RPT: Re-architecting Loss Protection for Content-Aware Networks

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Motivation: Delay-sensitive communication

Real-time streams: FaceTime, Skype, on-line games.
Maximum one way latency ~150ms

Minimizing data loss in time-critical communication is important, but challenging because of the time constraint.
Loss protection today:
Redundancy-based recovery

Forward Error Correction

- FEC couples delay with redundancy
- Small batch size makes FEC more susceptible to bursty loss
- Difficult to tune parameters (n and k) [TIP2001,INFOCOM2010]

Amount of redundancy 20%~50% in Skype video [Multimedia’09]
Content-aware networks changes the trade-off of redundancy

Content-aware networks = caching + content-aware processing to remove duplicates

Caching effectively minimizes the bandwidth cost of redundancy

Examples

Redundancy elimination (RE) [SIGCOMM’08]

Bandwidth overhead of 100% redundancy: 3%

Content-Centric Networking (CCN) [CoNEXT’09]
Deployment of content-aware networks

• Product: WAN optimizers (10+ vendors)
  – Cisco, Riverbed, Juniper, Blue Coat Systems
  – E.g., Cisco deployed RE on 200+ remote offices.
  – Corporate networks
    • Riverbed: 50+ corporate customers, datacenter deployments
Redundant Packet Transmission (RPT)

- Introduce redundancy in a way that the network understands

Questions/Challenges
- How do we make sure we retain the robustness benefits?
- How much redundancy is needed? How does it compare with FEC?
- Is this safe to use?
RPT on Redundancy Elimination (RE) Networks

RE cache holds packets received during the past ~10 secs
Loss model: Congestive packet loss that happens inside a router.

Decompressed packet
Compressed (deduplicated) packet

Packets

A’ A’ A

Incoming interfaces

RE Decode

RE cache

Queue

Outgoing interfaces

RE Encode

RE cache

Redundancy Elimination Router
RPT on Redundancy Elimination (RE) Networks

RE cache holds packets received during the past ~10 secs

Loss model: Congestive packet loss that happens inside a router.

Decompressed packet

Compressed (deduplicated) packet

Redundancy Elimination Router

Low overhead

Robustness
Redundant Packet Transmission

- Introduce redundancy in a way that the network understands
Redundant Packet Transmission

• Introduce redundancy in a way that the network understands

Benefits:
• Retain the robustness benefits of redundancy
• Minimize the bandwidth cost
• Application can signal the importance of data. (Fine-grained control)
A Case Study of RPT

Redundant Packet Transmission (RPT)
- Send multiple copy of the same packet.
- Send every packet $r$ times.

Redundant Packets Transmission

Hop-by-hop RE networks
Partially content-aware networks
SmartRE networks
Networks with link-layer loss
Content Centric Networks (CCN)
Analytical Comparison with FEC

2% random loss. $p = 0.02$

Fraction of Overhead

End-to-end data loss rate (%)

FEC(n=10,k=8)  Delay
Batch size (n=10)

Coded redundancy

Original pkts (k=8)

RPT(3)

Delay

Redundancy (r=3)

Naive

2% data loss
0 overhead
Analytical Comparison with FEC

2% random loss. $p = 0.02$

Fraction of Overhead

End-to-end Data loss rate (%)
Analytical Comparison with FEC

2% random loss. $p = 0.02$

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Max Delay@ 1Mbps</th>
</tr>
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<tbody>
<tr>
<td>FEC(10,7)</td>
<td>168 ms</td>
</tr>
<tr>
<td>FEC(20,16)</td>
<td>300 ms</td>
</tr>
<tr>
<td>FEC(100,92)</td>
<td>1300 ms</td>
</tr>
<tr>
<td>RPT(r)</td>
<td>Tunable</td>
</tr>
</tbody>
</table>

Skype video call 128~300kbps
Skype (HD) 1.2~1.5Mbps
Experimental Evaluation

• Thorough evaluation on 3 different aspects of RPT
  – End user performance
  – Ease of use (parameter selection)
  – Impact on other traffic

• Methodology
  – Real experiment
  – Trace based experiment
  – Simulation
Evaluation Framework

- RE router implementation (Click, NS2)
- Video quality evaluation using evalvid
E2E Performance: Video Quality

![Bar Chart]

- **Average PSNR (dB)**
  - **Encoded video at sender** (Before loss)

<table>
<thead>
<tr>
<th>Technique</th>
<th>PSNR (dB)</th>
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<tbody>
<tr>
<td>Naive</td>
<td>38</td>
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<tr>
<td>RPT(2)</td>
<td>37</td>
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<tr>
<td>RPT(3)</td>
<td>37</td>
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<tr>
<td>RPT(4)</td>
<td>37</td>
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<tr>
<td>RPT(5)</td>
<td>37</td>
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<tr>
<td>FEC(10,9)</td>
<td>36</td>
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<tr>
<td>FEC(10,8)</td>
<td>36</td>
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<tr>
<td>FEC(10,7)</td>
<td>36</td>
</tr>
<tr>
<td>FEC(10,6)</td>
<td>36</td>
</tr>
<tr>
<td>FEC(10,5)</td>
<td>35</td>
</tr>
</tbody>
</table>

**Techniques:**
- **RPT**
- **FEC**
E2E Performance: Video Quality

Average PSNR (dB)

- Encoded video at sender
- Received video

Packet loss rate ~2%

- RPT (2), (3), (4), (5)
- FEC (10,9), (10,8), (10,7), (10,6), (10,5)

Naive
E2E Performance: Video Quality

RPT(3) Overhead ~6%
FEC(10,9) Overhead ~10%
Naïve UDP

1.8dB ~ 3dB difference in quality
E2E Performance: overhead and robustness

Packet loss rate ~2%

E2E Performance: overhead and robustness

Packet loss rate ~2%
Impact on other traffic

- RPT flows get prioritized.

Packet loss rate: 9%.

Throughput reduction: 2%
Is flow prioritization a problem?

• **Not a problem:** Important flows should be prioritized.

• **Problem:** Unfair bandwidth allocation

How do provide fairness and robustness at the same time?

• Core problem: RPT flows are not reacting to congestion.
  
  → Apply TCP-friendly rate control to RPT.

• Challenge: correctly accounting for possible changes in loss pattern
Other results in the paper

• Demonstration of RPT in a real-world setting
  – E.g., Emulated corporate VPN scenario
• Trace-based experimental results
• Detailed parameter sensitivity study
• Network safety (impact on the network)
• Design and evaluation of TCP-friendly RPT
• Strategies on other content-aware networks
Generalized RPT

• Many sophisticated schemes are enabled by FEC.
  – Priority encoding transmission (PET), unequal error protection (UEP), multiple description coding (MDC)

→ Prioritization within a flow for graceful degradation of quality

UEP

Redundancy elimination networks [SIGCOMM’08]

PET/MDC

Very important: Sent x3 (byte-level redundancy)

Important: Sent x2
Conclusion

• Key Idea of RPT: Don’t hide, expose redundancy!
• Key Features
  – High robustness, low overhead → user performance
  – Ease of use: parameter selection, per-packet redundancy/delay control
  – Flow prioritization
• Applicability
  – Applies to delay-sensitive communications in content-aware networks in general.