1. Video Streaming over Networks: Technologies & Challenges

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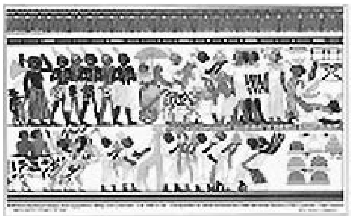
Digital Media World

- Many devices
- Wired or wireless
- Access from anywhere
- Software Integration
- Personalized delivery

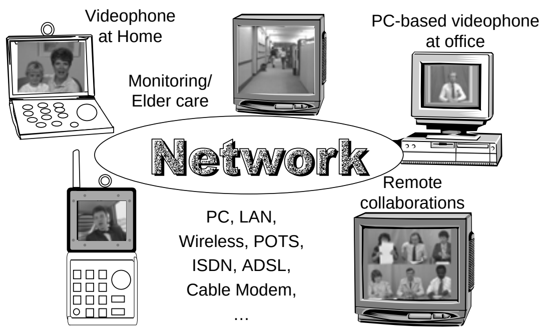
Rich Services

Visual Communication Applications (1/4)

- Applications driving the technology
- Visual communication needs evident from paintings in ancient caves



Visual Communication Applications (2/4)



Visual Communication Applications (3/4)

- **One-way applications**

  Video streaming, video on demand, Video broadcasting, Video email, Video surveillance, Digital TV, HDTV, DVD, VCD, Digital camera, Digital camcorder, Digital VCR, Games, …
  Limitation: Bandwidth

- **Two-way applications**

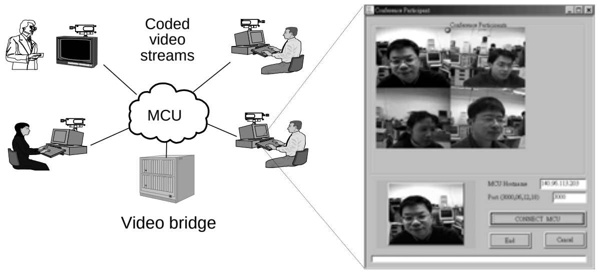
  Videophone, Videoconferencing, Distance learning, Remote collaboration, Games, …
  Limitations: Bandwidth, End-to-end Delay

Application Example: Videophone

- e.g., Panasonic
- H.324 compliant
- Regular phone line

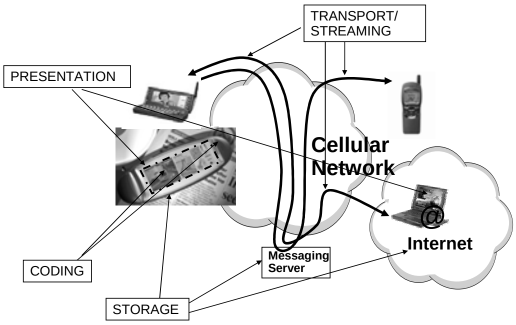
Application Example: Multipoint Videoconference

H.323 4-Way videoconference

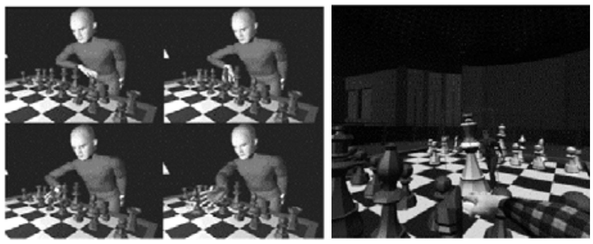


Application Example: Video Browsing & Streaming

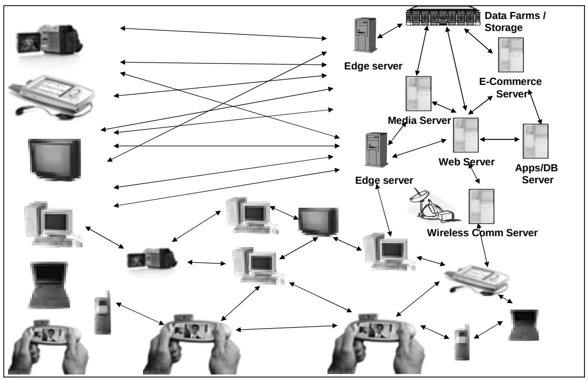
Application Example: Multimedia Messaging Services



Application Example: Networked Video Game



Digital Media: from desktop, to Internet, to handhelds, to wireless, and to peer-to-peer



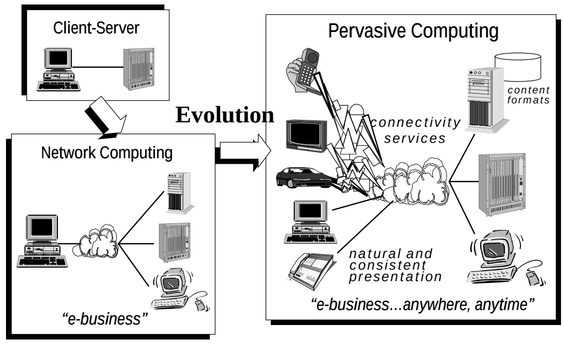
Digital Media Access & Pervasive Computing

- **Implications:**
  - **Blurring of Core vs. Edge**
  - **Migration from client-server to peer-to-peer framework**
  - **Where should data come from?**
  - **Where should computations be done?**
    - **Optimal partitioning of computations**

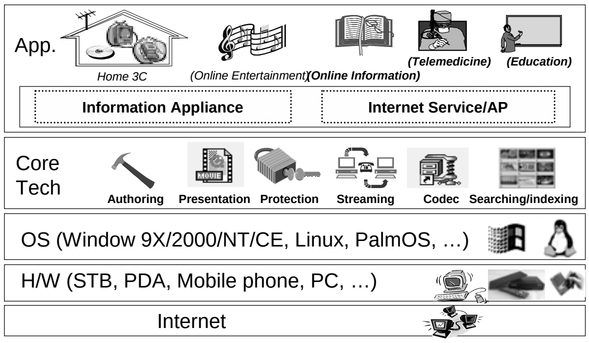
Inequality: compute, bandwidth, storage and display

Platform	CPU	Memory	Storage	B/W	Screen
Server	Multiple 1GHz+	2GB	100G to Terabytes	1+ Gbps	N/A
PC	Single 1GHz+	256M	40G	100 Mbps	1600 x 1200
Laptop	600 MHz	128M	10G	100 Mbps	1024 x 768
Media PDA	200MHz	16M	8M	19.2 kbps	320 x 240
PDA	70MHz	8M	8M	19.2 kbps	160 x 160

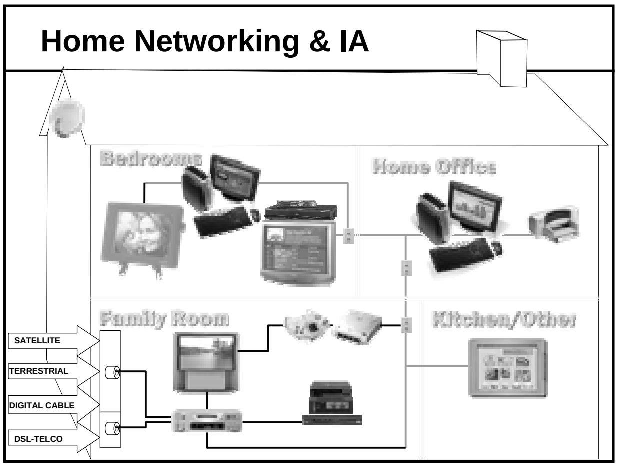
Pervasive Computing



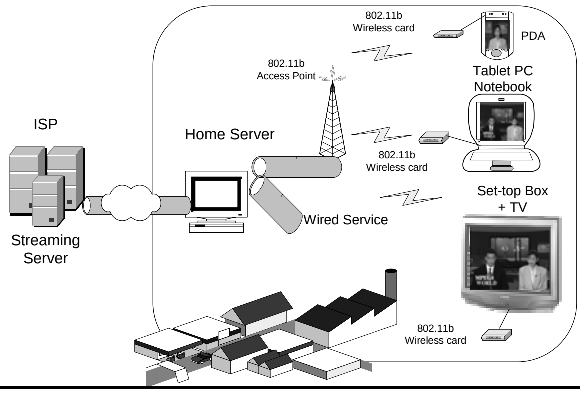
Networked Multimedia Tech. for 3C Industry



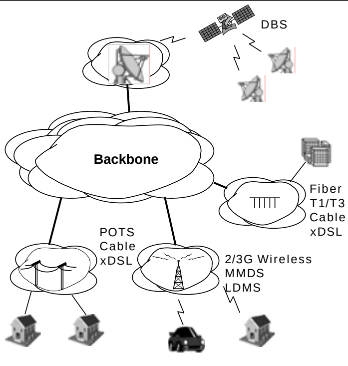
Home Networking & IA



Home Networking with Three-Tier Streaming



Networking

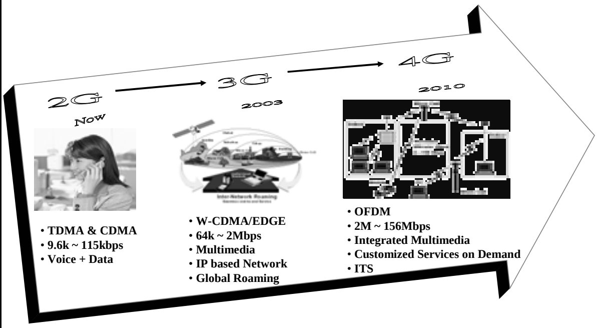


- Broadband Backbone
  - Multi-Gb/s Backbone
- Narrowband Access
  - POTS
- Broadband Access
  - Cable Modem
  - xDSL
- Wireless Access
  - DBS, LEOS
  - MMDS, LMDS
  - 3G IMT2000

Wire and Radio Networks for in-Home

Network	Scheme	Data-rate	Advantage	Disadvantage
CAT5+	4 Twisted pr.	1Gbps	Separate wiring; low cost; easy install. Telco compatible. "Fungible" wiring.	New wiring. Useful for audio and composite video. Inability to transmit CATV.
CATV	R6U Co-ax	1 GHz (150 6 MHz chs.)	Exists for TV sets; *could also serve IP throughout the home*	RF analog; no digital
Telephone	2-4 Tel. pr.	10 Mbps	Uses existing wiring	Questionable data-rate
Power	AC Power	?	Uses existing wiring	Unproven; safety
1394				Distance, lack of protocols
802.11b	Radio LAN	11 Gbps	No wires	Crowded spectrum, speed
802.11a	Radio LAN	*50 Gbps*	"	"
Bluetooth		1. Mbps	"	" Short distance, speed
Home RF		1 Mbps	"	" Low speed
Fiber	1394, SPDIF, etc.		Speed.	Install. skill; lack of home net equipment

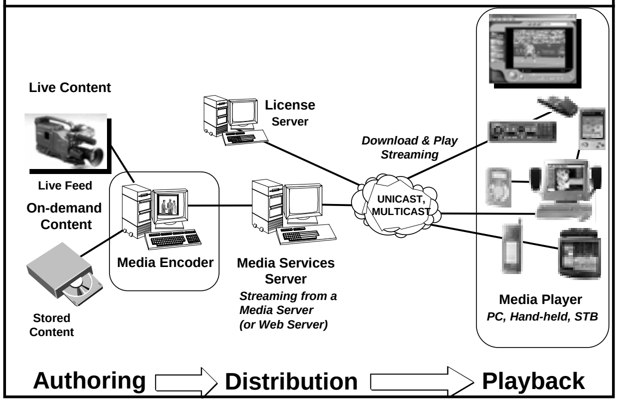
Wireless Network Evolution



Network Characteristics

- PSTN: up to 33.6 kbits/s, ubiquitous, low cost
- N-ISDN: 128 kbits/s, widely available, low cost
- ATM (B-ISDN): broadband cell-switched network, guaranteed QoS, variable bit-rate, priority, not widely available
- Ethernet: packet-switched network, non-guaranteed QoS, delay, delay variation, packet loss, congestion, widely available, low cost
- IsoEthernet: guaranteed QoS, not widely available, higher cost
- Mobile: low-bit-rate, fading, bit errors
- xDSL, cable, satellite, etc.

Components of Networked Multimedia



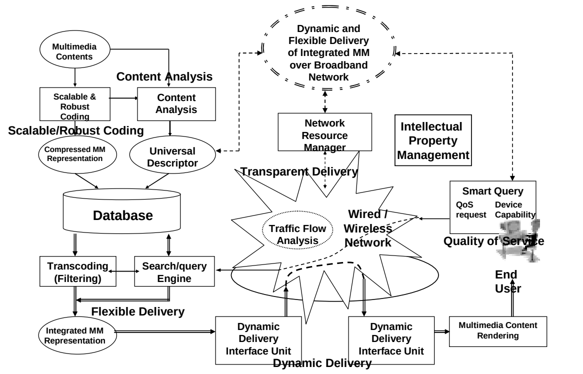
Components for Internet Video Delivery

- Content Creation: Digitization and Encoding
  - Most general purpose content starts life in analog form which needs conversion to digital form
  - Rich multimedia data types: audio, video, image, VRML, etc.
    - Lossy and lossless modes of compression
    - Download vs Broadcast (streamed) modes
  - Encoding tools typically have little knowledge of the distribution network or computational resources of the client playback device
  - Metadata for efficient search and retrieval
  - Rights of content provider must be insured

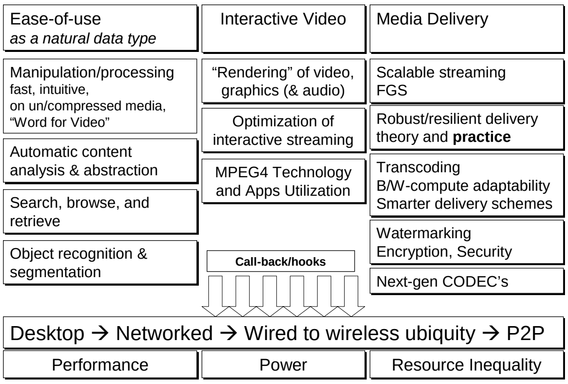
Components for Internet Video Delivery (Cont.)

- Transmission and Distribution
  - Live and pre-recorded Broadcast and VOD modes of operation
  - Redundant, Intelligent, and Reliable architecture needed
    - Redundant: Zero points of failure at each critical node of the distribution chain
    - Intelligent: Load balancing (dynamic capacity allocation) for efficient distribution
    - Reliable: Stream distributions that traverse public and private network segments; fortified against loss and congested
  - Architecture usually contains splitters/repeaters and caches for efficient usage of network/gateway capacity working in both a push and pull mode

Internet Media Delivery Framework



Building Blocks



Types of Networked Multimedia

Attribute	Value
Communication configuration	• Point-to-point • Point-to-multipoint • Multipoint-to-point • Multipoint
Symmetry of information flow	• Unidirectional • Bidirectional-symmetric • Bidirectional-asymmetric
Transmission control entity	• Source • Source and sink • Third party
Time aspects	• Real-time • Near-real-time • Non-real-time • Specified time
Media components	• Audio • Video • Text • Still picture • Graphics, data
Media component interrelations	• Synchronized • Independent
Time continuity	• Isochronous • Non-isochronous (i.e. supported by local storage)

Issues in Networked Multimedia

- Real-time constraints: delay, delay jitter
- Bandwidth requirement, VBR or CBR, symmetrical or asymmetrical
- Quality of Service (QoS): delay, delay jitter, packet loss, bit-error-rate, burst-error-rate, burst error length...
- Synchronization of video, audio, data, applications...
- Error robustness: error resilience, error concealment
- Cost

Problems in Internet Video streaming

- No QoS Guaranteed for current Network
  - No band width reservation;
  - No delay guarantee;
  - No packet loss guarantee
- Heterogeneity (multicast)
  - network: different users, different packet loss / delay
  - receiver: different latencies / visual quality requirements / processing powers / display formats

Key Areas in Internet Video streaming (1/3)

- Video Compression
  - Bandwidth variation, delay, packet loss
  - Functionality: VCR for pre-stored video, joining a live video, object manipulation
  - Complexity (real-time, non-real-time)
- Application-Layer QOS Control
  - Congestion control
    - server and/or receiver based rate control, rate shaping, etc.
  - Error control
    - FEC, delayed constrained retransmission, error resilient coding, error concealment

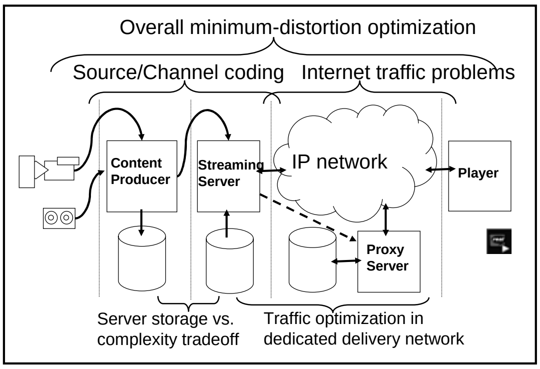
Key Areas in Internet Video streaming (2/3)

- Continuous Media Distribution Services
  - Network filtering
  - Application-level multicast
  - Content replication (mirroring, caching)
- Streaming Server
  - Real-time OS
    - Process management, resource management, file management
  - Storage System

Key Areas in Internet Video streaming (3/3)

- Media Synchronization
  - Intra-stream, inter-stream, and inter-object synchronization
- Protocols for Streaming Video
  - Network-layer protocols
    - IP
  - Transport protocols
    - UDP, TCP, RTP, RTCP
  - Session control protocols
    - RTSP, SIP

Open Problems in Internet Multimedia Delivery



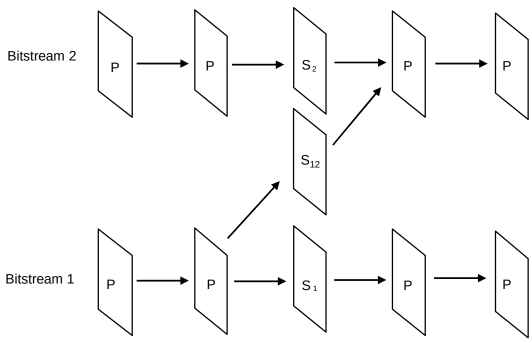
Bandwidth Variation

- "Broadband" Internet access has wider variation:
  - Cable modem: from < 100 to > 1000 Kbit/sec
  - DSL: from < 600 to > 6000 Kbit/sec

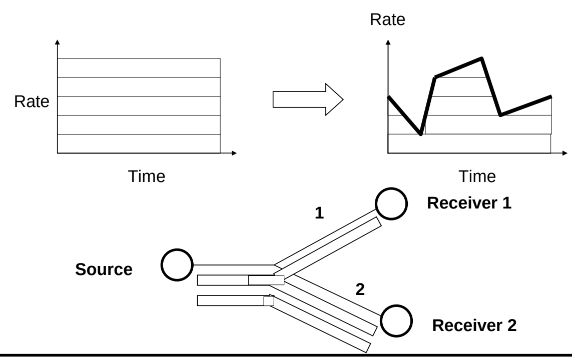
Video Adaptation for Heterogeneous Video Streaming

- Multiple Bit-streams pre-encoded with different bit-rates
  - Large storage
  - Drift problem
  - Complexity in bit-streams management and switching
  - H.264/MPEG-4 AVC SP/SI-frames (seamless switching)
- Real-time Transcoder
  - High complexity in the streaming sever
  - MPEG-21 RAE (Resource Adaptation Engine)
- Scalable video
  - Degree of scalability
  - MPEG-4 FGS (Fine Granularity Scalability), MPEG-21 SVC (Scalable Video Coding)

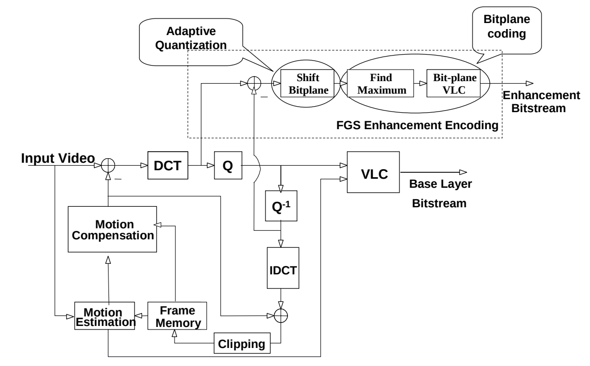
H.264 Bitstream Switching (SP-frames)



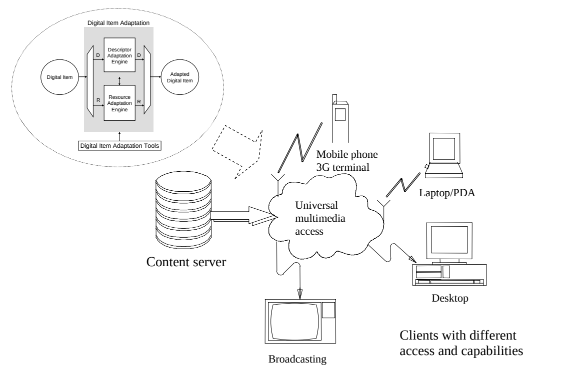
Scalable Coding



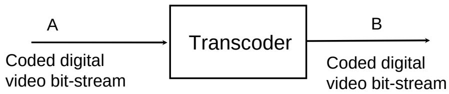
MPEG-4 Fine Granularity Scalability



MPEG-21: DIA for Universal Multimedia Access



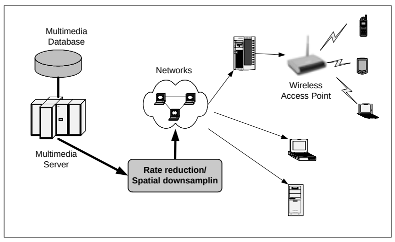
Video Transcoding



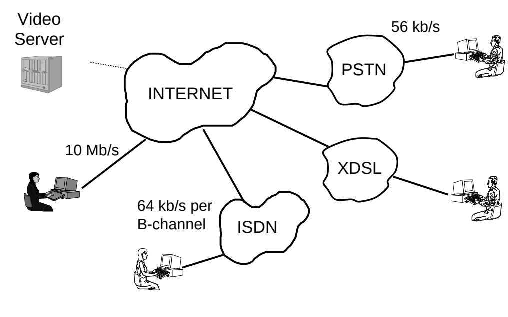
- Bit-rate adaptation
- Spatial/temporal resolution conversion
- Multipoint video conferencing
- Watermarking
- Error resilience
- Encryption
- Video multicast over heterogeneous networks

Heterogeneous Video Transcoding

- Adapting video streams to different types of terminals with different terminal capabilities such as screen size, amount of available memory, processing power and type of network access

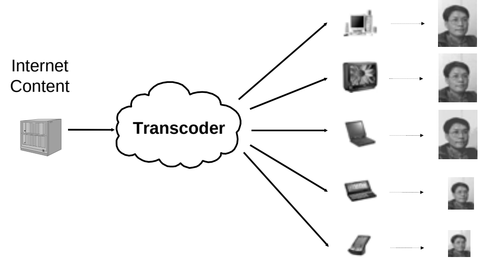


Video Transcoding: Heterogeneous Networks

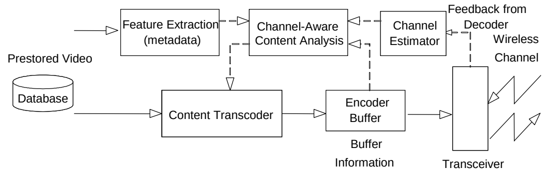


Video Transcoding: Heterogeneous Clients

To deliver multimedia data to diverse devices with different capabilities (Universal Multimedia Access)

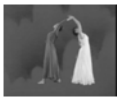


Example: Content-based Video Transcoding with Prestored Metadata



- Approach
  - The server offline extracts the compressed-domain features from the pre-encoded bit-stream
  - The features are then stored as auxiliary data to guide the content transcoding
  - Rate-distortion constrained transcoding

Demo: Content-based Error-Resilience Transcoding



Original

Proposed 10% | Non-E.R. 10% | Random 10% | Regular 10%

Proposed 20% | Non-E.R. 20% | Random 20% | Regular 20%

Demo: Content-based Temporal Transcoding for Rate Adaptation

Combine temporal scalability and key-frames for heterogeneous channels and user terminals

Demo: Content-based Temporal Transcoding for Rate Adaptation

Original | Summary

Movie,

1132 frames,

70 key frames

Movie,

1123 frames,

55 key frames

QoS Control for Networked Video

- Network Centric

  --- next generation network providing QoS support

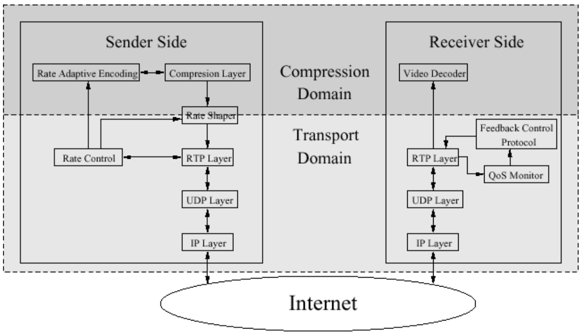
- End System-based

  --- compatible with current network structure
  - congestion control
  - error control

QoS Control for Networked Video

- Congestion Control
  - To reduce packet loss and delay
  - Rate control, rate adaptive control and rate shaping
- Error Control
  - To handle video quality when packet loss happens
  - FEC, retransmission, error resilience and error concealment

Congestion Control



Congestion Control (Cont.)

- Rate control:
  - UDP replaces TCP for delay reason
  - no congestion control for QoS in UDP
  - rate-based control is usually employed (source based, receiver based and hybrid)

Congestion Control (Cont.)

- Rate control – rate-based control
  - source based: the sender regulates video stream applied to unicast & multicast
  - receiver based: receivers regulate the receiving rate; typically for multicast
  - hybrid

Congestion Control (Cont.)

- Rate control – source-based
  - Probe-based
    - AIMD (Additive Increase Multiplicative Decrease)
    - MIMD (Multiplicative Increase Multiplicative Decrease)
  - Model-based

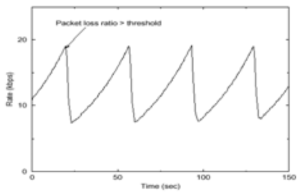


Fig. 5. Source rate behavior under the AIMD rate control.

Congestion Control (Cont.)

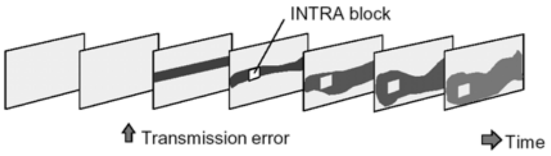
- Rate control – receiver-based
  - for solving the heterogeneity in multicast
  - probe-based approach
  - model-based approach
  - joint-leaving for large number of receivers -- congestion
  - shared learning or synchronization control

Congestion Control (Cont.)

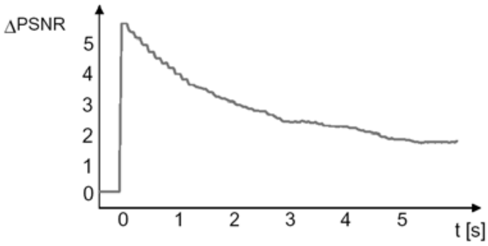
- Rate Shaping
  - adapt the video rate to target network rate constraint
- Server selective frame discard
- Selective DCT coefficient discard

Effect of Error Propagation

- The use of VLCs and predictive techniques in video coding leads to error propagation
- A single bit error can propagate to many bits
- MV prediction causes spatial error propagation
- Motion compensation causes temporal error propagation

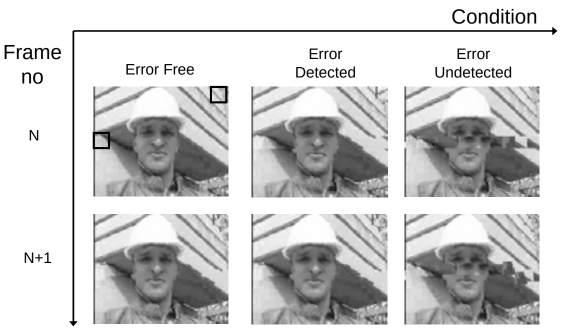


Effect of Error Propagation (Cont.)



- Single burst covering 1/3 of a frame
- Previous frame concealment
- Average over many trials
- No Intra

Effect of Error Propagation (Cont.)



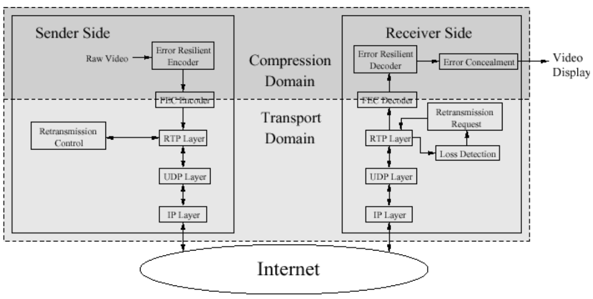
Error Control

- To prevent packet loss by matching the rate of video streams to the available bandwidth in the network.
- packet loss is unavoidable
- other mechanisms to maximize the video presentation quality

Error Control (Cont.)

- FEC
- Retransmission
- Error resilience coding
- Error concealment

Error Control (Cont.)



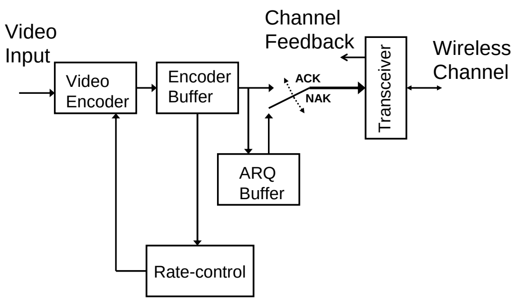
Error Control- FEC

- FEC – channel coding
- Unequal Error Protection and Equal Error Protection
  - increase transmission rate
  - increase delay: long block or interleaving
  - Not adaptive to varying loss characteristic

Error Control- ARQ

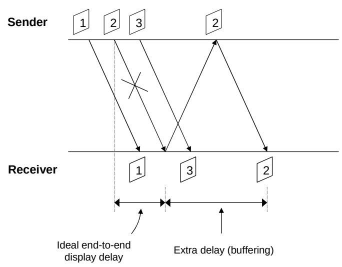
- ARQ
- Need 2-way communication channels
- Effective if round-trip delay is shorter than maximum delay allowed
- Delay-constrained retransmission
- Increase congestion

Error Control- ARQ (Cont.)



Error Control- ARQ (Cont.)

- Very effective with large de-jittering buffer
- Not realistic for delay stringent real-time applications



Error Control: Error Resilience Coding

- sequence number, duplicate packets, duplicate important information
- slice structure, resynch markers, intra-MBs, intra-slices, intra-pictures
- scalable coding with priority and unequal error protection
- multiple reference frames*, error tracking and intra-block refreshing
- video redundancy coding
- multiple description coding
- reversible variable length codes*
- error-resilience entropy coding*

  ...

Error Control: Error Concealment

Detecting errors through packet sequence number, packet error indicator, invalid codewords, invalid number of DCT coefficients, invalid range of parameters, incorrect sync-marker position, …

- Temporal error concealment
- Spatial error concealment
- Hybrid error concealment
- Late-cell/packet processing
- POCS

  ...

DEMO: Error Resilience Coding

Original

Non-E.R.10%

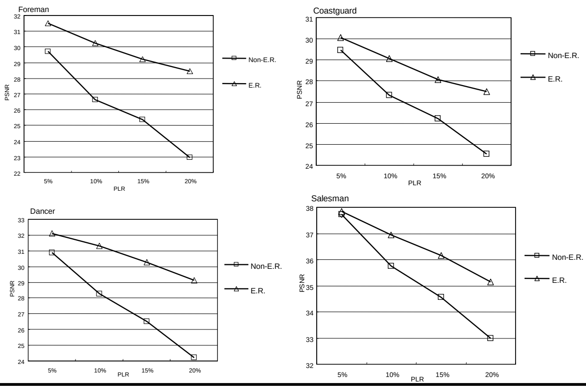
E.R.10%

Non-E.R. 20%

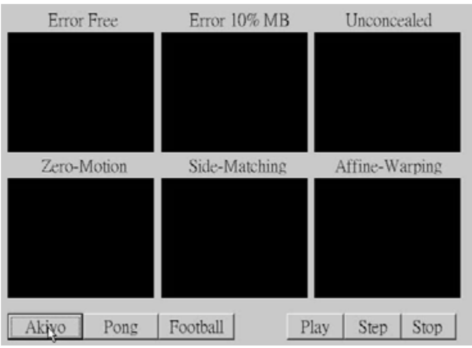
E.R. 20%

"Foreman" with packet loss rate = 10% & 20%

Performance Comparison: Error Resilience Coding



DEMO: Error Concealment



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