A Survey of Packet-Loss Recovery Techniques

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Overview

- This paper:
  - Loss characteristics of Mbone
  - Techniques to repair loss in a 'light-weight' manner
    - Concentrate on audio
  - Recommendations

- Other papers:
  - Fully-reliable (every bit must arrive), but not real-time
  - Real-time, but not receiver based approaches

Outline

- Overview
- Multicast Channel Characteristics
- Sender Based Repair
- Receiver Based Repair
- Recommendations

IP Multicast Characteristics

- Group address
  - Client receives to address
  - Sender sends to address, without client knowledge
- Loosely coupled connections
  - Not-two way (‘extension to’ UDP)
  - Makes it scalable
  - Allows clients to do local-repair
- Multicast router shared with unicast traffic
  - Can have high loss

Mbone Loss Characteristics

- Most receivers in the 2-5% loss range
- Some see 20-50% loss
- Characteristics differ, so local decisions
Mbone Jitter Characteristics
- High jitter
  - If too late, will be discarded and look like loss
- Interactive applications need low latency
  - Influence repair scheme

Media Repair Taxonomy
- Media Repair
  - Sender Based
  - Receiver Based

Sender Based Repair Taxonomy
- Sender Based Repair
  - Active
  - Passive
- Interleaving
- Forward Error Correction

Media Independent, Media Specific

Figure 3: A Taxonomy of Sender Based Repair Techniques
- Work from right to left
- Unit of audio data vs. a packet
  - Unit may be composed of several packets

Forward Error Correction (FEC)
- Add data to stream
- Use repair data to recover lost packets
- Two classes:
  - Media independent (not multimedia specific)
  - Media dependent (knowledge of audio or video)

Media Independent FEC
- Given $k$ data packets
- Generate $n-k$ check packets
- Transmit $n$ packets
- Schemes originally for bits (like checksum)
  - Applied to packets
  - So $i$th bit of check packet, checks $i$th bit of each associated packet

FEC Coding
- XOR operation across all packets
- Transmit 1 parity packet every $n$ data packets
- If 1 loss in $n$ packets, can fully recover
- Reed-Solomon treat as polynomial
Media Independent FEC
Advantages and Disadvantages

**Advantages**
- Media independent
  - Audio, video, different compression schemes
  - Computation is small and easy to implement

**Disadvantages**
- Add delay (repair wait for all $n$ packets)
- Add bandwidth (causing more loss?)
- Add decoder complexity

Sender Based Repair Taxonomy

Media Specific FEC

**Multiple copies of data**

**Quality of secondary frames?**

Media Specific FEC Secondary Frame

- Send packet energy and zero crossing rate
  - 2 numbers, so small
  - Interpolate from missing packet
  - Coarse, effective for small loss
- Low bit-rate encoded version of primary
  - Lower number of sample bits audio sample, say
- Full-version of secondary
  - Effective if primary is small (low bandwidth)

Media Specific FEC Discussion

- Typical overhead 20-30% for low-quality
  - [HSK98]
- Media specific FEC can repair various amounts by trading off quality of repair
  - Media independent FEC has fixed number of bits for certain amount of repair
- Can have adaptive FEC
  - When speech changes (cannot interpolate)
  - Add when increase in loss [PCM00]
  - Delay more than 1 packet when bursty loss

Media Specific FEC Advantages and Disadvantages

**Advantages**
- Low latency
  - Only wait a single packet to repair
  - Multiple if adapted to bursty losses
- Can have less bandwidth than independent FEC

**Disadvantages**
- Computation may be more difficult implement
- Still add bandwidth
- Add decoder complexity
- Lower quality
Sender Based Repair Taxonomy

Interleaving

Interleaving Advantages and Disadvantages

- **Advantages**
  - Most audio compression schemes can do interleaving without additional complexity
  - No extra bandwidth added
- **Disadvantages**
  - Delay of interleaving factor in packets
    - Even when not repairing!

Retransmission Discussion

- In a typical multicast session, can have every packet usually lost by some receiver
  - Will always retransmit at least once
  - FEC may save bandwidth
- Typically, crossover point to FEC based on loss rate
- Some participants may not be interactive
  - Use retransmission
  - Others use FEC
Retransmission Advantages and Disadvantages

- **Advantages**
  - Well understood
  - Only add additional data ‘as needed’

- **Disadvantages**
  - Potentially large delay
    + not usually suitable for interactive applications
  - Large jitter (different for different receivers)
  - Implosion (setting timers difficult)

Media Repair Taxonomy

- **Media Repair**
  - **Sender Based**
  - **Receiver Based**

  - Do not require assistance of Sender
    - Receiver recover as best it can
  - Often called Error Concealment
  - Work well for small loss (<15%), small packets (4-40 ms)
  - Not a substitute for sender-based
    - Rather use both
    - Receiver based can conceal what is less

Taxonomy of Error Concealment

<table>
<thead>
<tr>
<th>Error Concealment</th>
<th>Description</th>
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| Splicing          | Splice together stream on either side
  - Do not preserve timing
  - Advantage
    - “Easy, peasy smudge”
    - Works ok for short packets of 4-16 ms
  - Disadvantage
    - Crappy for losses above 3%
    - Interfere with delay buffering

- **Silence Substitution**
  - Fill the gap left by lost packet with silence
    - Preserve timing
  - Advantage
    - Still easy, peasy smudge
    - Works good for low loss (< 2%)
    - Works ok for short packets of 4-16 ms
  - Disadvantage
    - Crappy for higher losses (3%+)
    - Ineffective with 40ms packets (typical)

- **Noise Substitution**
  - Human psych says can repair if sound, not silence (*phonemic restoration*)
    - Replace lost packet with “white noise”
      - + Like static on radio
    - Still preserve timing
  - Similar to silence substitution
  - Sender can have “comfort noise” so receiver gets white-noise volume right
Repetition
- Replace missing packet with previous packet
- Can “fade” if multiple repeats over time
  - Decrease signal amplitude to 0
- Still pretty easy, but can work better
- A step towards interpolation techniques (next)

Interpolation Based Repair
- Waveform substitution
  - Use waveform repetition from both sides of loss
  - Works better than repetition (that uses one side)
- Pitch waveform replication
  - Use repetition during unvoiced speech and use additional pitch length during voiced speech
  - Performs marginally better than waveform
- Time scale modifications
  - “Stretch” the audio signal across the gap
  - Generate a new waveform that smoothly blends across loss
  - Computationally heavier, but performs marginally better than others

Regeneration Based Repair
- Interpolation of transmitted state
  - State-based decoding can then interpret what state codec should be in
  - Reduces boundary-effects
  - Typically high processing
- Model-Based recovery
  - Regenerate ‘speech’ to fit with speech on either side

Summary of Receiver Based Repair
- Quality increase decreases at high complexity
- Repetition is at ‘knee’ in curve
Groupwork

- Consider:
  - Interactive voice from Europe to U.S.
  - Multicast broadcast video of taped lecture
  - Multicast replicated database update
  - Interactive voice across city
- Choose a repair technique and why:
  - Interleaving
  - Retransmission
  - Media Specific FEC
  - Media Independent FEC

Recommendations: Non-Interactive Applications

- Latency less important
- Bandwidth a concern (mcast has various bandwidth)
- \( \rightarrow \) use interleaving
- \( \rightarrow \) repetition for concealment
- Retransmission does not scale
  - Ok for unicast
- Media independent FEC may be ok

Recommendations: Interactive Applications

- Want to minimize delay
  - \( \rightarrow \) Interleaving delay is large
  - \( \rightarrow \) retransmission delay can be large
  - \( \rightarrow \) media independent FEC usually large
    + (Or computationally expensive)
- Use media specific FEC
  - Approximate repair ok

Recommendations: Error Concealment

- Will be some residual error at receiver
- Silence substitution not acceptable
  - Use packet repetition
  - Others can be used, but more costly and not necessarily worthwhile

Evaluation of Science?

- Category of Paper
- Science Evaluation (1-10)?
- Space devoted to Experiments?