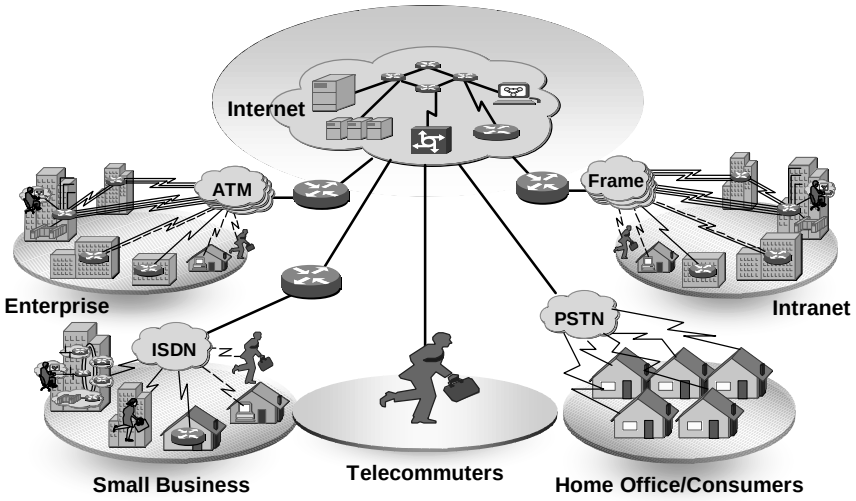
18-796

Multimedia Communications:
Coding, Systems, and Networking

Prof. Tsuhan Chen
tsuhan@ece.cmu.edu

Networking Issues

Network Characteristics

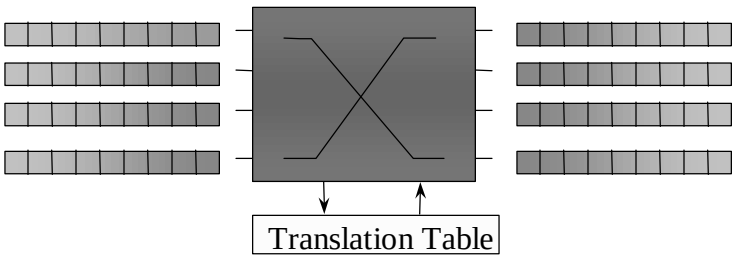


Considerations in Networked Multimedia

- Error resilience
- Bandwidth requirements
  - Constant bit rate (CBR) vs. variable bit rate (VBR)
  - Symmetrical vs. asymmetrical
- Quality of Service (QoS)
  - Delay, delay jitter
  - Packet loss, bit-error rate, burst-error rate, burst error length...
- Real-time constraints
- Synchronization of video, audio, data, applications...
- Cost

Circuit-Switched Network

- Principle
  - Several connections are time-multiplexed over one link
  - A dedicated circuit is established during the complete duration of the connection



Circuit-Switched Network (cont.)

- Features
  - Constant bit-rate, e.g., 64 kbits/s PCM channel
  - Short transmission delay
  - Small delay jitters
- Examples
  - PSTN (Public Switched Telephone Network)
    - POTS (Plain Old Telephone Service)
  - ISDN (Integrated Service Digital Network)
    - N-ISDN (Narrowband-ISDN)

Circuit-Switched Network (cont.)

- Suitable for real-time applications that requires constant bandwidth
  - Audio
  - CBR compressed video
- Not efficient for applications that are bursty
  - Data
    - File transfer, fax, e-mail, telnet, web-browsing, etc.
  - VBR compressed video

Packet-Switched Network

- Principles
  - Communication links are shared by multiple users
  - Information encapsulated in "packets"
    - Header: source and destination information for routing, error correction, etc.
    - Data
  - "Connectionless"

Packet-Switched Network (cont.)

- Features
  - Variable length packets are allowed
  - Large transmission delay
  - Large delay jitters
- Examples
  - Local Area Networks (LAN)
    - Ethernet: IEEE 802.3
    - Token Ring: IEEE 802.5 (by IBM)
  - Wide Area Networks (WAN)

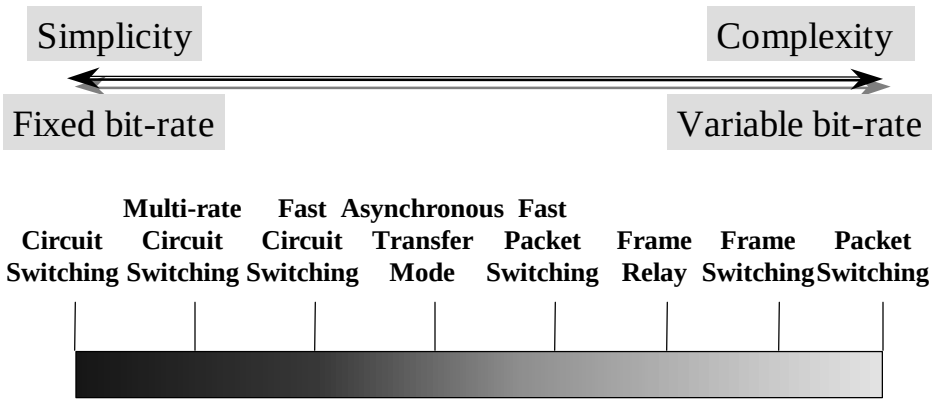
Packet-Switched Network (cont.)

- Suitable for applications which require dynamic bandwidth
  - Data
  - VBR compressed video
- Problem with delay-sensitive applications
  - Real-time video and audio
    - Videoconferencing

Circuit-Switching vs. Packet-Switching

	Circuit -Switched	Packet-Switched
Dedicated Connection	Yes	No
Call Setup	Yes	No
Bandwidth	Fixed	Dynamic
Fixed Route	Yes	No
Network Congestion	Setup time	Anytime
Utilization Charge	Transmission time based	Transmission packet based

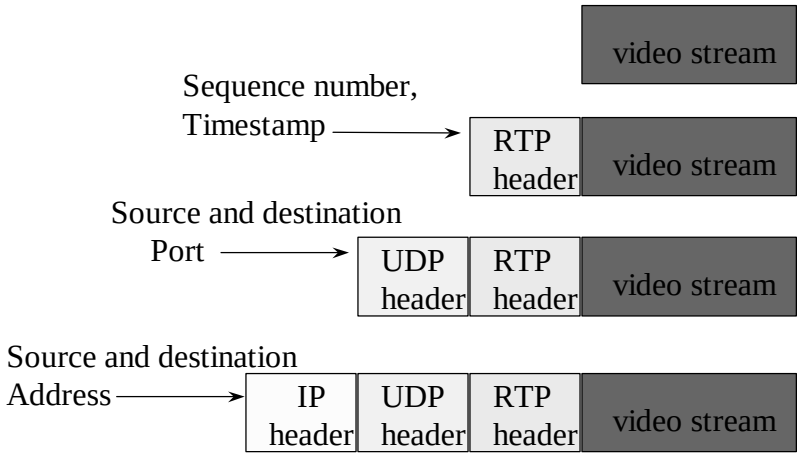
The "Spectrum"



Example Networks

- PSTN: up to 56 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 yet
- 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, bit errors, fading
- Others: xDSL, cable, satellite, etc.

Data Encapsulation Example



TCP & UDP

- TCP (Transmission Control Protocol)
  - Acknowledgment is required for every packet
  - Offers reliable in-sequence delivery
  - Long latency
  - Connection-oriented protocol
- UDP (User Datagram Protocol)
  - No acknowledgment is needed
  - Offers best effort delivery
  - Simple protocol, connectionless

RTP

- RTP (Real-time Transport Protocol)
  - Provides TimeStamp to resolve delay jitters
  - Provides sequence number for in-sequence ordering of received packets
  - Provides payload type information defined by IETF
    - H.261, H.263, JPEG-compressed video, MPEG1/MPEG2 video, etc.
    - The payload format adds redundant information to the header to eliminate data dependency between packets

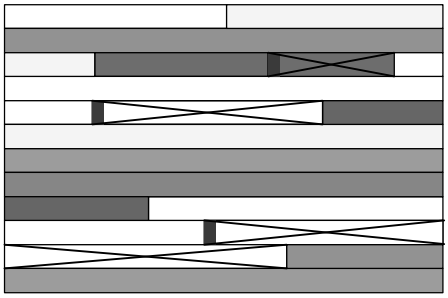
RTCP

- RTCP (Real-Time Control Protocol)
  - A companion protocol to RTP
  - Used to monitor the Quality of Service (QoS) and convey information such as name or e-mail to conference participants
  - Sender report and receiver report are used to report reception quality, e.g., round-trip delay, packet loss rate, and inter-arrival jitters

Error Resilience

- Multimedia delivery over unreliable channels
  - Wireless
  - Internet
  - etc.
- Transmission errors
  - Random bit error
    - Bit inversion, bit insertion, and bit deletion
  - Bursty error
    - Packet loss, defect in storage media, system failure
    - Due to VLC, random bit error can result in bursty error

An Example



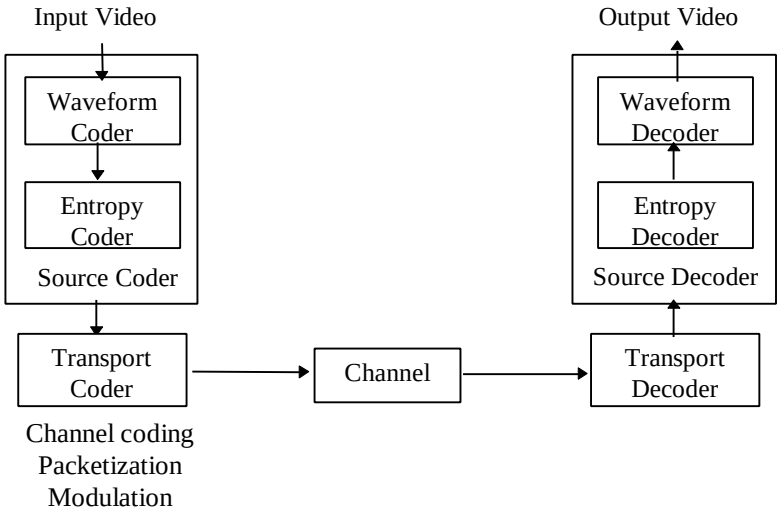
Errors

- GOB/Slice structure
  - Start code (sync word) at each slice
  - One error makes the rest of slice useless
    - For the decoder, the whole slice is useless
  - Errors do not cross slice boundary
- Errors also propagate into P and B frames

Error Recovery

- Perfect recovery
  - Bit level error detection and correction
  - e.g., forward error correction (FEC), automatic retransmission request (ARQ)
- Lossy recovery
  - Approximation to the original statistics
  - Processing to make error less perceptible by humans

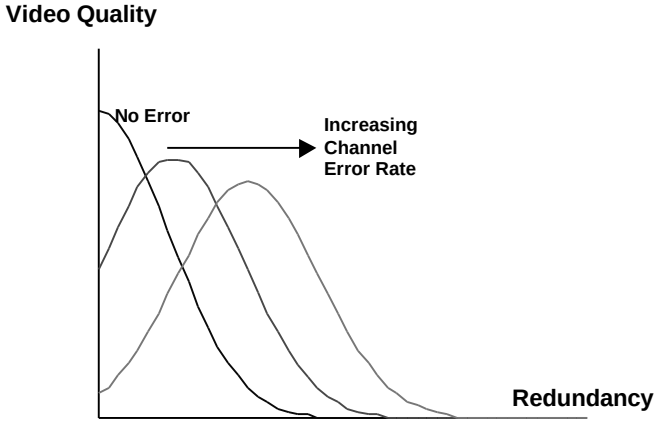
Video Communication



Source Coding vs. Channel Coding

- Source coding
  - Remove redundancy based on source statistics
  - To achieve compression and save bandwidth
- Channel coding
  - Add redundancy based on the channel characteristics
  - To help error detection, recovery, and concealment
- Conflicting?
- Joint source and channel coding

Concealment Redundancy



– For a fixed bitrate and various channel error rates

Error Detection Methods

- At the transport codec level
  - Header information: e.g., packet sequence number
  - FEC: e.g., in H.261, 18 bit FEC for 493 bits of video
- At the video codec level
  - Detecting difference of adjacent lines or blocks
  - Syntax: e.g., more than 64 DCT coefficients
  - Non-existing VLC entries, e.g.,

0
101
1110
1111

Error

01011010011001...

Error Resilience

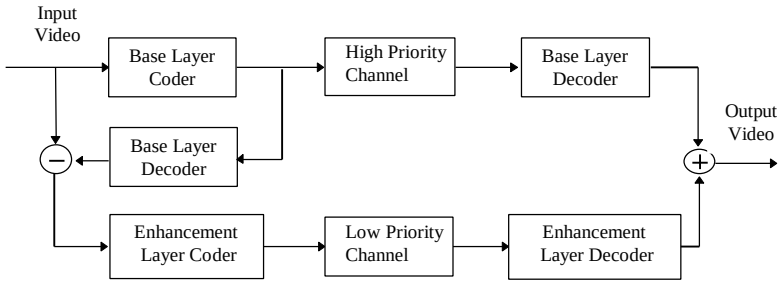
- Forward error concealment
  - Add redundancy at the encoder to enhance error resilience of the coded bit streams
- Error concealment by post-processing
  - Operations at the decoder to recover the damaged areas
- Interactive error concealment
  - Dialog between the source and destination to minimize the end-to-end error

Forward Error Concealment

- Layered coding with prioritized transport
- Multiple description coding
- Robust waveform coding
- Robust entropy coding
- Transport level control

Layered Coding with Prioritized Transport

- Transport Prioritization
  - Low priority cells may be dropped, e.g., in ATM
  - Unequal transmission power, e.g., in wireless
  - Unequal error protection

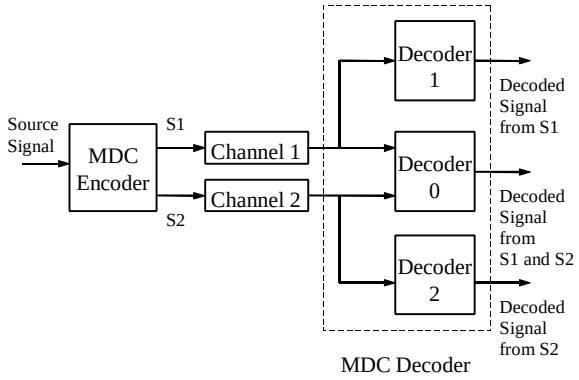


(cont.)

- Frequency domain partitioning
  - e.g., MPEG2 data partitioning
- Successive amplitude refinement
  - e.g., MPEG2 SNR scalability
- Spatial/temporal resolution refinement
  - e.g., MPEG2 spatial/temporal scalability

- Coding modes and motion vectors are essential, so usually in the base layer

Multiple Description Coding



- Parallel channels with similar and independent statistics
- The signal can be recovered from any one channel
- More channels received, better quality

Multiple Description Coding (cont.)

- Spatial domain subsampling
- Transform domain subsampling
- Multiple description scalar quantization
  - 2R bits vs. R+1 bits (good for low bit rate)
  - e.g., quantization of DCT coefficients
- Correlation inducing transform
  - To introduce correlation to the variables (such as DCT coefficients), apply 45° rotation transform of each pair of uncorrelated variables
- More on boards...

Robust Waveform Coding

- Adding auxiliary information to help error concealment
  - e.g., Motion vectors for intra MBs in MPEG-2
- Restricting prediction domain
  - e.g., Independent Segment Decoding in H.263

Robust Entropy Coding

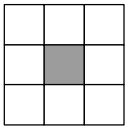
- Synchronization codeword
  - Error propagation up to the next sync word
  - Use long codeword to prevent sync word emulation
- Error resilient entropy coding (EREC)
  - Slots of equal sizes. Fitting one block into one slot. Put remaining bits into other slots.
  - Can resynchronize at each block. Low-freq DCT can be more reliable.
- Reversible VLC

Transport Level Control

- Robust packetization
  - Coding modes repeated in successive packets
- Spatial block interleaving
  - Adjacent blocks are put into non-successive packets
- Dual transmission of important information
  - e.g., picture header information, quantization matrix

Post-Processing Techniques

- Motion compensated temporal prediction
  - Given motion vector, replace the damaged MB with the motion compensated block
- Maximally smooth recovery
  - Exploit both spatial and temporal correlation
  - Does not work for object boundary
- Projection onto Convex Sets (POCS)
  - Iterations of two projections: smoothing and replacement



Post-Processing Techniques (cont.)

- Frequency domain interpolation
  - Interpolate missing DCT coefficients from neighboring blocks that are not damaged
  - Requires block interleaving for better quality
- Recovery of coding modes and motion vectors
  - Interpolate from adjacent blocks, usually from above and below (due to the GOB/slice structure)

Interactive Error Concealment

- Selective encoding
  - Avoid using damaged regions for prediction
  - H.263: Reference Picture Selection Mode
  - When error rate is high, use more intra coding and shorter slices
- Retransmission without waiting
  - Keep decoding while a trace of affected pels is recorded
  - Upon arrival of the the retransmitted data, correct the affected pels
  - Can achieve perfect recovery without the associated delay
- Multicopy retransmission (for high error rate)

Evaluation of Error Resilience

- Image quality
- Delay
- Bitrate overhead
- Processing complexity

- Application dependent
  - Delay is important for two-way commination
  - Retransmission works for point-to-point, but not for multipoint applications
  - Post-processing works in most applications

References

- *Special issue on Multimedia Modem, IEEE Communication Magazine*, December 1996
- R. Schaphorst, *Videoconferencing and Videotelephony: Technology and Standards*, Artech House, 1996
- J. Duran and C. Sauer, *Mainstream Videoconfernecing*, Addison Wesley
- IETF Home Page: http://www.ietf.org/
- RTP site: http://www.cs.columbia.edu/~hgs/rtp/drafts.html
- N. Ohta, *Packet Video: Modeling and Signal Processing*, Artech House, 1994