Experiences with Wide-Area ATM Networking

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Overview

- Networking experiences on the MAGIC testbed
  - Introduction to MAGIC
  - Early experiences with TCP/IP over ATM WANs
- Networking experiences on the AAI testbed
  - Overview of AAI
  - Measurement of ATM WAN performance
  - Simulation tools of WAN performance
Multidimensional Applications and Gigabit Internetwork Consortium (MAGIC)

- An architecture and implementation of a nationwide internet of high-speed IP/ATM testbeds
- A scalable, dynamically constructed, network-based, distributed storage system
- Distributed processing to enable on-demand data visualization
- Controlled access to datasets and to computing resources
- An interactive application for 3-D fusion and visualization of georeferenced data
- Techniques for adapting application to network conditions and host capabilities

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MAGIC-II Participants

• DARPA-funded
  – University of Kansas (Prime contractor)
  – Corporation for National Research Initiatives
  – Earth Resources Observation Systems Data Center
  – Lawrence Berkeley National Laboratory
  – Minnesota Supercomputer Center
  – SRI International

• Organizations contributing resources
  – Sprint
  – Splitrock Telecom
MAGIC-II Core Network

- OC-48 backbone in the Midwest, OC-3 in California, DS3 connectivity between the Midwest and California
- Seven sites with OC-3 or OC-12 access
- Each site has an ATM LAN and multiple workstations for distributed storage and processing

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MAGIC-II Nationwide Test Environment

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KU-ITTC MAGIC-II Research Agenda

• Create a diverse large scale network incorporating ATM wireless, distributed computing and storage technologies within the MAGIC-II internetwork, resulting in a network system with a wide range of link bandwidths and quality as well as network element capabilities.

• Develop, implement, and demonstrate technologies to monitor and distribute network 'state' to enable applications to work at their highest efficiency while satisfying users requirements in dynamic environments.

• Develop, implement, and demonstrate technologies to provide application specific services using network 'state' information to respond to dynamic environments.
TCP/IP Over ATM WANs
Early Experiences (Early 1993)

- MAGIC testbed — tests over 1000 km WAN
- High throughput hosts and interfaces
- DEC Alphas capable of 134 Mb/s TCP throughput
- DEC OTTO interface · ATM @ SONET OC-3c rates
- ATM cell-level flow control — OTTO and AN2 switch
- ATM cell-level pacing — OTTO/AN2 scheduled transmission mode
Experiment 1

• Question: **WAN performance limited by TCP window size?**

• Experiment: DEC Alpha 3000/400 with a DEC OTTO OC-3c interface to DEC Alpha 3000/400 over a 600 km link, 8.8 ms round-trip delay

• Results

<table>
<thead>
<tr>
<th>TCP Window Size</th>
<th>0.5k</th>
<th>1k</th>
<th>2k</th>
<th>4k</th>
<th>8k</th>
<th>16k</th>
<th>32k</th>
<th>64k</th>
<th>128k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput (Mb/s)</td>
<td>0.47</td>
<td>0.93</td>
<td>1.8</td>
<td>3.7</td>
<td>7.4</td>
<td>14.9</td>
<td>29.8</td>
<td>59.6</td>
<td>119</td>
</tr>
</tbody>
</table>

• Consistent with the theoretical limits caused by latency
• Large windows necessary for acceptable throughput
Experiment 2

- Questions: High bandwidth TCP sources will overrun ATM switch buffers at points of bandwidth mismatch? improved by pacing?
- Experiment: Alpha (OC-3c) in Lawrence, Kansas, to SPARC-10 (TAXI) in South Dakota (600 km) — a single host to another host
  - Alphas with DEC OTTO cards, SPARC-10 with FORE Systems 100 Mb/s TAXI
  - Switches --> FORE Systems ASX-100
  - 128 kB TCP windows, 64 kB write buffers
- Results
  
<table>
<thead>
<tr>
<th>No Pacing</th>
<th>Pacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87 Mb/s</td>
<td>68.20 Mb/s</td>
</tr>
</tbody>
</table>
Experiment 3

• Question: Will TCP rate control be more effective if TCP segment size small relative to buffers?

• Experiment: Alpha (OC-3c) in Lawrence, Kansas, to SPARC-10 (TAXI) in South Dakota (600 km), vary TCP segment size

• Results:

  File Name: edc_mtu.eps
  Creator: gnuplot
ACTS ATM Internetwork (AAI)
(ACTS = Advanced Communications Technology Satellite)

• Objectives
  – Evaluate use of ATM WAN for joint use of parallel and vector processors
  – Evaluate use of national-scale, high-speed terrestrial/satellite ATM network
  – Evaluate ATM WAN for congestion, signaling, and multicast technologies

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AAI Network Topology

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KU-ITTC AAI Research Agenda

• Determine performance characterization of ATM WANs
  – Measurement
  – Simulation
• Characterize ATM WAN traffic profiles
• Evaluate performance of ATM WAN congestion controls
WAN Measurement Tools

• NetSpec: A first step toward network benchmarking
  – Multiple host network loading
  – Automated execution
  – Reproducible experiments
  – Multiple traffic types
    • Full speed (as fast as the source can transmit to the network)
    • Constant bit rate, CBR (transmission of a periodic pattern of bursts)
    • Random (transmission of a random pattern of bursts)
      – WWW
      – FTP
      – MGEG Video
      – Teleconferencing video
      – Voice
      – Telnet

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NetSpec Example

<table>
<thead>
<tr>
<th></th>
<th>Tx (Mbps)</th>
<th>Rx (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-C</td>
<td>29.319</td>
<td>29.287</td>
</tr>
<tr>
<td>B-D</td>
<td>29.366</td>
<td>29.204</td>
</tr>
</tbody>
</table>

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Aggregate Network Throughput Performance

• Throughput metrics
  – Maximum losses throughput
  – Peak throughput
  – Full load throughput

  Transfer from local to remote host memory as fast as possible
Throughput versus Aggregate Load

Throughput versus offered load

Maximum lossless

Peak

TCP pacing
No pacing

Aggregate throughput (Mbps)
Aggregate pacing bandwidth (Mbps)
Performance of FTP over ATM WAN’s
# Throughput Performance with Standard FTP

<table>
<thead>
<tr>
<th>Source/Destination</th>
<th>File Size (million bytes)</th>
<th>Throughput (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-C</td>
<td>14</td>
<td>2.56</td>
</tr>
<tr>
<td>B-A</td>
<td>17</td>
<td>3.60</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>3.63</td>
</tr>
<tr>
<td>D-B</td>
<td>75</td>
<td>2.88</td>
</tr>
<tr>
<td>D-A</td>
<td>75</td>
<td>4.61</td>
</tr>
<tr>
<td>D-C</td>
<td>75</td>
<td>3.39</td>
</tr>
<tr>
<td>A-D</td>
<td>333</td>
<td>2.56</td>
</tr>
<tr>
<td>A-B</td>
<td>333</td>
<td>1.76</td>
</tr>
<tr>
<td>A-C</td>
<td>333</td>
<td>3.28</td>
</tr>
</tbody>
</table>
Throughput Performance with Modified FTP

<table>
<thead>
<tr>
<th>Source/Destination</th>
<th>MTU Size (Bytes)</th>
<th>File Size (million bytes)</th>
<th>Throughput (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-D</td>
<td>4470</td>
<td>17</td>
<td>15.2</td>
</tr>
<tr>
<td>B-D</td>
<td>4470</td>
<td>55</td>
<td>12.8</td>
</tr>
<tr>
<td>D-B</td>
<td>9188</td>
<td>17</td>
<td>22.4</td>
</tr>
</tbody>
</table>

FTP Throughput Results with Large Windows
Simulation of ATM WAN’s

• Goals
  – Determine the level of model fidelity required to accurately predict ATM WAN performance
  – Determine the feasibility of measurement based validation of ATM WAN simulation models
  – Identify factors influencing ATM WAN performance
Simulation Parameters

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP MTU size</td>
<td>9180 bytes</td>
</tr>
<tr>
<td>TCP processing and OS overhead time</td>
<td></td>
</tr>
<tr>
<td>- DEC 3000 AXP</td>
<td>200-300 µs</td>
</tr>
<tr>
<td>- SGI</td>
<td>550 µs</td>
</tr>
<tr>
<td>- SPARC 10</td>
<td>550 µs</td>
</tr>
<tr>
<td>- SPARC 5</td>
<td>700 µs</td>
</tr>
<tr>
<td>TCP user send buffer size</td>
<td>64 kBytes</td>
</tr>
<tr>
<td>Slow-timer period</td>
<td>0.5 s</td>
</tr>
<tr>
<td>Fast-timer period</td>
<td>0.2 s</td>
</tr>
<tr>
<td>Minimum RTO</td>
<td>1.0 s</td>
</tr>
<tr>
<td>AAL5 SAR processing time</td>
<td>0.2 µs</td>
</tr>
<tr>
<td>AAL5 cell payload size</td>
<td>48 Bytes</td>
</tr>
<tr>
<td>Switch processing time</td>
<td>4 µs</td>
</tr>
<tr>
<td>Switch output buffer size per VC</td>
<td>256 cells</td>
</tr>
<tr>
<td>OC-3c link speed</td>
<td>155 Mb/s</td>
</tr>
<tr>
<td>TAXI link speed</td>
<td>100 Mb/s</td>
</tr>
<tr>
<td>DS-3 link speed</td>
<td>45 Mb/s</td>
</tr>
</tbody>
</table>
Network Configuration
Comparison of Experimental and Simulation Performance Predictions

<table>
<thead>
<tr>
<th>Connection</th>
<th>Experimental Results</th>
<th>Simulation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline results</strong>: Point-to-point connections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIOC to ARL</td>
<td>4.2 Mb/s</td>
<td>7.18 Mb/s</td>
</tr>
<tr>
<td>TIOC to EDC</td>
<td>64.2 Mb/s</td>
<td>65.98 Mb/s</td>
</tr>
<tr>
<td><strong>Simultaneous traffic streams</strong>: Single source, two destinations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIOC to ARL</td>
<td>4.45 Mb/s</td>
<td>4.60 Mb/s</td>
</tr>
<tr>
<td>TIOC to EDC</td>
<td>64.36 Mb/s</td>
<td>61.37 Mb/s</td>
</tr>
<tr>
<td><strong>Simultaneous traffic streams</strong>: Two sources, single destination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARL to TIOC</td>
<td>2.15 Mb/s</td>
<td>4.87 Mb/s</td>
</tr>
<tr>
<td>EDC to TIOC</td>
<td>52.42 Mb/s</td>
<td>65.01 Mb/s</td>
</tr>
<tr>
<td><strong>Simultaneous full duplex traffic streams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIOC to ARL</td>
<td>4.34 Mb/s</td>
<td>5.16 Mb/s</td>
</tr>
<tr>
<td>ARL to TIOC</td>
<td>4.3 Mb/s</td>
<td>5.16 Mb/s</td>
</tr>
<tr>
<td>TIOC to EDC</td>
<td>22.18 Mb/s</td>
<td>41.80 Mb/s</td>
</tr>
<tr>
<td>EDC to TIOC</td>
<td>31.18 Mb/s</td>
<td>41.30 Mb/s</td>
</tr>
</tbody>
</table>
Lessons Learned

• ATM wide-area networking is a reality
• High throughput is achievable with TCP/IP over ATM WANS
• Complex traffic control is feasible at high speeds
• There is a growing need for network-wide benchmarking tools, e.g., NetSpec
• Simulation of large and complex ATM networks is computationally intensive
• Computer simulation can be used to predict the performance of some aspects of ATM WANs