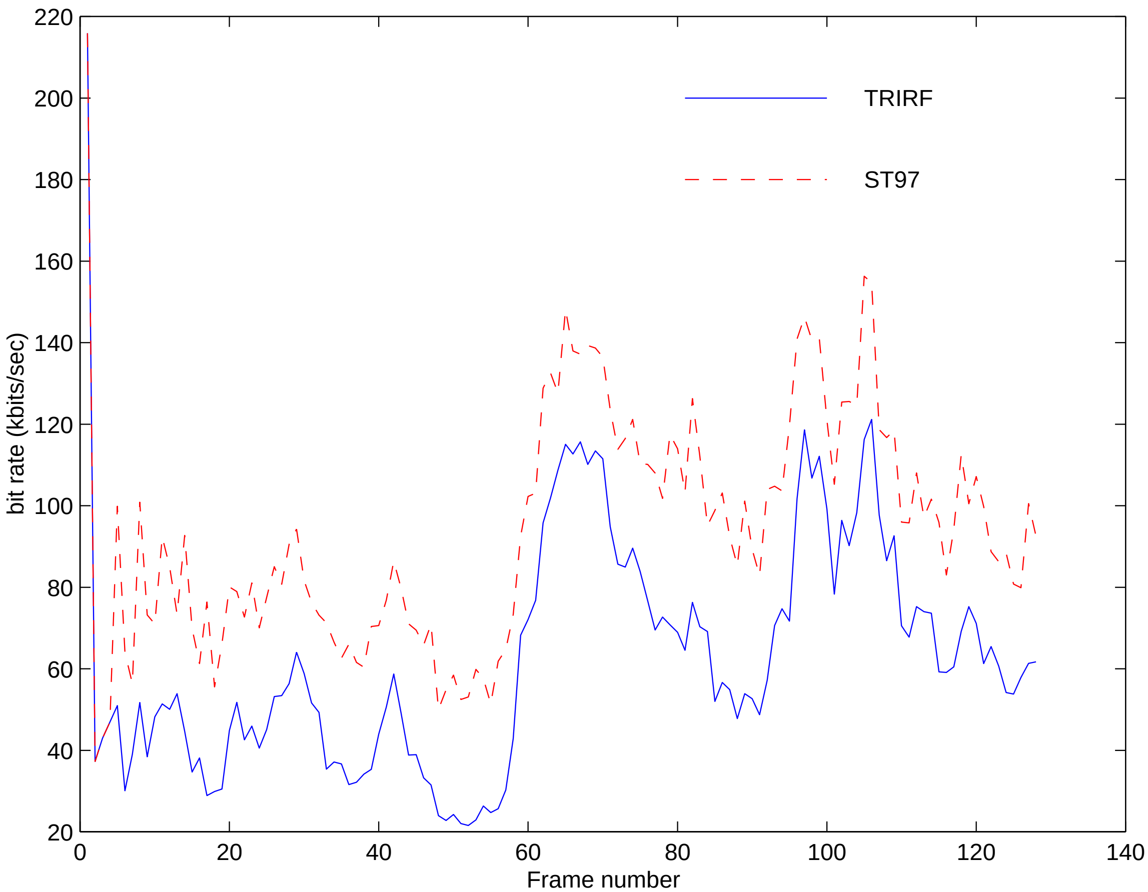
Results on Stream-Based Video (Cont'd)



Average simulation results for Mother and Daughter sequence. ($\epsilon = 10^{-3}$, $n_{rd} = 3, PSNR = 31.4dB$)

1999 2nd Annual Int. Symp. on Adv. Radio Technologies

Results on Stream-Based Video (Cont'd)



Average simulation results for Carphone sequence. ($\epsilon = 10^{-3}, n_{rd} = 3, PSNR = 27.8dB$)

Results on Packet-Based Video

Sequence	Lum-PSNR(dB) TRIRF	Lum-PSNR(dB) ST97	Bitrate (kb ps) TRIRF	Bitrate (kb ps) ST97
Carphone	27.2	27.3	63.1	80.9
Foreman	23.7	23.9	84.9	100.9
Mthr-Dotr	31.0	31.3	27.8	41.8
Salesman	30.5	30.7	23.1	45.9

Averaged PSNR and bit rate comparisons of the test sequences. Packet loss rate (PLR)=10^{-1}, Round-trip delay = 300ms.

Conclusions

- A novel coding method TRIRF-frame coding is proposed
- TRIRF-frame coding prevents error propagation while maintaining high compression
- 26-78% lower bitrate over Steinbach'97 in poor channel conditions
- 3-10% lower bitrate over Steinbach'97 in moderate channel conditions
- significant improvement when PLR is high.

Future Work

- Application to packetized video transmission systems
- Improved error concealment through region-based video compression
- Comparison with ARQ-type retransmission in short-delay applications $t_d = 0$ or 1