Beyond Audio & Video
Multimedia Networking Support for Distributed, Immersive Virtual Environments

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Multimedia Networking
Beyond Audio and Video

- Support for real-time delivery of audio and video on the Internet was the “killer app” of the 1990’s
- What did we learn?
  - Per flow bandwidth/delay guarantees are too hard to support and are likely unnecessary
  - If the Internet could be made to act like a “lightly loaded LAN” then end-system media adaptation was sufficient
- So what’s next? What are other interesting continuous-media (CM) flows to study?
  - How well do network mechanisms and end-system adaptations scale to meet the requirements of “next generation” CM applications?

Beyond Audio and Video
Support for distributed virtual environments

- Goal: Use resources distributed across the Internet to provide users with a sense of immersion in a virtual world

Distributed Virtual Environments
Distributed virtual laboratories

- Computers and computer interfaces are fundamental to modern scientific instruments

Data Acquisition  |  Processing  |  Display & Control
--- | --- | ---
LAN  |  Switch
Distributed Virtual Environments
The UNC nanoManipulator system

- A virtual environment interface to a scan-probe microscope
- Provides telepresence on sample surfaces scaled 1,000,000:1

The UNC nanoManipulator
Atomic force microscopy simplified

Microscope
Tip
Sample Surface Scanned Back & Forth

Distributed Virtual Environments
The nanoManipulator as a distributed system

Distributed Virtual Environments
Haptic displays: Feeling a surface

User feels a series of approximating planes
(At a 20 Hz update rate, surface appears smooth)
Supporting DVEs
The impact of Internet pathologies on nM flows

- Packet delay, delay-jitter, and loss lead to “pops” and “gaps” in audio playout
- For haptics display, Internet pathologies lead to incorrect surface shape

![Diagram showing actual surface, desired representation, and representation with delay]

Essential problems: Manage delay, delay-jitter, and loss
- The abstract requirements are the same as for interactive audio/video applications, just the constants change

Approach:
- Investigate the use end-system audio/video media adaptations for ameliorating the effects of delay-jitter and loss
- Investigate the use of novel router active queue management mechanisms for realizing better-than-best-effort services (differentiated services) for DVE flows

Supporting DVEs
End-system media adaptation

- To ameliorate the effects of loss we use a simple FEC scheme [MMCN 01]
- To ameliorate the effects of delay-jitter we use an elastic display queue management scheme called queue monitoring (QM) [MMSJ ‘95]

![Diagram showing media receiver’s processing pipeline]

Delay-Jitter Adaptation
Principles of display queue management

- Enqueue all arriving samples — Variable playout delay but minimal gap-rate
- Discard late samples — Constant playout delay but high gap-rate
Delay-Jitter Adaptation
Principles of display queue management

If display queue length grows, network delay is decreasing
If queue length shrinks, network delay is increasing
If queue remains constant, network delay is stable

Queue monitoring

- Define a threshold value and a decay rate dropping queue elements in an effort to reduce latency
  - If queue element $k$ always contains a media sample for threshold $x$, then it is “safe” to drop the element in location $k$
- Drop quickly from long queues, drop slowly from short queues

Queue monitoring performance

- In a laboratory testbed simulating a small-scale internetwork, queue monitoring is effective
- For haptics data flow, queue monitoring results in a gap-rate equal to the packet-loss rate
  - At the cost of slightly increased latency
- Remote operation of the nanoManipulator on the East coast of the USA confirms these results
- (See paper for details)

Protocol | Loss | Drop rate | Gap rate | Latency |
---------|------|-----------|----------|---------|
UDP      | 9.7% | 11.7%     | 21.5%    | 89 ms   |
QM (30, 2) | 10% | 0.6%      | 10.6%    | 94 ms   |
QM (150, 2) | 9.7%| 0.02%     | 9.7%     | 96 ms   |
QM (3600, 2) | 9.5%| 0.001%    | 9.5%     | 91 ms   |

For haptics data flow, queue monitoring results in a gap-rate equal to the packet-loss rate
- At the cost of slightly increased latency
End System Media Adaptation

What more is needed?

• Queue monitoring (and other adaptations) can work well but…
  – They don’t scale well
  – They don’t address issues of fair bandwidth allocation between TCP and non-TCP flows

• We are also investigating the use of router-based mechanisms for realizing better-than-best-effort services
  – (Within the context of the differentiated services architecture for the Internet)

Towards QoS Networking

The differentiated services architecture

• ISPs allocate and sell capacity for a “premium” service

Towards QoS Networking

The differentiated services architecture

• ISPs allocate and sell capacity for a “premium” service

• Packets are marked according to “service profiles”

Realizing Differentiated Services

Active queue management

• This is significant utility in realizing differential services with a single router queue
  – In this model, a key technology for realizing differential services is a packet dropping policy
### Realizing Differentiated Services

**RED active queue management**

- Basic mechanism for realizing differentiated services is the *random early detection (RED)* congestion avoidance mechanism

### Realizing QoS Through AQM

**“Class-based thresholds”**

- Designate a set of traffic classes and allocate a fraction of a router’s buffer capacity to each class
- Once a class is occupying its (weighted average) limit of queue elements, discard *all* arriving packets
- Within a traffic class, further active queue management may be performed

### Active Queue Management

**CBT performance comparison**

<table>
<thead>
<tr>
<th>Queue Management Scheme</th>
<th>Drop Rate for Marked Flows</th>
<th>Latency for Marked Flows</th>
<th>TCP Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIFO</td>
<td>32.4%</td>
<td>63.2 ms</td>
<td>200 kbps</td>
</tr>
<tr>
<td>RED</td>
<td>30.0%</td>
<td>26.2 ms</td>
<td>300 kbps</td>
</tr>
<tr>
<td>CBT</td>
<td>1.3%</td>
<td>28.4 ms</td>
<td>790 kbps</td>
</tr>
</tbody>
</table>

- Reserving buffer capacity for multimedia (*nano*) flows improves both TCP and multimedia performance
  - At the cost of small router state complexity
Beyond Audio and Video
Network support for immersive DVEs

Summary

- Distributed virtual environments represent a significant generalization of the traditional multimedia networking problem

- We’re attempting to...
  - Allow co-existence of selected non-congestion responsive UDP traffic and responsive TCP traffic through differentiated services
  - Apply audio/video end-system media adaptations to ameliorate remaining congestion effects

- Conclusion: Mechanisms for supporting real-time audio and video flows work well for immersive DVEs