Robust Visual Communications: Possibilities for Sensor Networks

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Visual Communications over Networks

• Goal: maximize the *end-to-end* performance, from source generation to end-user. Issues to consider:
  
  • Source characteristics and their implications for transmission (e.g., data correlation, data dependencies)
  
  • Transmission characteristics and their implications for source coding (e.g., available bandwidths, packet loss rates, bit error rates, queuing delays).
  
  • End-use of the data (e.g., relative visual importance, reproduction of key features).
Source Coding & Transmission Issues

- Approaches to the packet loss problem.
- Maximizing bandwidth efficiency by maximizing visual quality at low rates.
- Approaches to the bit error problem.
- Optimal data partitioning for heterogeneous multipath transmission.
1. *Data transform* is invertible and most commonly a *frequency* transform...
   - Block-based (e.g., JPEG with a DCT; MPEG).
   - Wavelet-based (e.g., JPEG-2000).

2. *Quantization* reduces the amount of data and should consider human visual system characteristics for best performance.
3. *Entropy coding* is lossless and compacts the bit stream (coding is variable-length).

MPEG and many other video coders include a motion-compensation step in the data transform.
The Packet Loss Problem

- Image data transmitted in a packet-based system over a lossy link is corrupted.
- Sequence numbers identify lost packets.
- Bit errors are handled by other schemes.
- Packets are lost in their entirety.
- Data is interleaved to avoid large contiguous areas of lost information within a frame.
Two Dual Approaches

- **Decoder-based adaptive reconstruction** — exploit characteristics of visual information.
  - Good when decoder computation is available.
  - Generally higher quality.

- **Reconstruction-optimized source coding** — the compression algorithm is designed to maximize reconstruction performance for a given algorithm.
  - Useful when computation is constrained.
  - Frequency transforms, multiple-description coding, scalable coding provide options. These *may* require higher bandwidth.
Maximizing Visual Quality at All Bit Rates

A scalable stream describes the image at all bit rates....but low-rate images have visible artifacts.
Visually Optimized Low-Rate Image Compression

- Subthreshold human visual system (HVS) properties are often assumed at low rates, where distortions are *suprathreshold*.

- Our experiments have quantified HVS sensitivities to wavelet-based compression distortions in natural images.

- Results: extending subthreshold results to suprathreshold compression is not optimal.
Contrast-Based Quantization Results

Our strategy

0.1 bpp

JPEG-2000
The Bit Error Problem

- Entropy coding is *variable-length coding*. Errors in the bit stream can cause the decoder to lose synchronization and decode garbage.

- Defining garbage:
  - Bit-level synchronization — parsing the stream correctly into codewords.
  - Symbol-level synchronization — getting the correctly decoded data into the right spatial location in the image.
Synchronization Solutions

- Reversible variable-length codes (a stream is decodable both forward & backward).
- Resynchronizing variable-length codes (codes which minimize the amount of “garbage”).
  - Tolerate BERs of up to $10^{-4}$.
  - Reduce burst errors to bit errors.
- These techniques permit use of significantly weaker channel codes.
- These techniques should be combined with error detection & concealment — they require decoder resources.
Optimal Data Partitioning for Heterogeneous Multipath Transmission

- Multiple sub-channels have differing bandwidths, packet loss rates, propagation delays.

- Any one channel is not sufficient to transmit the bitstream. How do we partition it to meet user QoS constraints?
Two Cases

1. The logical channel has sufficient resources to transmit the entire bitstream. Optimize the resource utilization to achieve a desired condition:
   - Partition data to minimize delay.
   - Partition data to maximize bandwidth efficiency.

2. The logical channel has insufficient resources; try to optimize the performance based on limited resources.
The Source Model

- **Continuous bitstreams** — bitstreams which can be partitioned at any point; they are either decodable as a whole, or they have no fixed breakpoints (e.g., scalable or non-scalable images).

- **Discrete bitstreams** — bitstreams which have fixed breakpoints, between which are considered continuous (sub) streams (e.g., video).

- Bitstream segments can have different priorities.

- A single stream may be partitionable in multiple ways, depending on the user requirements: visual properties, desired use, regions-of-interest...
The Transmission Model

- Channel state is dynamic and is estimated in intervals of time $T$:

Number of channels available: $N(nT)$
Propagation delay: $\tau_{prop, i}(nT)$
Probability of failure/loss: $p_{fail, i}(nT), p_{loss, i}(nT)$
Two Coding Strategies

- Assign FEC across channels and FEC within failure protection channels in one of 2 ways:

- This problem is essentially designing product codes for non-rectangular data arrays.
The Partitioning Problem & Solutions

- Assign fractions of segments to each channel to meet the desired constraints.
- Optimal resource utilization has been solved for continuous bitstreams and for discrete bitstreams with both continuous and discrete partitioning.
- Optimizing performance with limited resources has been solved for both continuous and discrete bitstreams.
- Some solutions are closed form; some can be achieved via greedy solutions; some require searches.
Concluding Comments

• Visual data has a high information content and should not be treated as “raw data.”

• For maximum efficiency, visual data representation (compression) must incorporate robustness.

• Transmission over networks must consider the data representation.