Simulating Delay Tolerant Networking (DTN) for CubeSats

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Agenda

- Motivation for Networking CubeSats
- DTN on CubeSats
- What is the DTN Simulation Platform?
  - Video screencast of the running simulation
- Simulation Architecture
- Results and Conclusions
Why Network CubeSats?

- Take advantage of launching in clusters
  - More connections with ground stations
- Limited Power
  - Transmit data “hop-by-hop” to:
    - Other CubeSats
    - Larger higher power relay satellite
      - Earth’s moon is 384,000 km away
      - Mars is 55-400 million miles away
- Limited Computing
  - Use distributed computing techniques presented later

Credit: NASA JPL The Interplanetary Internet (IPN)
Why Network CubeSats?

Next-generation communication protocol concepts for future nanosatellite constellations

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Why DTN on CubeSats?

Why DTN on CubeSats?

DTN Space Space Missions

Summer 2005
Deep Impact NETwork experiment
Range: 20 million miles
Uplink data rate: 2 Kbps
Avg downlink data rate ~165 Kbps

Summer 2008
UK-DMC (Disaster Monitoring Constellation) Images UDP/IP using Cisco router in Low Earth Orbit (CLEO)

July 2009
International Space Station Testing Bio-processing Apparatus (CGBA)

Source: http://www.nasa.gov/mission_pages/station/research/experiments/DTN.html
Why DTN on CubeSats?

DTN Space Space Missions

Spring 2011
EO-1: Tested The Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFTP)

Diagram Credit: DTN over Internet Router In Space (IRIS) Test Report
June 30, 2011 Faith Davis(GSFC), Jane Marquart(GSFC), Greg Menke(Columbus Technologies), Stephen Leslie(GSFC), Leor Bleier (GSFC)
DTN Simulation

Topologies Created

- Sun-Synchronous Repeating Ground Track
- Flower Constellation
- Free-flying cluster
Real-time Simulation Interface
(video)
DTN Simulation

System Architecture

- Entire testbed can be one host machine
- NS-3 simulates the physical and link layer channels
  - Input mobility patterns, transmission power, 802.11 DCF parameters
  - Models delays, transmission rates, errors, packet loss with detailed scheduling
- DTN implementations are installed on Virtual Machines, Linux Containers (LXCs), or laptops/smart phones
  - DTN2, ION, IBR-DTN, JDTN, Bytewalla, N4C
- Connections are bridged through the Linux host routing sub-system
  - Uses the brctl function

Diagram:

[Diagram showing the system architecture with various components like VirtualBox, Host OS, DTN2, Virtual Hardware, Input mobility patterns, etc.]
Bridging Connections

- Each vm on the host has a virtual Ethernet (veth)
  - Host allocates a unique IP for each veth

- Host also maintains tap interface
  - Monitors traffic flow between node non-obtrusively
  - Uses the tunctl command

- NS-3 connects networking devices to an internal channel.

- While running the simulation, the network status of each LXC or virtual machine can be view in real-time
  - Uses the netstat command
DTN Simulation

Link Budget

Friis Equation

\[ P_{rx} = G_{tx} + G_{rx} - 20 \log \left( \frac{4\pi \times d}{\lambda} \right) + P_{tx} \]

\[ = 10 dB + 10 dB - 20 \log \left( \frac{4\pi \times 2,000 \text{km}}{.125 m} \right) + 30 dB \]

\[ = -116 dB \]

Node Transmission Range Parameters Table

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambda = Wavelength</td>
<td>.125 meters</td>
</tr>
<tr>
<td>Grx = Rx Antenna Gain</td>
<td>10 dB</td>
</tr>
<tr>
<td>Gtx = Tx Antenna Gain</td>
<td>10 dB</td>
</tr>
<tr>
<td>Ptx = Power Transmitted</td>
<td>30 dBm</td>
</tr>
<tr>
<td>d = Transmission Distance</td>
<td>2,000 Km</td>
</tr>
<tr>
<td>Prx = Power Received</td>
<td>-116 dBm</td>
</tr>
</tbody>
</table>
Network Parameters

- Standard slot time for 802.11g-2007 is 20ms.
- For 2,000 km, 6 ms is needed for one way propagation.
- Slot time of 15 ms was a total of propagation, clear channel assessment (CCA), turnaround, and processing.
- Distributed Coordination Function (DCF) Inter-frame Spaces (DIFS) and SIFS were set from the slot time:
  - Wi-Fi and Carrier sense multiple access (CSMA) models were used.
- Routing Protocols: static, prophet, and flood (flood used for current simulation).

\[
\text{SlotTime} = \text{Air Propagation} + \text{CCA} + \text{Turnaround} + \text{Mac Processing}
\]

\[
\begin{align*}
\text{DIFS} &= \frac{5}{2} \times \text{SlotTime} \\
\text{SIFS} &= \frac{1}{2} \times \text{SlotTime}
\end{align*}
\]
DTN Simulation

Results

- Tested Wi-Fi physical channel on CSMA
  - Applications included dtnping, dtnsend, and dtnrecv
  - Proves the platform can model DTN network connectivity
- Test bed output of virtual machine are transparent to IP packets
  - Users can parse packet capture data through a network sniffer such as WireShark
- Nodes of 50 meters starting distance have an average datarate of 755.84 Kbps
- Nodes with range of 2000 km 10.44 Kbps
- Comparing to an earlier study, a UDP/IP network of nodes at distances of 2000 km had a data rate of 80 bps
Website

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