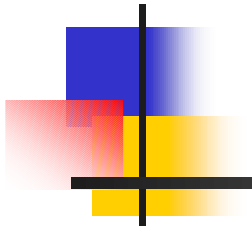

Design of a Space-Based Internet Emulation System

Masters Thesis Defense

Sujit R. Baliga

11/18/2002

Committee:

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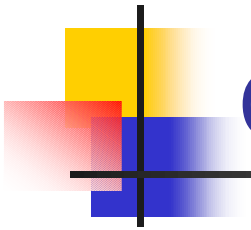
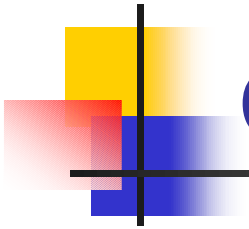
Dr. Joseph B. Evans

Dr. Victor Frost



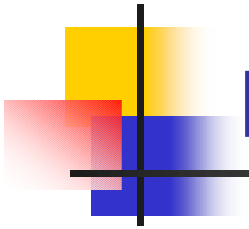
Organization

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



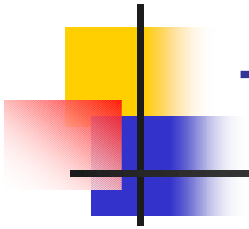
Objectives for SBI

- 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

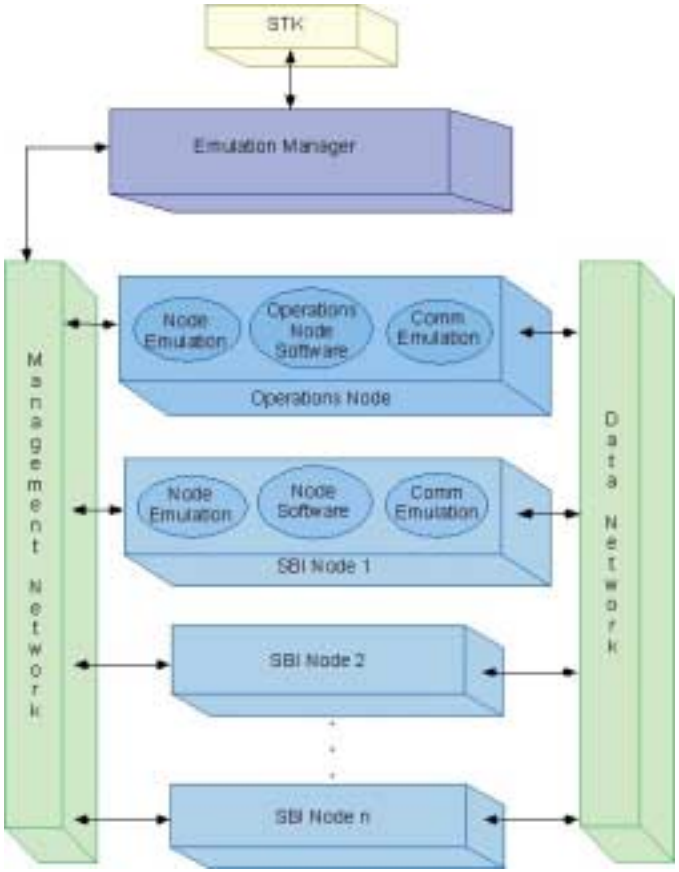
- Emulate the satellite network environment
  - Link Delays
  - Error rates
- Real-time system
  - Works with real-time offset
- Inter-node data traffic
  - Validates network routes
  - Models actual satellite traffic
- Modular system
  - Facilitates replacement of entire modules
  - For evaluating various algorithms and packages in routing, orbit computations



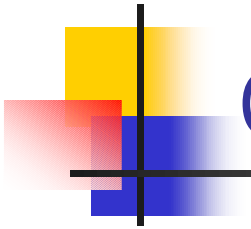
The SBI Emulation System

- 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



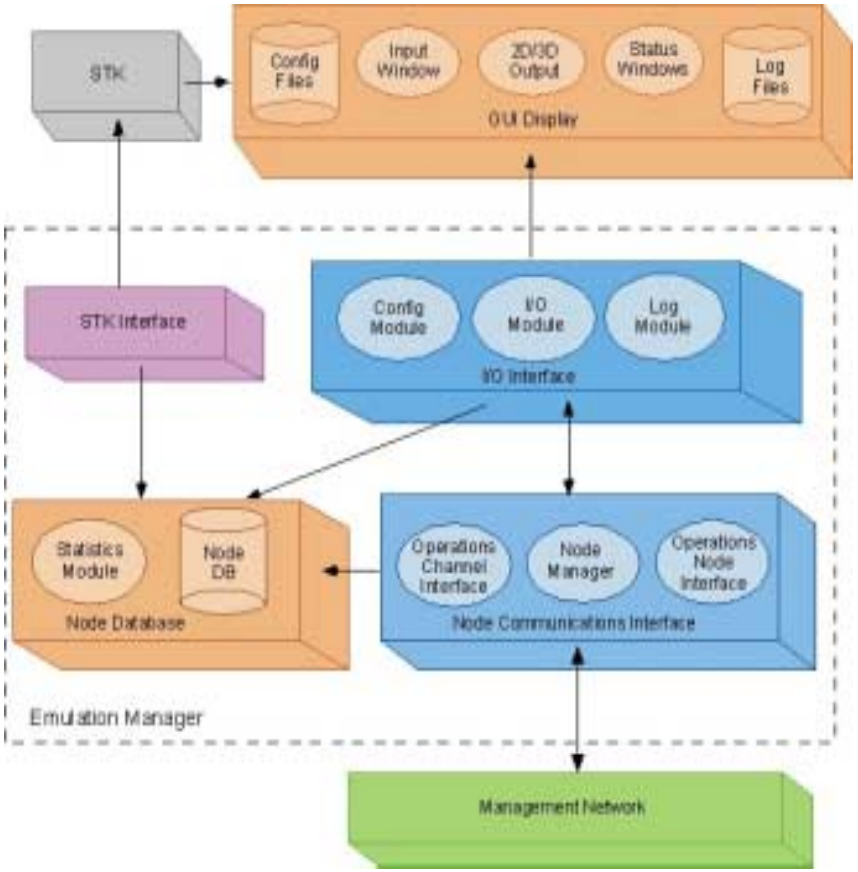
- Emulation Manager
- Operations Node
- Common Nodes
- Networks
- External Software



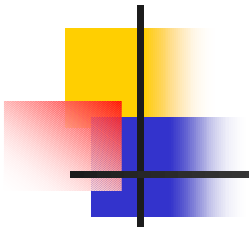
Components

- 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

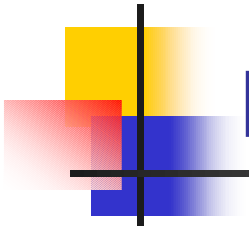


- I/O Interface
- Node Communication
- Node Information
- STK Interface



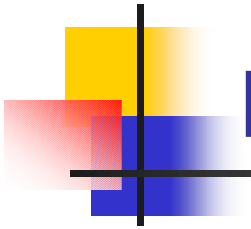
I/O Interface

- 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



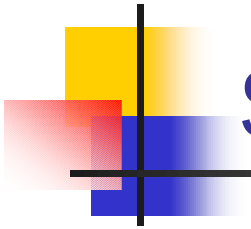
Node Communication

- 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

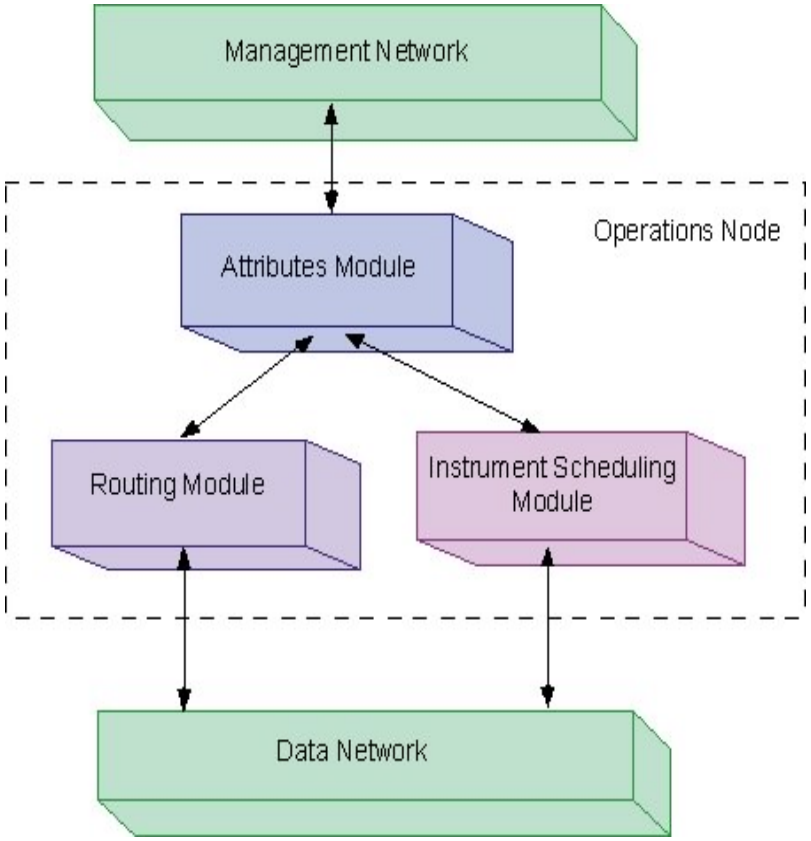
- Stores information regarding nodes
  - Satellite, Ground station data
    - Positional parameters, interface and instrument data
  - Node Interface data
    - Bandwidth
  - Instrument data
    - Data type, rate, source and destination
- Computes Statistics
  - Network access times



STK Interface

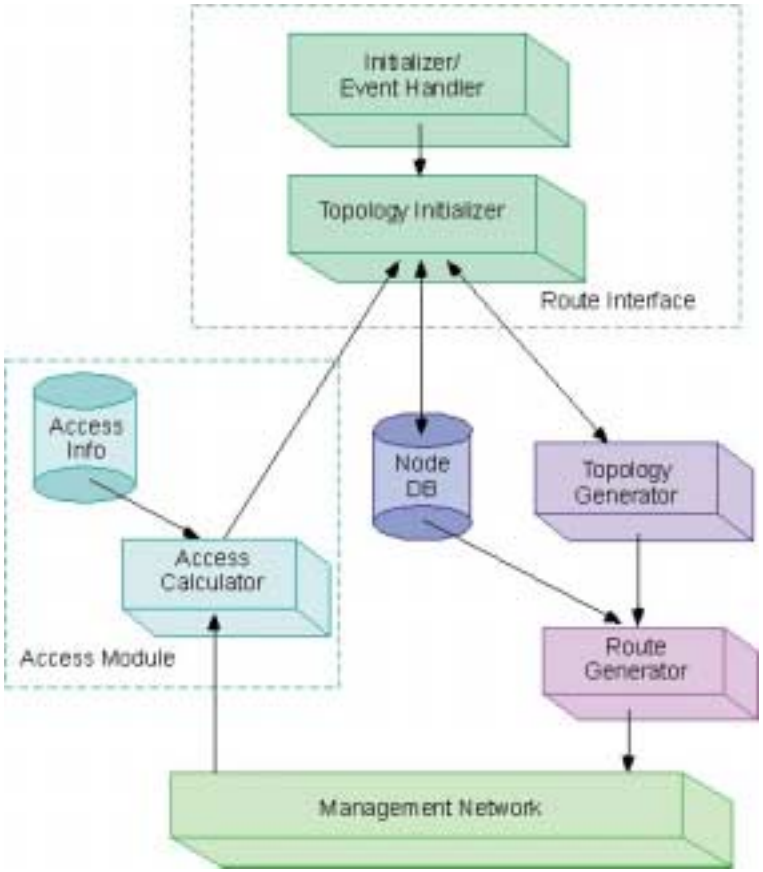
- Establishes TCP connection to STK
- Receives node information and propagates satellites
- Receives route information and displays network routes
- Receives requests from Operations Node Interface
  - Satellite parameters and position
  - Node access times and distances
  - Emulation time
- Transmits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

Operations Node

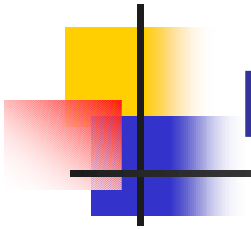


- Attributes
  - Initializes, stores data and mediates between EM and other Operations Node modules
- Routing
  - Generates route updates and transmits to all SBI nodes
- Scheduling
  - Generates schedules for satellite instruments

Operations Node Routing



- Route Interface
- Access Module
- Topology Generation
- Route Generation

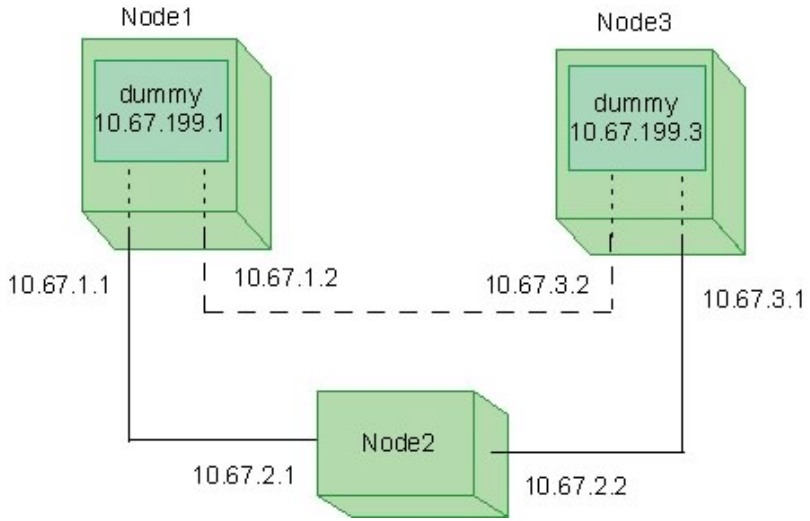


Routing Program

- 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

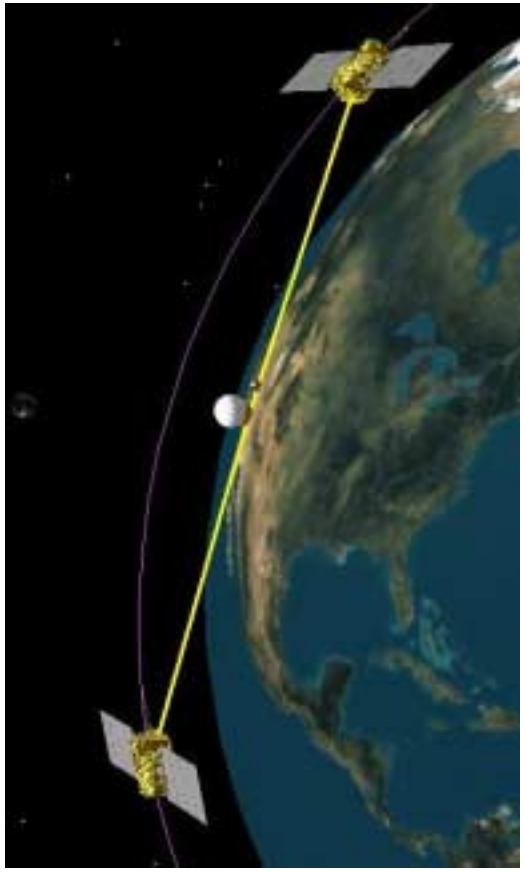
Data Termination Interfaces

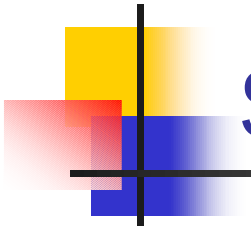


- Routes change constantly
- Routes to data source and sink also change
- Static interface needed for source/sink
- Use “dummy interface” as data source and sink
- Need extra route to reach dummy interface

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



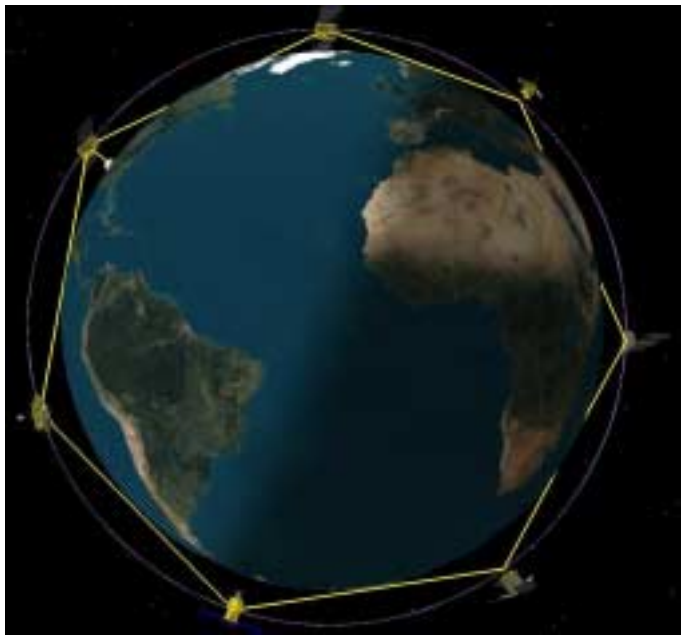


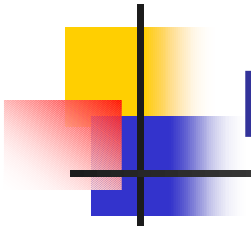
Strategies

- 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



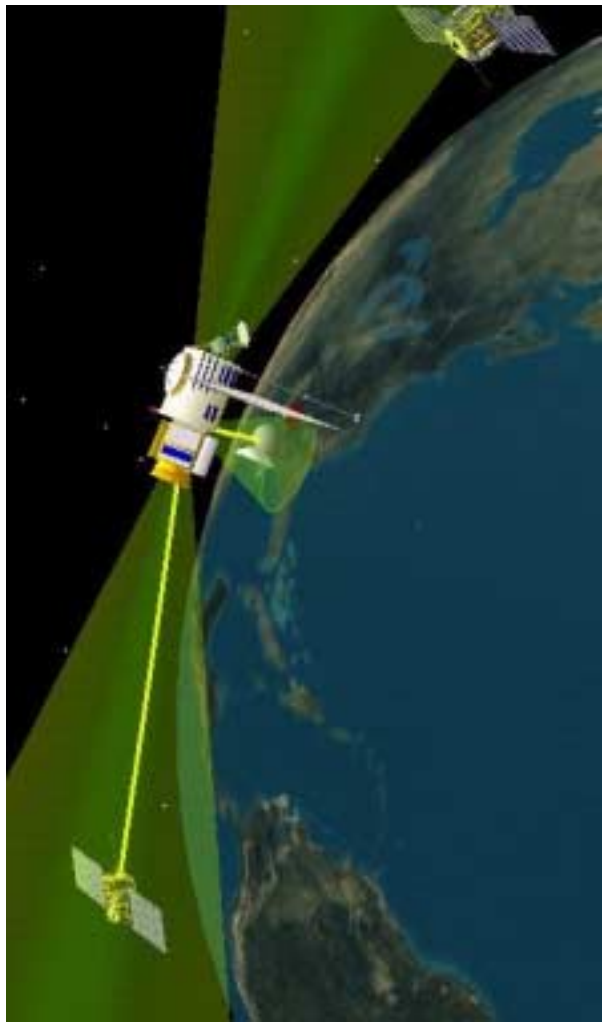


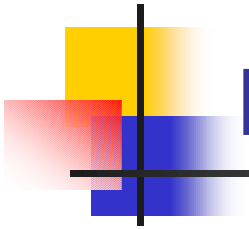
Routing in SBI

- 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

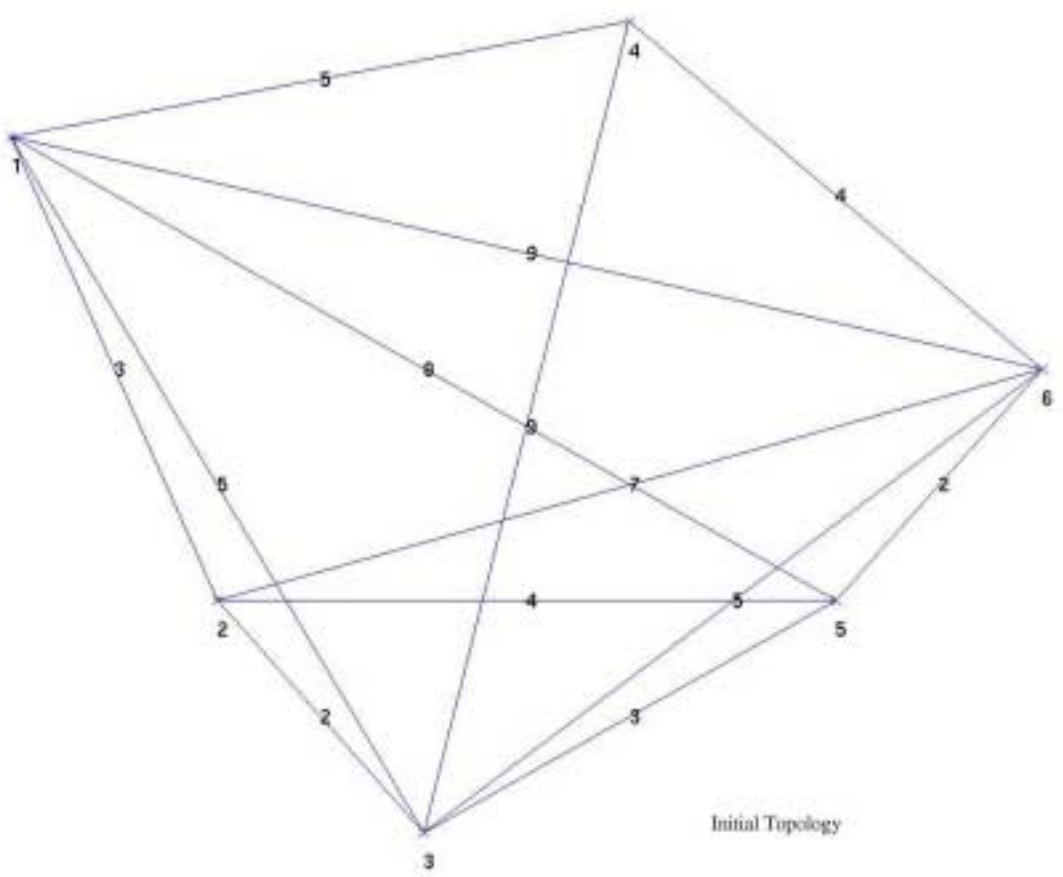




Routing Algorithm

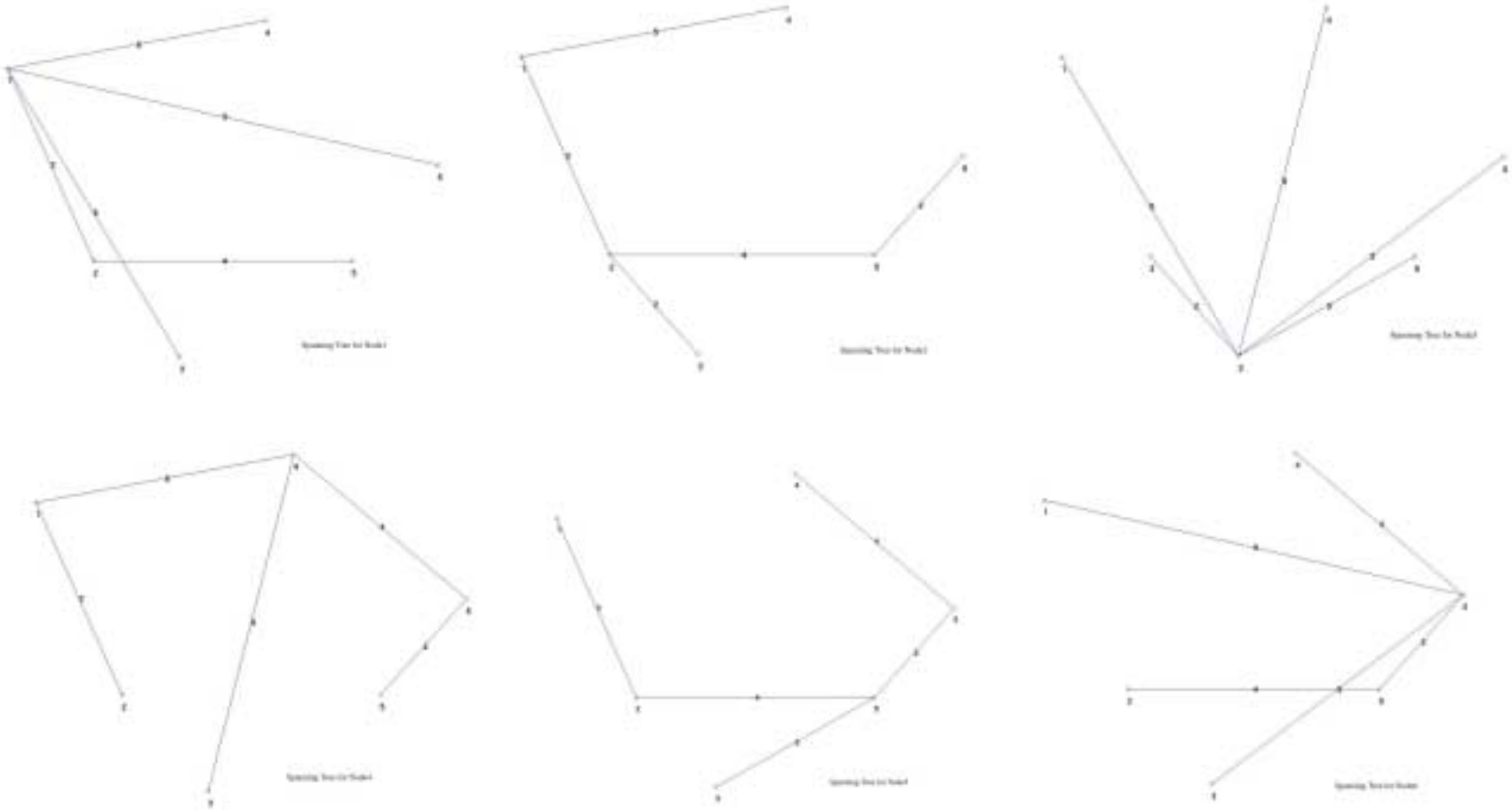
- Link costs
  - Costs based on link distances
- Minimum Spanning Trees
  - Compute shortest paths to each node in the network
  - Assures that every node in network is connected
- Link Limiting
  - For each node, #links > #interfaces ?
  - Remove least-used links for that node
- Re-compute spanning 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

	1	2	3	4	5	6
1	-	3	1	2	-	1
3	1	1	-	1	1	1
6	1	-	1	2	3	-

Link Usage

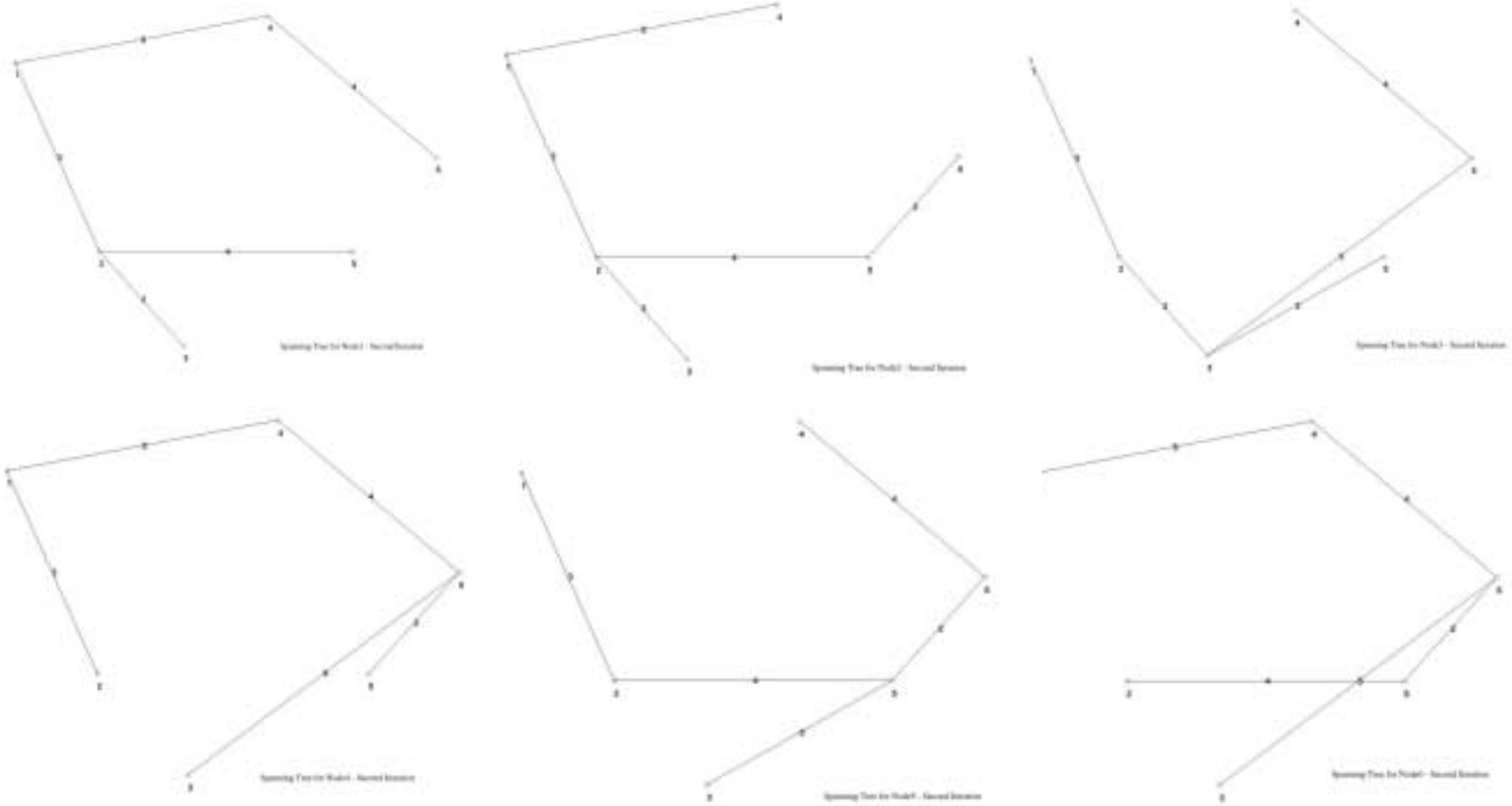
Links to be removed:

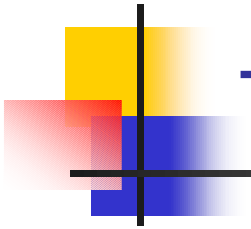
1-6, 3-4, 3-1

	1	2	3	4	5	6
1	**-**	**3**	**5**	**5**	**8**	**9**
2	3	-	2	8	4	6
3	**5**	**2**	**-**	**9**	**3**	**5**
4	5	8	9	-	6	4
5	7	4	3	6	-	2
6	**9**	**7**	**5**	**4**	**2**	**-**

Cost Matrix

Second Iteration

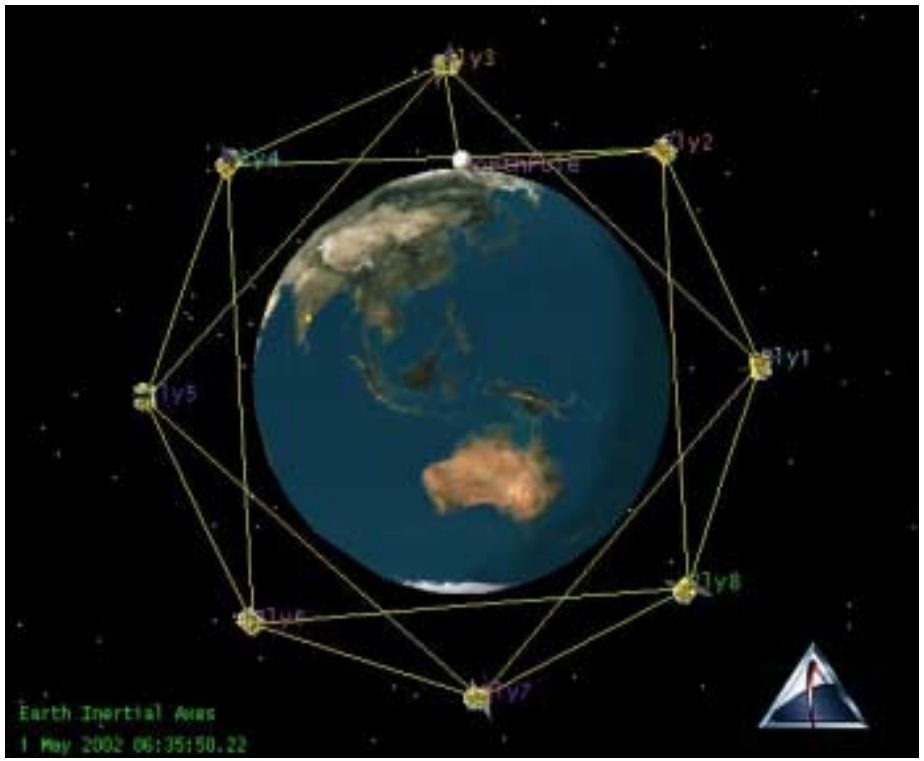


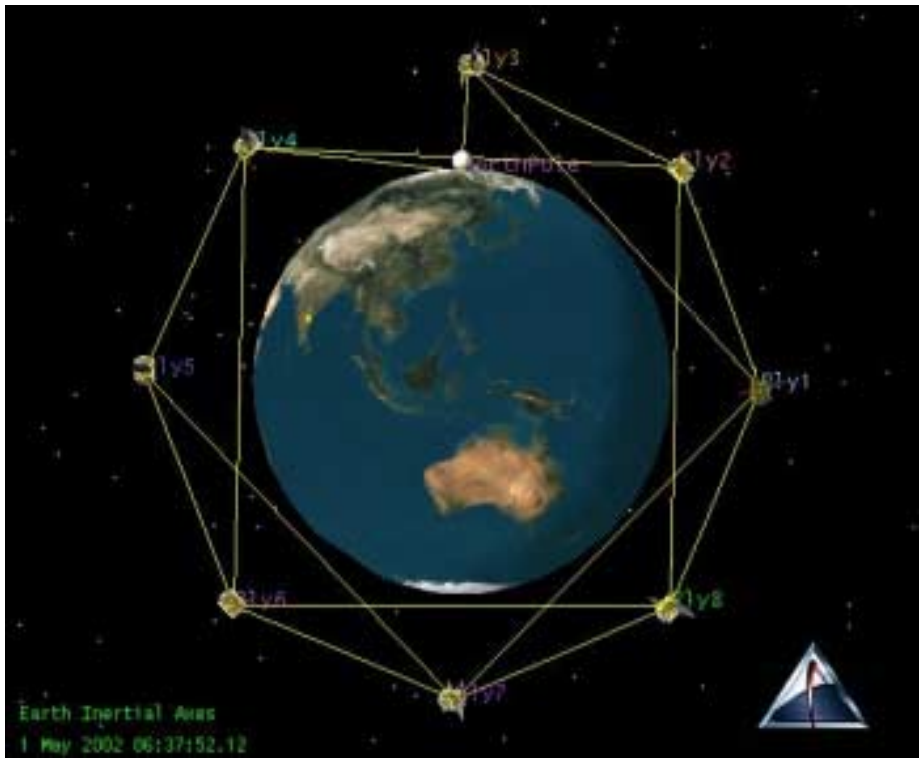


Testing

- 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


Earth Inertial Axes
1 May 2002 06:35:50.22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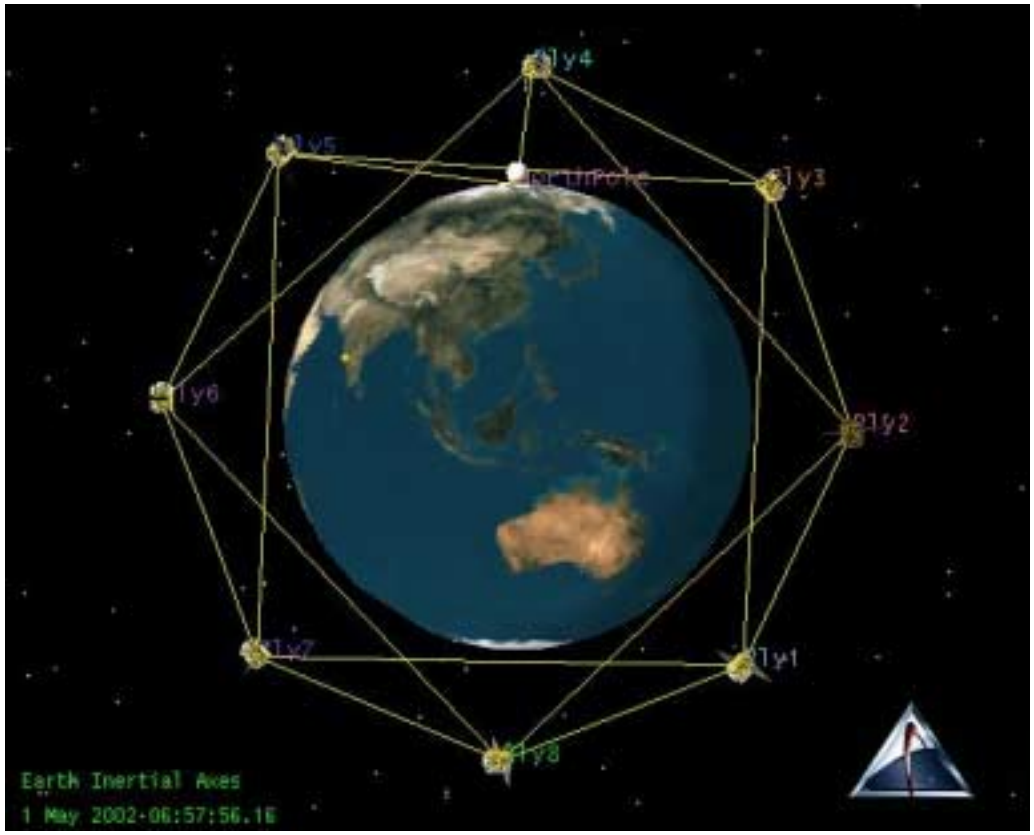
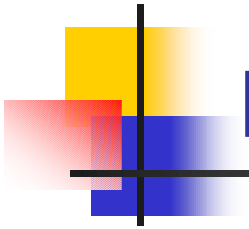
Results

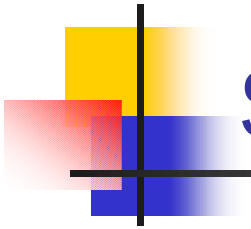


- Route changes shown
- Rly2 and Rly3 initially connected to facility
- Rly3 and Rly4 next
- Rly4 and Rly5 finally



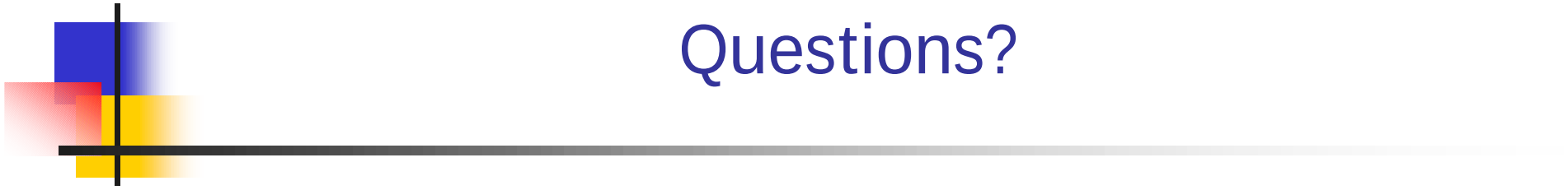
Future Work

- 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?