I.4. Wireless Video Delivery

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Outline

- Introduction
- Trade-off between Source & Channel Coding
- Combating Transmission Errors
- Error Resilient Techniques for Low Bit-Rate Video
- Discussions

Introduction

- Wireless communication grows rapidly, but transmitting vide over wireless networks faces several challenges
- Wireless network: high error rate, bandwidth variation and limitation, power limitation, etc.
  - Bandwidth limited: need higher compression rate
  - Error-phone: need error resilient abilities

Introduction

- The convergence of mobile and multimedia is now under way
- The goals of current second-generation cellular and cordless communications:
  - Supporting integrated voice and data
- In third-generation wireless networks
  - To provide truly ubiquitous access and integrated multimedia services

Introduction

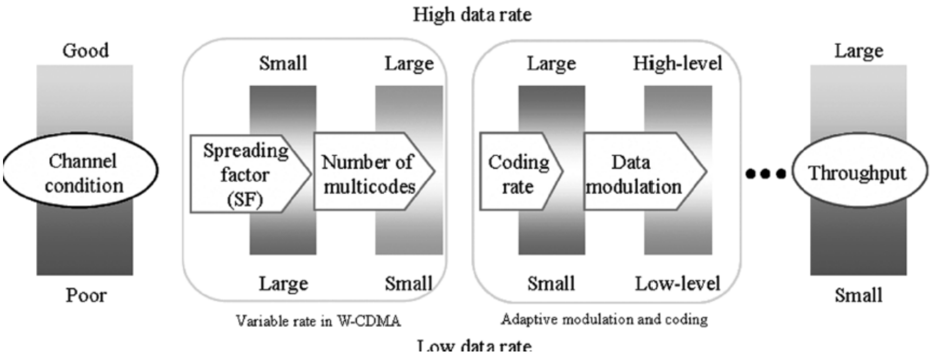
- Today’s “second-generation” cellular telephony networks, such as GSM
  - Provide 10 – 15 kbit/s
  - Suitable for compressed speech, but too little for motion video
- Beyond the limited available bit rate, wireless multimedia transmission, offers some technique challenges:
  - The inability to provide QoS
  - How to combat transmission errors?
    - FEC
    - ARQ

Recent Mobile Networks

- The mobile network progressed from 1G(analog) to 2G (digital) and 3G, drives the mobile multi-media
- Different radio access networks (RANs) are going to be integrated into one IP network
- Today’s mobile networks try to preserve a low error rate by controlling available bandwidth
  - Out of control results in burst errors
- In 3GPP W-CDMA standards, link error quality in toll-quality services is generally very high
- The trend of mobile network will be heterogeneous rather than homogeneous

QoS Trends: A large Variation of Bandwidth and Delay

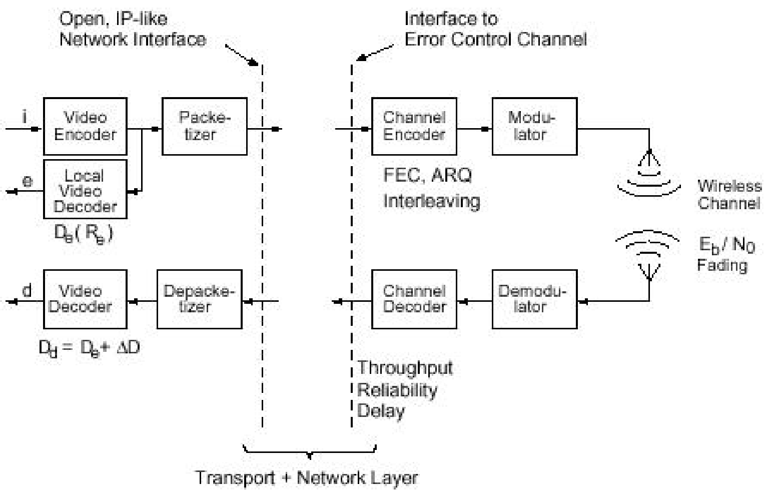
- The emerging networks is for use of “adaptive modulation and coding” (AMC)
  - Adaptively changes the level of modulation



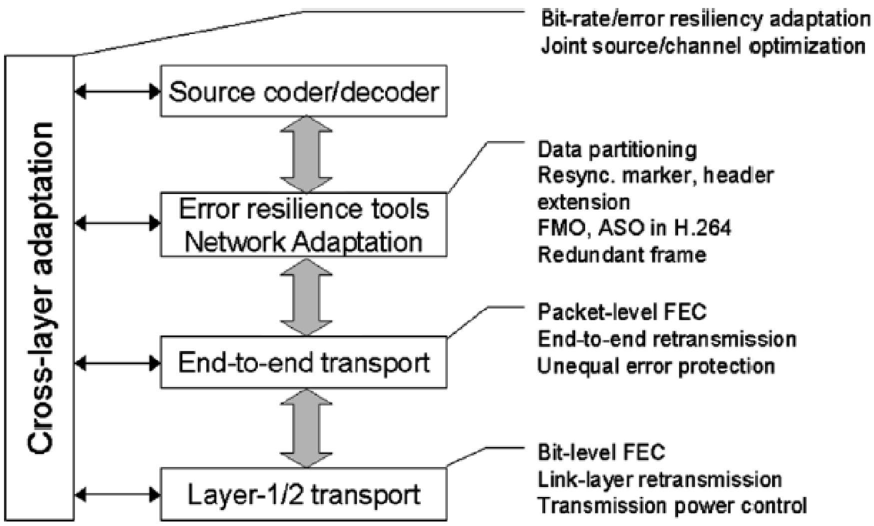
Layer-1/2 Characteristics in RANs

Radio Access	PHY	Channel Bandwidth	Modulation	Channel Coding	Error Recovery
W-CDMA [12]	64 - 384 Kbps	5 MHz	QPSK (downlink) BPSK (uplink)	Convolutional or Turbo Code	SR-ARQ
HSDPA [13], [14]	64 Kbps - 14 Mbps (downlink)	5 MHz	QPSK 16QAM (downlink)	Rate 1/3-1 Turbo Code based	Type-I HARQ with chase combining, Type-II HARQ
CDMA-2000 [12]	1.2 - 307.2 Kbps(1X)	1.25 MHz(1X) 5 MHz(3X)	QPSK(downlink) BPSK (uplink)	Convolutional or Turbo Code	SR-ARQ
CDMA-2000 1x EV-DO [15]	Downlink peak rate: 1.25 - 2 Mbps Uplink peak rate: 144 Kbps	1.25 MHz	QPSK, 8PSK, 16QAM (downlink) BPSK (uplink)	Convolutional or Turbo Code	Type-II HARQ
GPRS [16]	9.06 - 171.2 Kbps	200 KHz	GMSK	Convolutional Code for CS1-4 mode none for CS4 mode	SR-ARQ FEC
EDGE [17]	8.8 to 473.6 Kbps	200 KHz	GMSK 8PSK	Convolutional Code (CS1-4, MCS1-9)	HARQ II
801.11 [18], [19], [20]	6-54 Mbps (11a) 1-11 Mbps (11b) 1-54 Mbps (11g)	20-22 MHz	OFDM (11a) CCK (11b) OFDM+PBCC(11g)	Convolutional	SW-ARQ

Components of a Wireless Video System



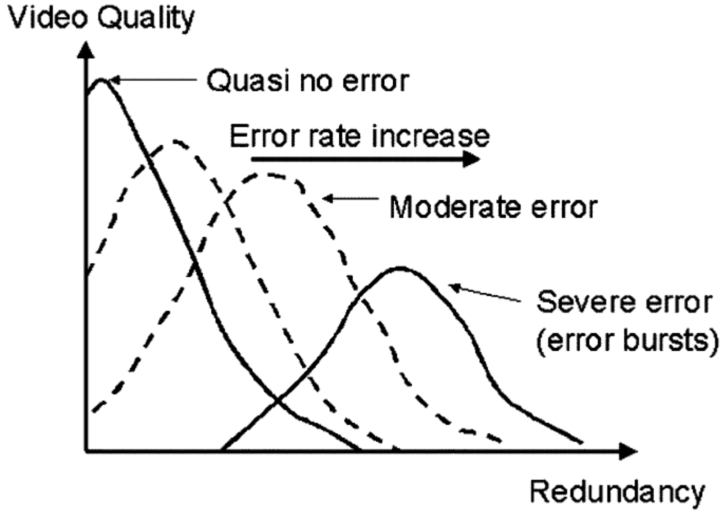
Block Diagram for Error Control of Wireless Video



Trade-off between Source and Channel Coding

- The classical goal of *source coding* :
  - To achieve the lowest possible distortion for a given target bit rate
- The classical goal of *channel coding* :
  - To deliver reliable information at a rate that is closed as possible to the channel capacity
- Joint source/channel coding optimization:
  - Keep the source and channel coder separate
  - But optimize their parameters jointly
  - A key problem of this is the bit allocation between the source and channel coder

Video Quality vs. Redundancy in Error Prone Environments



Distortion Measures

- D_e: the video signal distortion introduced by the source encoder
- D_d: the distortion at the output of the video decoder
- In practice, the most common distortion measure is mean-square error (MSE)
- The distortion at the encoder is defined as follows:

$$D_e = \frac{1}{XYT} \sum_{x=1}^{X} \sum_{y=1}^{Y} \sum_{t=1}^{T} (i[x,y,t] - e[x,y,t])^2$$

Distortion Measures (Cont.)

- The MSE at the decoder is :

$$D_d = \frac{1}{XYTL} \sum_{x=1}^{X} \sum_{y=1}^{Y} \sum_{t=1}^{T} \sum_{l=1}^{L} (i[x,y,t] - d_l[x,y,t])^2$$

- The distortion due to source coding is described by D_e
- The distortion caused by transmission errors is described by $\triangle D$

$$\Delta D = D_d - D_e$$

Distortion Measures (Cont.)

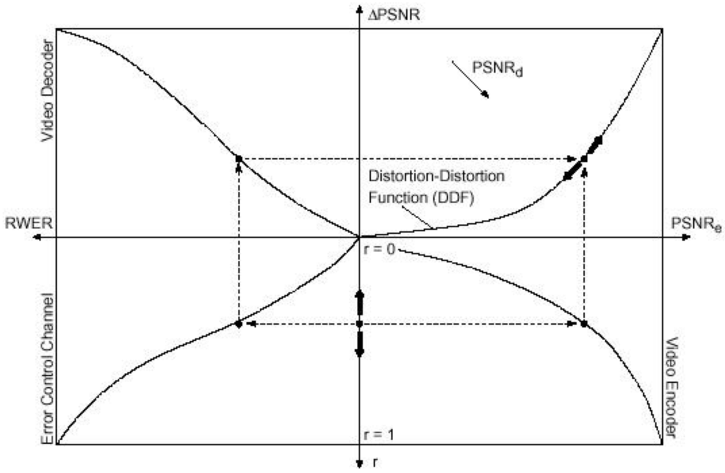
- MSE is commonly converted to *peak signal-to-noise ratio (PSNR)*
- PSNR is defined as 10 $\log_{10}(255^2/\text{MSE})$
- It is expressed in decibels (dB) and increases with increasing picture quality

$$PSNR_e = 10\log_{10}\frac{255^2}{D_e} \qquad PSNR_d = 10\log_{10}\frac{255^2}{D_d}$$

$$\triangle PSNR = PSNR_e - PSNR_d = 10\log_{10}\frac{D_e}{D_d} = 10\log_{10}\frac{D_e}{D_e + \triangle D}$$

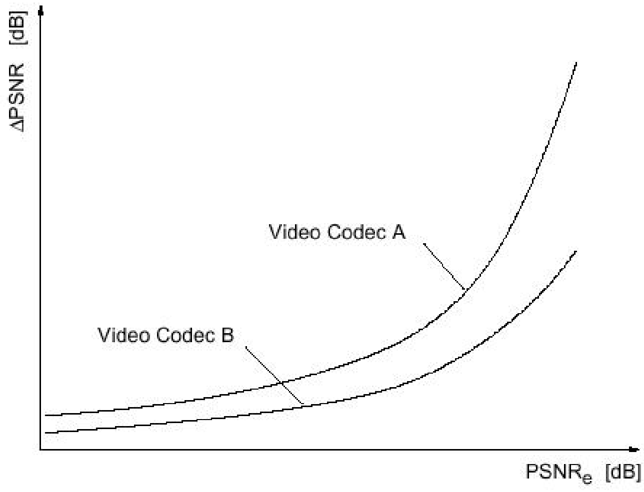
Distortion-Distortion Function (DDF)

- The interaction of the various characteristics :



r = Re/Rc

DDF of Two Typical Codecs



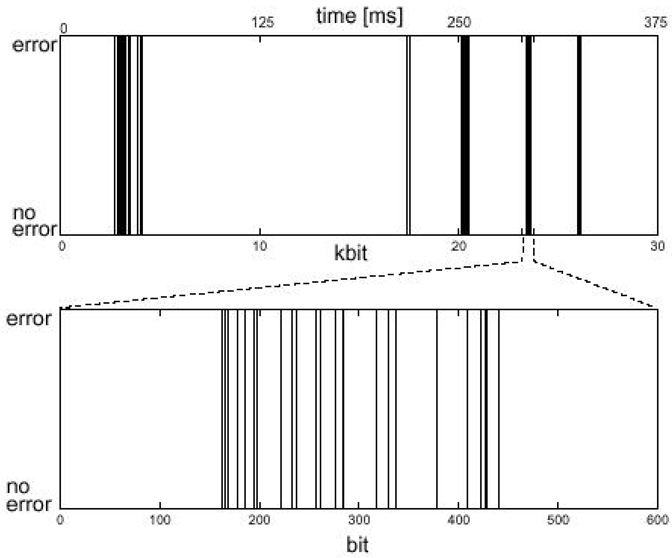
Combating Transmission Errors

- Characteristics of the mobile radio channel:
  - It is a hostile medium
  - The propagation of electromagnetic waves is influenced by :
    - Absorption、reflection、diffraction、and scattering
  - It must cope with time-varying channel conditions
    - Large scale fading: by the *path loss*
    - Small scale fading: caused by *multipath propagation*
  - Errors are not limited to single bit errors but tend to occur in bursts
  - In severe fading situations the loss of synchronization may cause an intermittent loss of the connection

Modulation

- Since we cannot feed bits to the antenna directly, an appropriate digital modulation scheme is needed
- Three basic modulation techniques
  - ASK: amplitude shift keying
  - FSK: frequency shift keying
  - PSK: phase shift keying
- The choice of a modulation scheme is a key issue in the design of a mobile communication system
  - Because each scheme possesses different performance characteristics

Burst Errors Encountered for Rayleigh Fading Channel



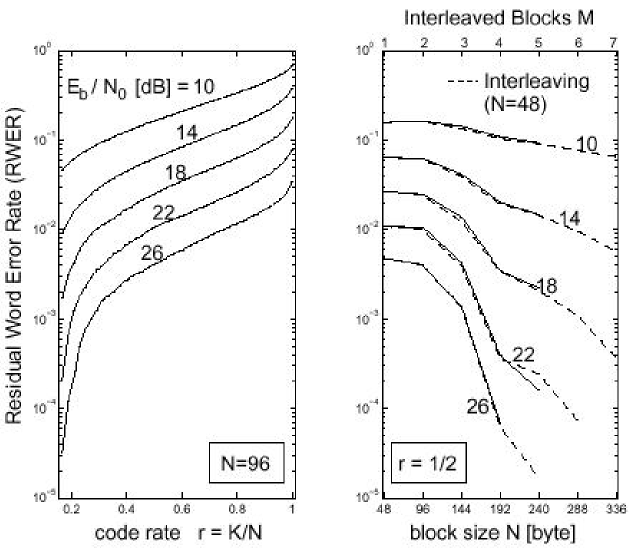
Channel Coding & Error Control

- Two main categories of channel coding and error control:
  - FEC: Forward Error Correction
  - ARQ: Automatic Repeat Request
    - ARQ requires a feedback channel to transmit retransmission requests
    - FEC has no such requirement
  - We address interleaving as a way to enhance FEC in the presence of burst errors

Forward Error Correction

- Add redundant parity bits,
  - used to detect and recover lost information
- Good for random errors with low BER, not suited for long burst errors
- Reduce effective channel bandwidth
- Increase delay and complexity
- Adding interleaving to against for burst error
  - The idea behind interleaving is to spread the error burst in time
  - Frequently used for bursty channels if the additional delay is acceptable

RWER vs. Channel Code Rate & Block Size



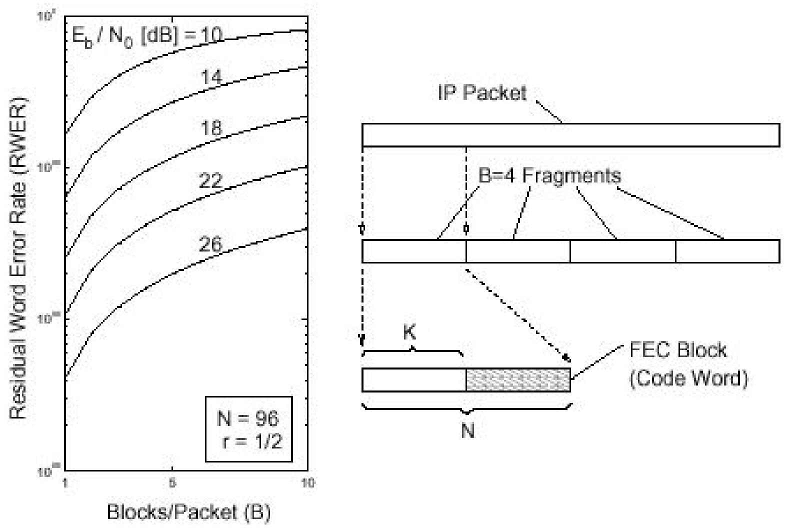
Automatic Repeat Request

- In contrast to FEC, ARQ requires a feedback channel
- The feedback channel conveys the status of received packets (ACK or NACK)
- Effective against burst errors and packet losses
- Cannot be used in systems that do not have a feedback channel (e.g., broadcasting)
- Generally not suited for real-time video communication over error-prone networks

IP over Wireless

- One issue when operating IP over a wireless radio link :
  - Fragmentation and reassembly of IP packet
- One way to avoid fragmentation is :
  - Use the minimum packet size along the path from the transmitter to the receiver
- Furthermore, the overhead of IP packet headers may become prohibitive
  - Typically 48 bytes

Packet Error Rate vs. IP Packet Fragmentation and Reassembly



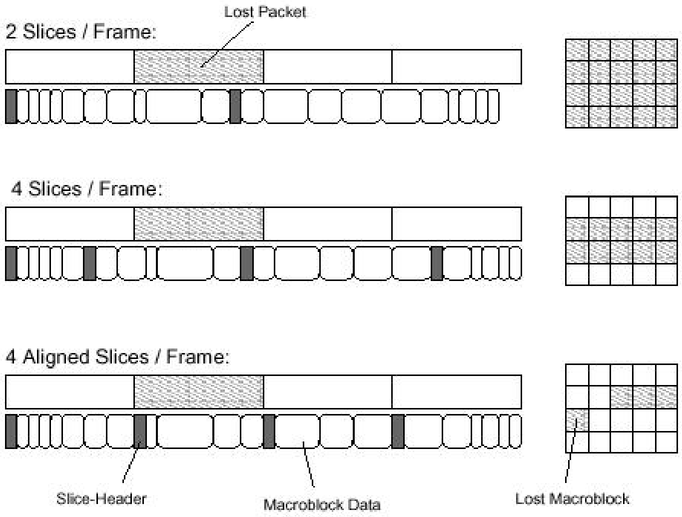
Error Resilient Techniques for Low Bit-Rate Video

- Input format and rate control:
  - QCIF (176 x 144 pixels)
  - Frame rate -> 12.5 frames/s
- Error detection and resynchronization:
  - With FEC, errors can often be detected
  - A more difficult problem than error detection is resynchronization after a detected error
  - The common solution is to insert unique synchronization codewords into the bitstream
    - *ex. H.263 : a 17-bit sync word is "00000000000000001"*

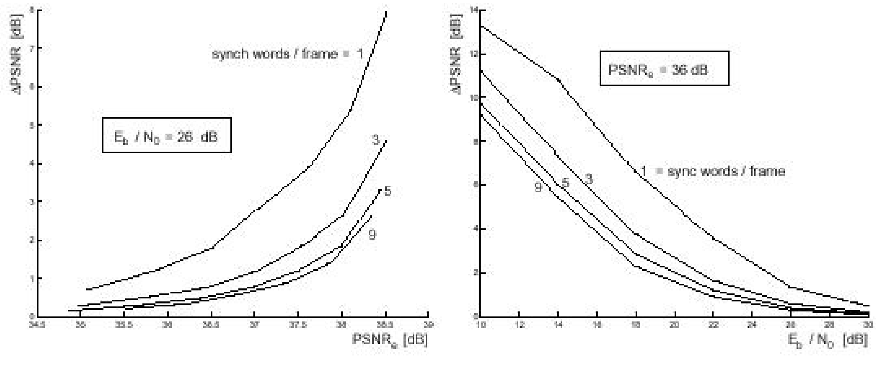
Error Detection & Resync

- Data dependencies across slice boundary should be removed to contain the errors within a slice
- may be inserted at various locations to contain the errors to a small spatial region

H.263 Resync Techniques



Video Quality vs. Number of Sync Words

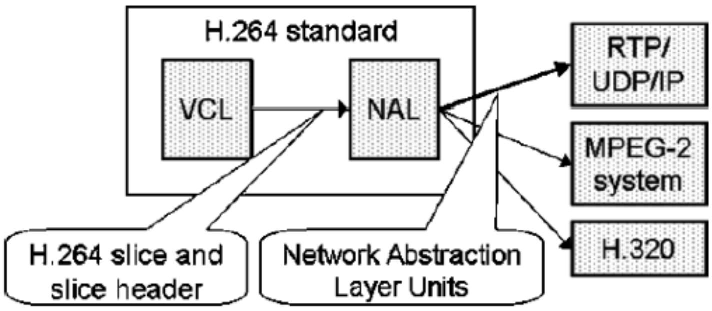


Sequence: Mother & Daughter

Error Resilience Tools in MPEG-4

- **MPEG-4 Error Resilient Tools**
- Resynchronization marker
  - Localizes error in VLC
- Data partitioning
  - Insert synchronization between different data, to preserve important data for error concealment
- Reversible Variable Length Code
  - Can recover more residual data when their error in the middle to VLC bitstreams
- Adaptive Intra-Refresh (AIR)
  - Intra blocks stop the error propagation in temporal domain, adaptively use it on motion domains is efficient

Error Resilience Tools in H.264

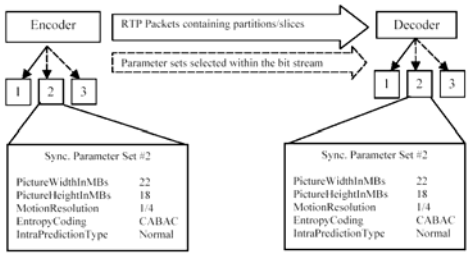


- Video coding layer (VCL)
  - Signal processing, compress the video
- Network abstraction layer (NAL)
  - Encapsulates the slice from VCL into NAL units, suitable for transmission over packet network, solve the problems on packet base

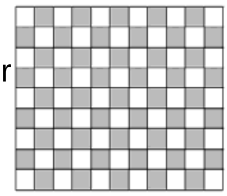
Error Resilience Tools in H.264

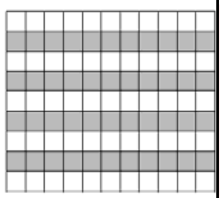
Features of NAL

- Parameter set structure:
  - use parameter index to indicate a set of parameters



- Flexible Macroblock Ordering (FMO)
  - Non-raster scan of macroblock, helpful for applying spatial concealment





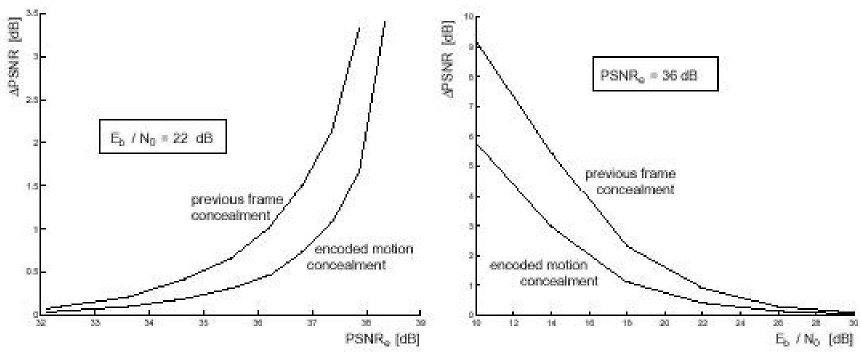
Error Resilience Tools in H.264

- Arbitrary slice ordering (ASO)
  - Improve end-to-end delay in real-time application
  - Use on the network without out-of-order delivering
- Redundant pictures
  - Redundant slices or MBs provide more protection for these region
- Data partitioning
  - Like MPEG-4, pools the same type of data together, Use unequal protection to protect the important data to yield better visual quality
- SP/SI synchronization/switching pictures
  - Allow switch video to low bitrate data seamlessly

Error Concealment

- Previous frame concealment
  - The corrupted image is replaced by corresponding pixels from the previous frame
  - Good results with little motion
- Encoded motion concealment
  - The MV used at the encoder are also used at the decoder for motion-compensated concealment
  - Can't be implemented in practice, because error-free transmission of MV assumption

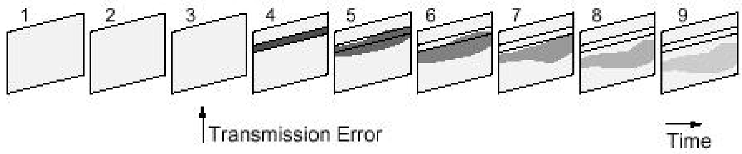
Video Quality vs. Error Concealment Techniques



Sequence: Mother & Daughter

Mitigation of Inter-frame Error Propagation

- In general, three basic approaches are introduced:
  - The prediction from previous frames is omitted by using the INTRA mode.
  - The prediction from previous frames is restricted to error free image regions.
  - The prediction signal is attenuated by leaky prediction.
- Illustration of spatio-temporal error propagation

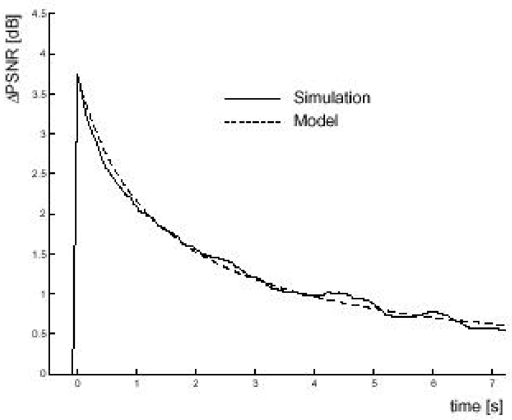


Leaky Prediction

- A well-known technique for increasing the robustness of DPCM systems
- Attenuating the energy of the prediction signal
- Reduce coding efficiency
- Increase error resilience
- More advantageous than for intra coding
  - Increased flexibility in the design

Picture Quality Recovery after Previous Frame Concealment of one GOB

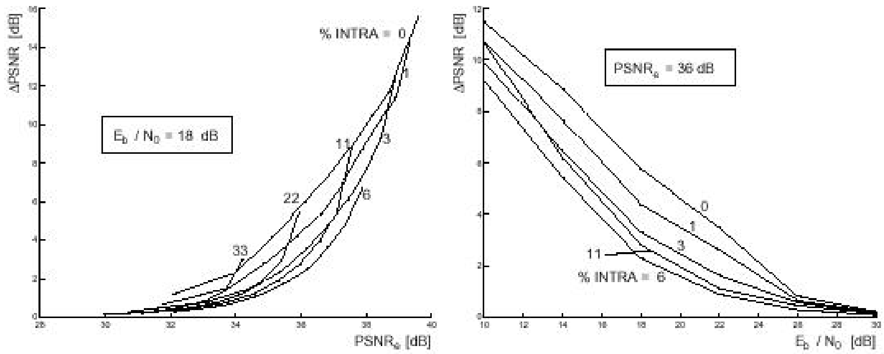
- Leakage introduced by spatial filtering is the cause of this recovery



H.261 Payload Specific Header

- A reliable method to stop interframe error propagation is the regular insertion of I-frames
- there is a trade-off to be considered:
  - An increased percentage helps to reduce interframe error propagation.
  - coding efficiency is reduced at the same time.

Picture Quality vs. Amount of Intra Blocks

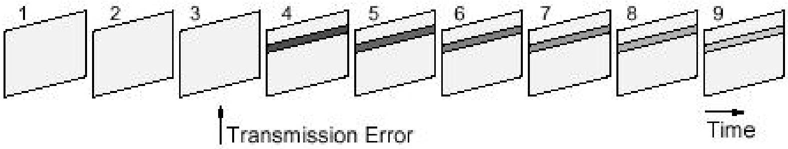


Sequence: Mother & Daughter

Error Confinement

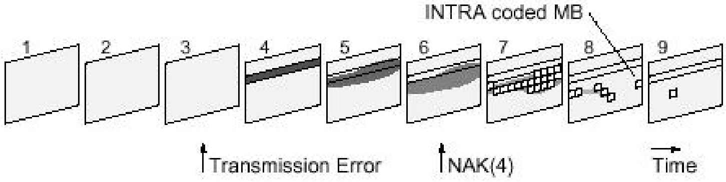
- Interframe error propagation not only results in a temporal but also spatial error spreading
- Confine the error to a well-defined subregion of the frame
- The *independent segment decoding mode* (ISD mode):
  - Decribed in Annex R of H.263
  - Each GOB is encoded as an individual subvideo
  - Reduces the efficiency of motion compensation
  - To reduce the loss of coding efficiency, combined with the *unrestricted motion vector mode* (UMV mode)

Reduction of Spatio-Temporal Error Propagation Using ISD Mode

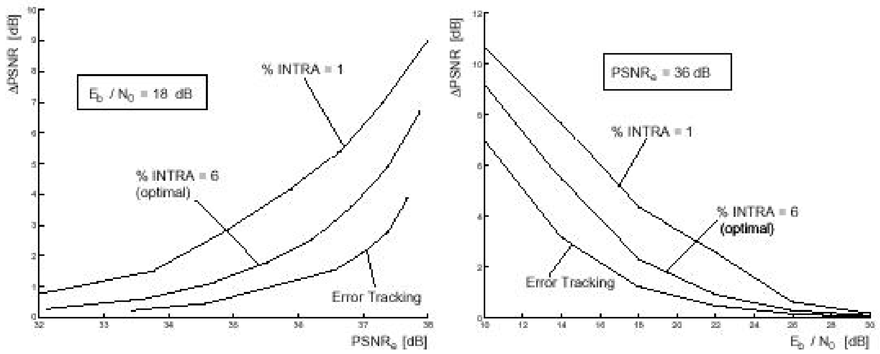


Feedback Based Error Control

- Error tracking:
  - Uses the intra mode for selected MBs to stop interframe error propagation
  - Not increase the delay between encoder and decoder
  - Suitable for applications that require a short latency
  - Illustration of spatio-temporal error propagation when Error Tracking is used.

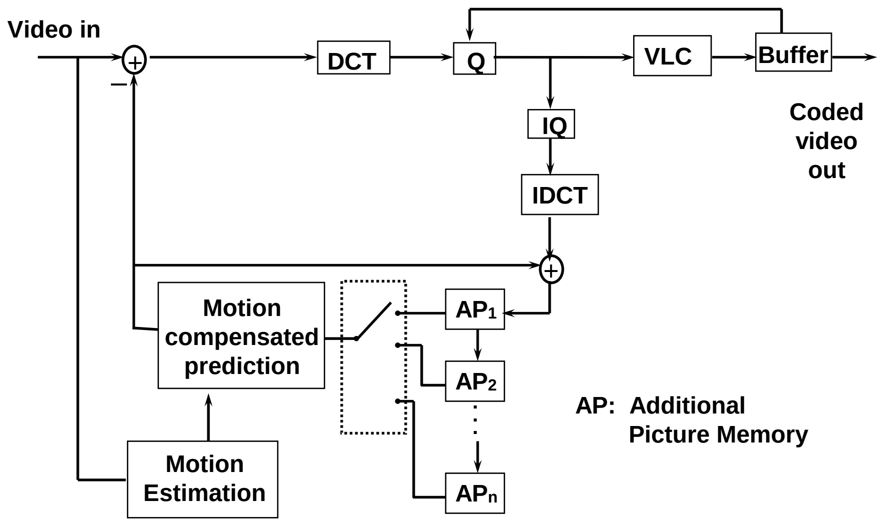


Picture Quality with Error Tracking



Sequence: Mother & Daughter

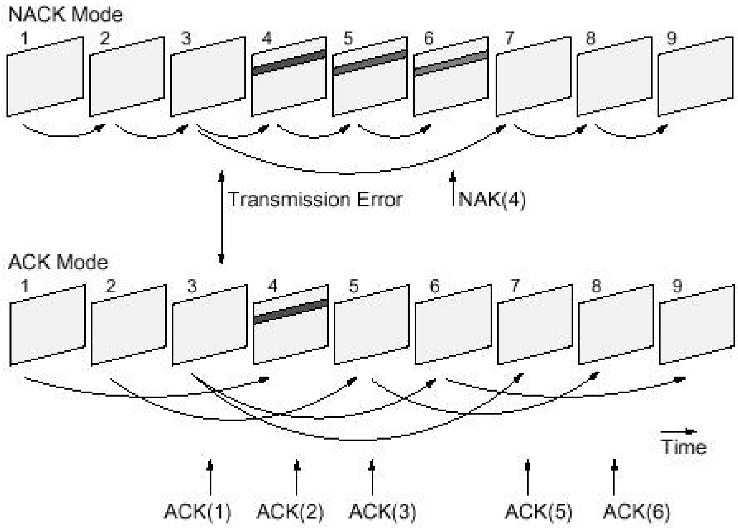
Reference Picture Selection (RPS)



Reference Picture Selection (RPS)

- RPS dynamically replaces reference pictures in the encoder in response to an ACK of the decoder
- Two modes of operation are defined depending on the acknowledgment message
  - ACK mode
  - NACK mode
- Both methods are sensitive to errors in the feedback channel
- The NACK method is effective for low error rates and the ACK method is effective for high error rates

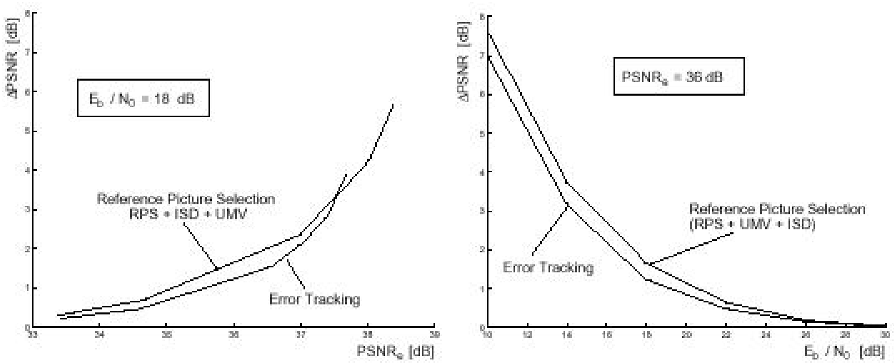
Spatio-Temporal Error Propagation with RPS



Reference Picture Selection (Cont.)

- The advantage of the RPS mode over simply switching to intra mode is the increased coding efficiency
- Increasing round-trip time
- Error propagation is avoid entirely
  - Since only error-free pictures are used for prediction
- Increased storage requirements
  - Additional frame buffers

Picture Quality with RPS

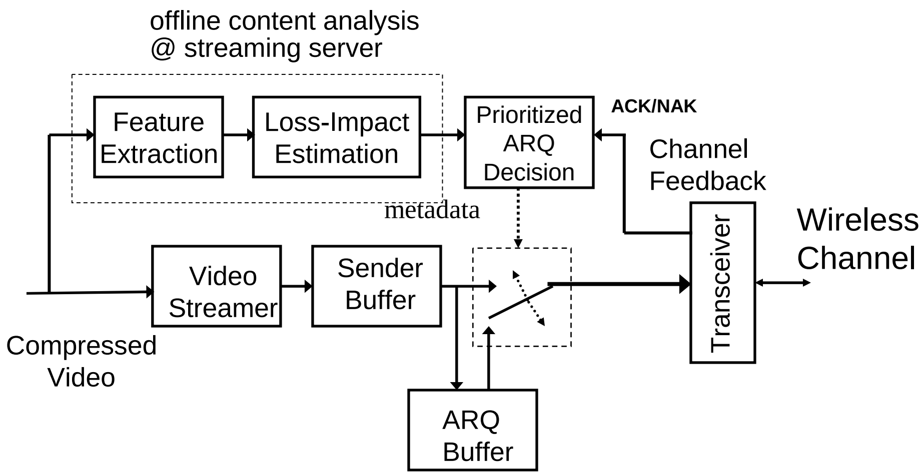


Sequence: Mother & Daughter

Future Directions

- Layered or scalable coding:
  - Can be considered as one of data partition methods, can be used as resilient tools with unequal protection
- Packet scheduling
  - Use source coding information, schedule the packet by its dependency and importance
  - One of the cross layer methods
- Transmission power optimization
  - Power consumption is import in mobile device
  - Manage power optimization with R-D optimization

Example: Retransmission Scheduling

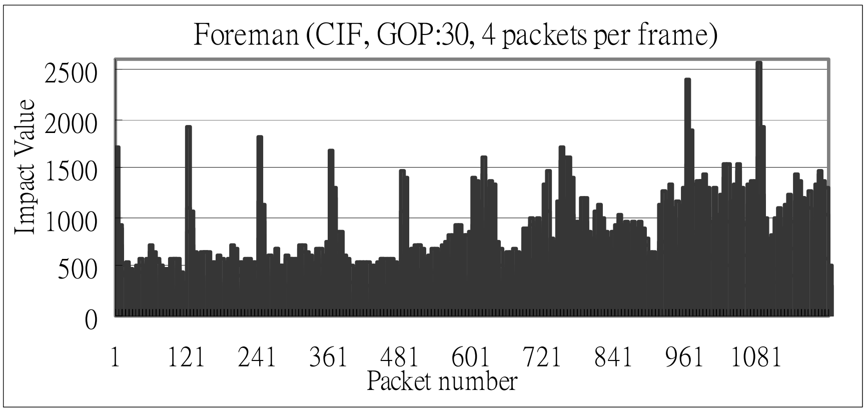


Estimation of Packet-Level Loss-Impact

- An offline process at the pre-encoding stage
- The estimation is performed for I/P-frames in a GOP since the error propagation is constrained within a GOP
- Evaluate the loss impact value of each slice (packet)
  - Mark slice *m* of frame *n* as a lost packet and decode it with zero MV concealment
  - Compute and sum up all the degraded PSNR values in the GOP containing the simulated lost slice

$$Impact_n^m = \sum_{j=n}^{N_{\mathrm{GOP}}} \left(PSNR_j - PSNR_j^{\mathrm{EC}} \right)$$

Illustration of Packet-Level Loss-Impact



0.2% extra overhead cost is required for the side info

Prioritized Retransmission

- **Based on the Greedy algorithm**
- **Server side:**
  if receiving a retransmission request for a lost packet P_i
  {
    find P_j with smallest impact factors in the regular packets with size(P_j) ≥ size(P_i) under $T_d(P_i)$ constraint
    if (P_j exists and its impact is smaller than P_i)
      retransmit P_i and drop P_j
    else
      send the regular packets and ignore the retransmission request for P_i
  }

Performance Evaluation

- Foreman

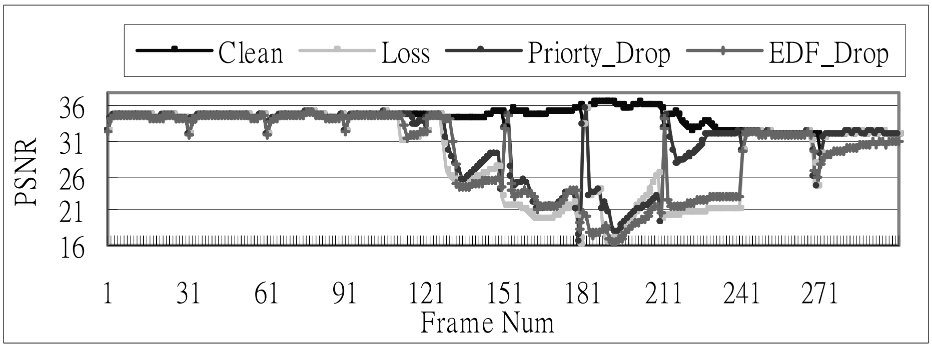
PLR	Error-Free	Without ARQ	Proposed Method	EDF
5%	34.11 dB	29.14 dB	30.71 dB	29.28 dB
10%	34.11 dB	27.34 dB	29.00 dB	27.96 dB

- Coastguard

PLR	Error-Free	Without ARQ	Proposed Method	EDF
5%	32.65 dB	29.09 dB	30.77 dB	28.76 dB
10%	32.65 dB	26.68 dB	27.91 dB	27.39 dB

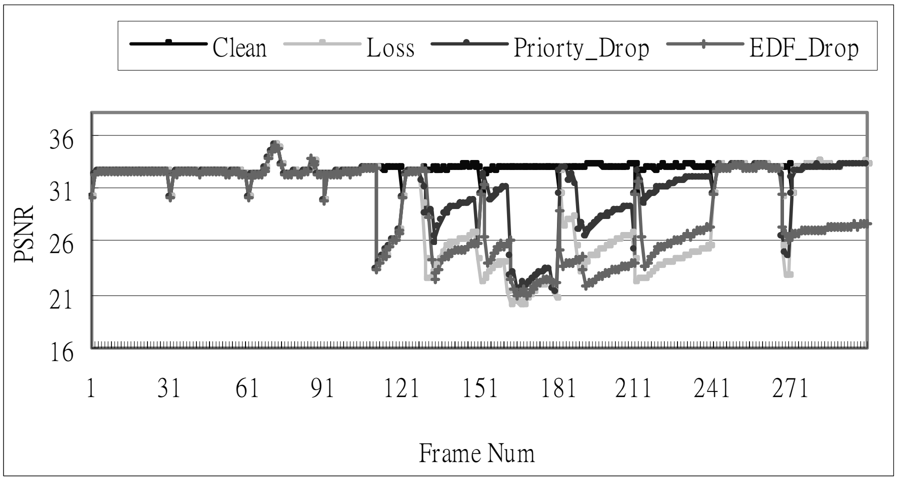
Performance Evaluation

- Frame-by-frame PSNR curve
  - Foreman (PLR = 5%)



Performance Evaluation

- Coastguard (PLR = 5%)



Conclusions

- Introduce the DDF as a tools for comparing wireless video systems
- Two major problem with wireless video
  - Only low bit rates are available
  - Pass loss and multipath fading cause time-variant error rates
- In designing the digital transmission system
  - Trade-off among *throughput, reliability,* and *delay*
- The error resilient techniques fall into two major categories
  - Techniques that reduce the amount of introduced errors (e.g., resync, error concealment)
  - Techniques that limit interframe error propagation (e.g., leaky prediction, intra update)