Design of a Space-Based Internet Emulation System

Masters Thesis Defense
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Organization

- Objectives
- Strategies
- Architecture
- Components
- Routing
- Testing and Results
- Future Work
Objectives for SBI

- **What**
  - Earth-Observation satellites participate in an IP network in space
  - Able to network with other satellites and ground stations
  - Emulation testbed to observe and evaluate characteristics of SBI

- **Why**
  - Receive real-time data from satellites
  - Eliminate on-board data recorders
  - Avoid use of proprietary protocols and expensive hardware

- **How**
  - Earth-Observation Satellites capable of originating, relaying and terminating traffic
  - Specialized high-speed relay satellites to provide extended capacity
  - Internetworking for coordinated, continuous data collection
Emulation Strategies

- Emulate the satellite network environment
  - Link Delays
  - Error rates

- Real-time system
  - Works with real-time offset

- Inter-node data traffic
  - Validates network routes
  - Models actual satellite traffic

- Modular system
  - Facilitates replacement of entire modules
  - For evaluating various algorithms and packages in routing, orbit computations
The SBI Emulation System

- Controlling and monitoring emulation software
- Routing programs for generating network topology
- Instrument scheduling for data traffic generation
- Nodes capable of sourcing, relaying and sinking data
- Networks for transmission of control signals and data traffic
- Software for orbital computations, satellite propagation and data traffic generation
- User interface
Architecture

- Emulation Manager
- Operations Node
- Common Nodes
- Networks
- External Software
Components

- **Common Nodes**
  - Represent satellites and ground stations
  - Generates data according to satellite traffic models, routes data

- **Networks**
  - Management Network
    - Includes EM and Nodes
    - Control commands, Node status, Network updates
  - Data Network
    - Node inter-connections
    - SBI data traffic

- **External Software**
  - Satellite ToolKit
    - Satellite propagation, Orbital computations, Graphical output
  - Netspec
    - Data traffic generator
Emulation Manager

- I/O Interface
- Node Communication
- Node Information
- STK Interface
I/O Interface

Input
- XML File
  - Satellite Orbital Data, Ground Station Position
  - Node Interface Data
  - Satellite Instrument Data

Output
- 2-Dimensional Earth projection view
- 3-Dimensional Globe view
- Network Status
  - Network Routes
  - Interface Information - Data transfer rates
  - Link Information - Bandwidth, delay, BER
- Instrument Status
  - Instrument Data
Node Communication

- **Operations Node Interface**
  - Receives and processes requests for node information
    - Satellite position, node access times and distance

- **Operations Channel Interface**
  - Receives routes and scheduling information from Operations Node
  - Updates emulation information
  - Transmits to destination nodes

- **Node Manager**
  - Sets up, controls and monitors the nodes
Node Information

- Stores information regarding nodes
  - Satellite, Ground station data
    - Positional parameters, interface and instrument data
  - Node Interface data
    - Bandwidth
  - Instrument data
    - Data type, rate, source and destination

- Computes Statistics
  - Network access times
STK Interface

- Establishes TCP connection to STK
- Receives node information and propagates satellites
- Receives route information and displays network routes
- Receives requests from Operations Node Interface
  - Satellite parameters and position
  - Node access times and distances
  - Emulation time
- Transmits data back to requesting module
Operations Node

- **Attributes**
  - Initializes, stores data and mediates between EM and other Operations Node modules

- **Routing**
  - Generates route updates and transmits to all SBI nodes

- **Scheduling**
  - Generates schedules for satellite instruments
Operations Node Routing

- Route Interface
- Access Module
- Topology Generation
- Route Generation
Routing Program

- **Route Interface**
  - Stores node information on startup
  - Event handler - Sets off an alarm for each event
  - Initializes link costs for topology computations

- **Access Module**
  - Provides link access and node distance information during topology computations
  - Receives information from Emulation Manager

- **Topology Generator**
  - Generates network topology

- **Route Generator**
  - Translates topology into routes in terms of node interfaces
  - Transmits routes to all nodes in the system
Routing in a Satellite Network
Data Termination Interfaces

- Routes change constantly
- Routes to data source and sink also change
- Static interface needed for source/sink
- Use “dummy interface” as data source and sink
- Need extra route to reach dummy interface
Problems

- **LEO satellites**
  - Move typically at > 25000 km/hr
  - At 800 km altitude, have ~15 minute window of transmission to a ground station

- **Satellite network changes**
  - Rapidly and regularly in order of minutes

- **Conventional terrestrial routing**
  - OSPF, RIP
  - Extensive computations on satellites
  - Involve information transfer between nodes
  - Becomes obsolete soon in a satellite network
Strategies

- Exploit predictability, regularity of satellite orbits
- Satellite mobility
  - Routing protocol oblivious to mobility
  - Can be processed as regular static network
- Centralized routing is good option
  - Can be computed on ground station
  - Less processing on the part of satellites
    - Saves on satellite power budget
  - Less computing hardware onboard
    - Hardware cannot be upgraded in orbit
- Two protocols recommended
  - DT-DVTR
  - Virtual Node
Protocols

- Discrete Time-Dynamic Virtual Topology Routing
  - Link activation/deactivation occurs at discrete times
  - Network assumed static in intervals
  - Topology computed for static network
  - Can be computed offline and transmitted to satellites

- Virtual Node
  - Fixed virtual network
  - Routes remain the same, satellites move
  - Each satellite hands over routing information to the next satellite
  - Ideally suited for constellations
Routing in SBI

- Uses DT-DVTR approach
- Gain/Loss of line-of-sight termed an Event
- Events occur at discrete times
- Network assumed static between events
- Events clubbed together to avoid overload
- Extended spanning tree algorithm used to compute topology over static network
- Routes transmitted to all nodes over Management Network
Routing in SBI

- Node characterized by number of interfaces
- Interface simulates a transceiver
- Number of links constrained by interfaces
- Compute topology – Limit number of links
Routing Algorithm

- Link costs
  - Costs based on link distances

- Minimum Spanning Trees
  - Compute shortest paths to each node in the network
  - Assures that every node in network is connected

- Link Limiting
  - For each node, \#links > \#interfaces?
  - Remove least-used links for that node

- Re-compute spanning trees
  - To regenerate complete network topology
Example Topology

- 6 nodes
- 3 interfaces on each node
- Link costs shown
Generating Topology
Link Limiting

- Remove least-used links
  - Least likely to affect the network
  - Alternate paths found by re-running MST
  - If tie, remove link with higher cost

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Link Usage

Links to be removed:

1-6, 3-4, 3-1

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Cost Matrix
Second Iteration
Testing

- Tests conducted with user-drawn scenarios
- Nine Node Polar Satellite Scenario
  - Eight satellites in polar orbit
  - Facility at North Pole
- Twenty Five Node Scenario
  - Eight satellites in equatorial orbit
  - Sixteen in two orbits of 60 degree inclination
  - Facility at Goddard
- Tested for
  - Route updates
  - Scenario continuity
  - Data traffic movement
Results
Results

- Route changes shown
- Rly2 and Rly3 initially connected to facility
- Rly3 and Rly4 next
- Rly4 and Rly5 finally
Future Work

- Higher number of nodes
  - LEO constellations have tens of nodes
- Complex routing algorithms
  - Handling QoS
  - Multiple redundant routes
- Distributed Routing
  - More intelligent nodes
Summary

- A system which can be used to evaluate the feasibility and performance in an Earth-orbital environment of
  - Satellite constellation topologies
  - Satellite transport protocols
  - Satellite routing protocols
- A system which provides
  - Scalability and repeatability
  - Good match to the real world system
  - Cost-effective in terms of money and time
Questions?