Technology Developments
Integrating a Space Network Communications Testbed

SpaceOps (June-22-2006)

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Future of Exploration Missions: Lunar Network Scenario

LRS – Lunar Relay Satellite
LPN – Lunar Proximity Network
CEV – Crew Exploration Vehicle
DSN – Deep Space Network
ISS – International Space Station
Space Communications Testbed: Objectives and Benefits

- Low cost method to validate communication architectures
- Detailed testing & performance evaluation of:
  - Space & ground networks
  - Client software applications
  - End-to-end communication involving real & emulated equipment
Space Communications Testbed: Objectives and Benefits (cont.)

- Flexible platform to evaluate technologies
- Validation & refinement of space network architecture requirements
- Analyze risks associated with communication architecture designs
- Testing system interoperability
What We Did

- Partitioned system responsibilities among the participating groups
- Designed system architecture
  - Defined interfaces for testbed components
  - Developed simulation scenario
- Constructed & tested initial prototype
  - Integrated MACHETE (network simulator) into testbed
Integration of MACHETE and Testbed

Deployment Geometry

Link Engineering

Network & Protocol Simulation

SOAP

MACHETE Simulation Tool

QualNet

Testbed

MACHETE – Multi-mission
Advanced Communications
Hybrid Environment for Test and Evaluation

External HW/SW
Two ways to integrate

MACHETE External Data Interfaces

- Transport layer: TCP-bridge [JPL, Scalable Networks Inc.]
  - Socket Connections
- Network layer: IP Network Emulator (IPNE) [Scalable Networks Inc.]
  - IP Packet Capture with “libpcap”
# IPNE or TCP-bridge?

<table>
<thead>
<tr>
<th>Feature</th>
<th>IPNE (with NAT)</th>
<th>TCP Bridge</th>
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<tr>
<td>Application Compatibility</td>
<td>Works with any applications that can communicate via TCP/UDP over IP.</td>
<td>Application data must be formatted for the custom bridging protocol.</td>
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<tr>
<td>Reliable Data Capture</td>
<td>No, since IP transmission is considered best-effort and not all packets are guaranteed to be sniffed.</td>
<td>Yes, since TCP supports reliable transmission.</td>
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<tr>
<td>Flexibility / Scalability</td>
<td>Can accommodate almost any type of testbed network topology.</td>
<td>Limited in how the testbed network can be setup. The number of external sources is limited to the network bandwidth.</td>
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<tr>
<td>Ease To Setup Network Testbed</td>
<td>Complex</td>
<td>Relatively simpler</td>
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Space Communications Testbed
Block Diagram

LAN A:
Simulation data

LAN B:
Simulation data

LAN C:
Monitor & control data

Testbed Controller
Monitor & Control Messaging

External components can control MACHETE remotely through web-services:

- Currently support:
  - Start/Stop
  - Request run-time simulation statistics
Teleoperation

External traffic points

Internally simulated traffic
Lessons Learned

- Testbed equipment performance limitations
  - With the IPNE interface, packet loss may occur due to the unreliable nature of IP
  - Hardware performance (CPU, NIC, RAM, etc)
  - Software performance (libpcap, QualNet, OS, etc)

- Testbed behaviors and characteristics can unintentionally influence simulation results, e.g.
  - Increased latency
  - Packet loss
  - Throughput degradation
We measured end-to-end effective bandwidth with IPerf.

With MACHETE, we observed throughput degradation at 10 Mbps.

Without MACHETE, throughput degradation occurs at 70 Mbps.

The use of MACHETE places a constraint on what you can simulate.
Lessons Learned (cont.)

- **Synchronization Issues**
  - IPNE does not synchronize IP packet flow between testbed components with simulation time
    - Simulation results are non-repeatable
  - Interfacing at the transport layer can provide synchronization with metadata
Lessons Learned (cont.)

- Tradeoff between IP and TCP interface
  - TCP:
    - Require fine granularity; reproducible results
    - Smaller/simpler testbeds; require socket interface
  - IP:
    - Can tolerate “some” unintentional effects; do not require reproducible results
    - More flexibility in testbed topology; works with off-the-shelf Internet applications
Conclusion & Future work

- Must match the capabilities of the testbed with the simulation studies and analysis objectives
- Future work
  - Further characterize MACHETE performance limitations
  - Extend web services M&C capabilities, e.g. pause/resume and simulation parameter modifications