Space-Based Networking Technology Developments in the Interplanetary Network Directorate Information Technology Program

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Presented at

2nd IEEE International Conference on

Space Mission Challenges for Information Technology 2006

Pasadena, California

19 July 2006

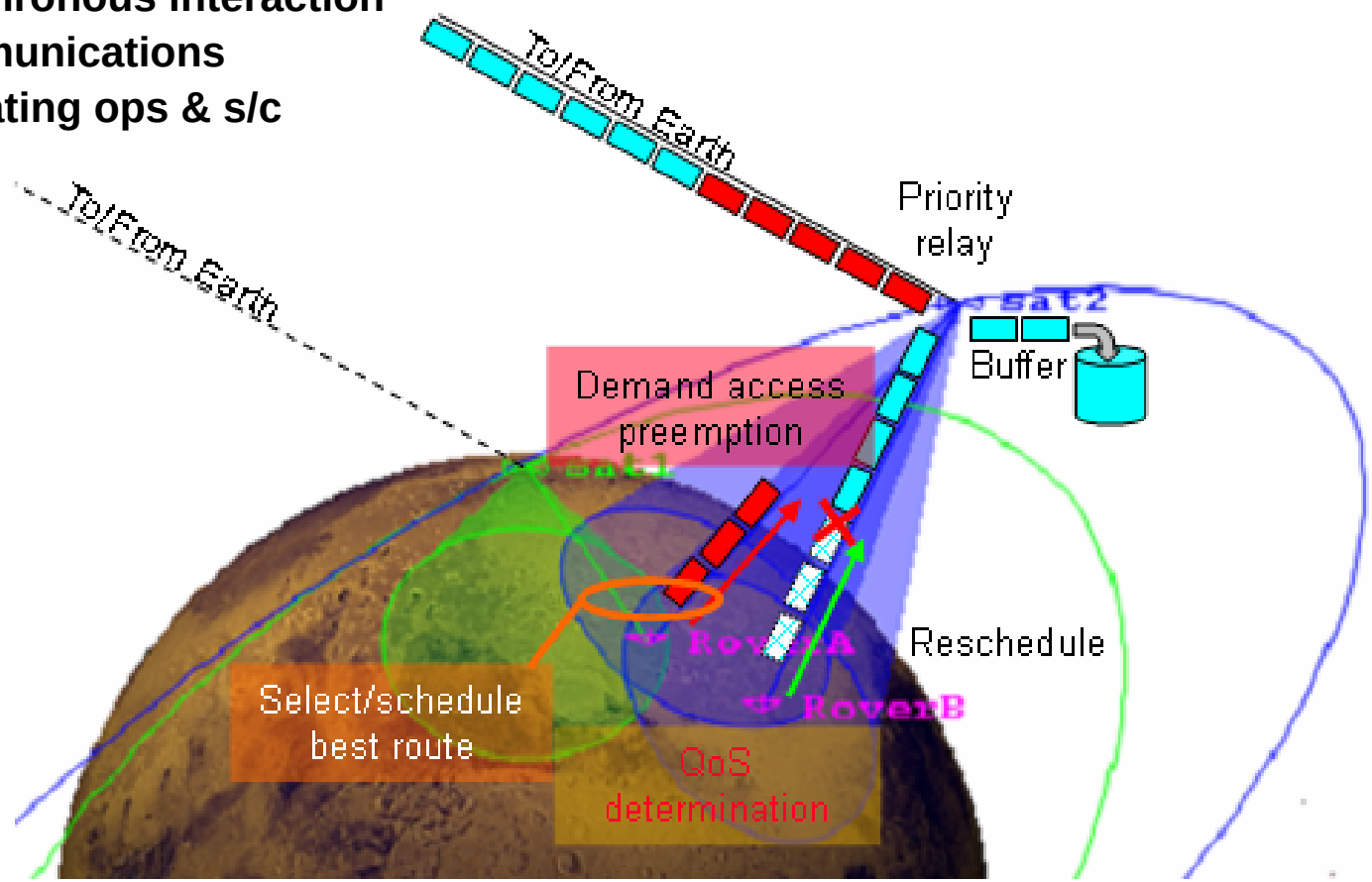
Overview

- Space-Based Networking R&D Objectives and Benefits
- Space-Based Networking Architecture
- Distributed Scheduling
- Middleware
- Communications Protocols
- Simulation
- Conclusions

Space-Based Networking Objectives

Develop space networking services & protocols in integrated embedded infrastructure enabling

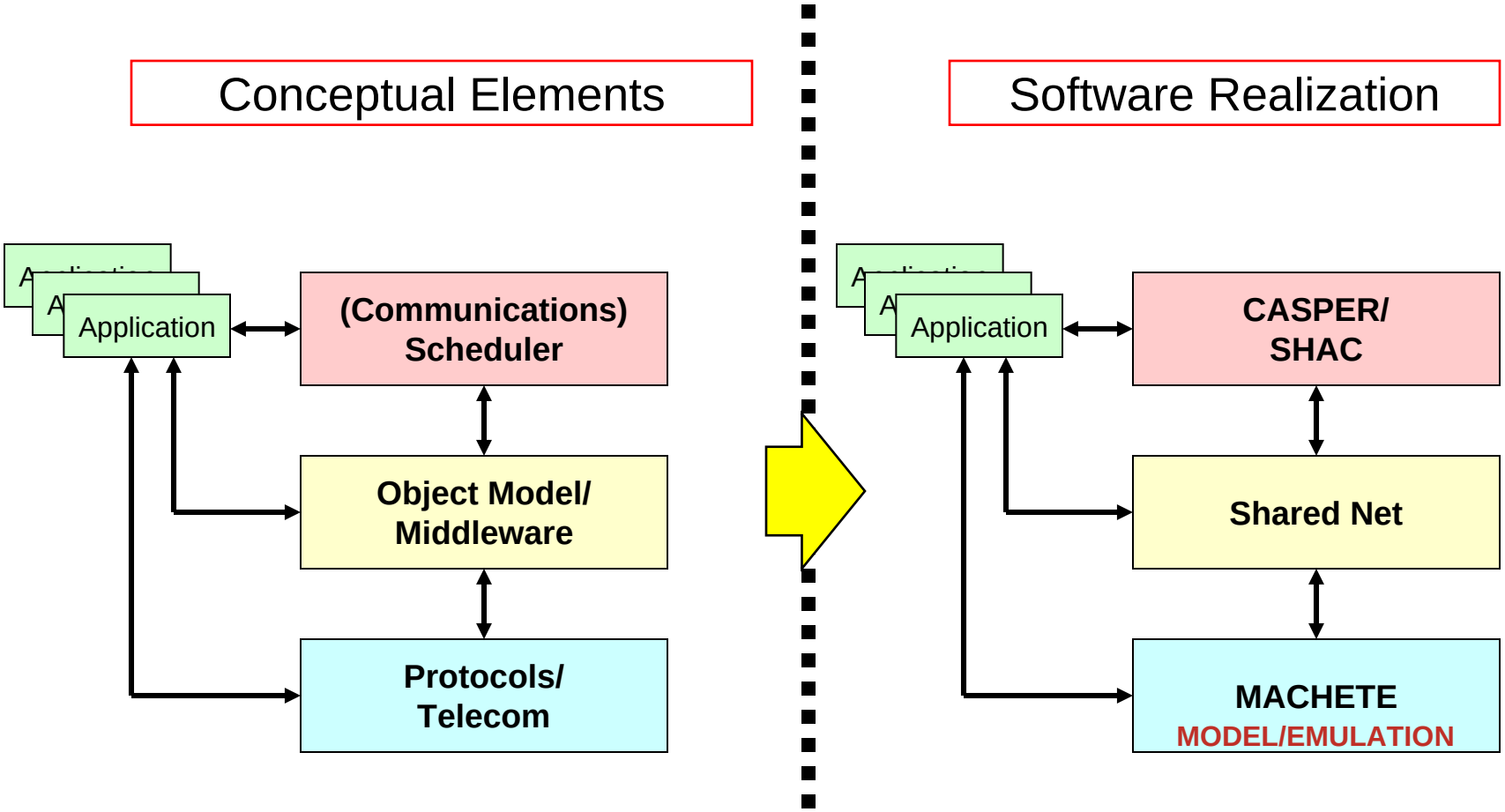
- **differentiated quality of service (QoS)**
- **demand access**
- **autonomous asynchronous interaction**
- **scheduling of communications activities accommodating ops & s/c constraints**



Space-Based Networking Benefits

- Dramatically increased value per bit returned through QoS prioritization techniques
- Increased operational flexibility and turnaround
- Reduced operations costs for spacecraft commanding
- Higher throughput by operating adaptively
- Simplify applications interface to communications services
- Lower costs from shared software development
- Lower operating costs via automation
- Lower mission risk by using proven software infrastructure
- Increase science by opportunistic sharing of resources among missions

Space-Based Networking Architecture



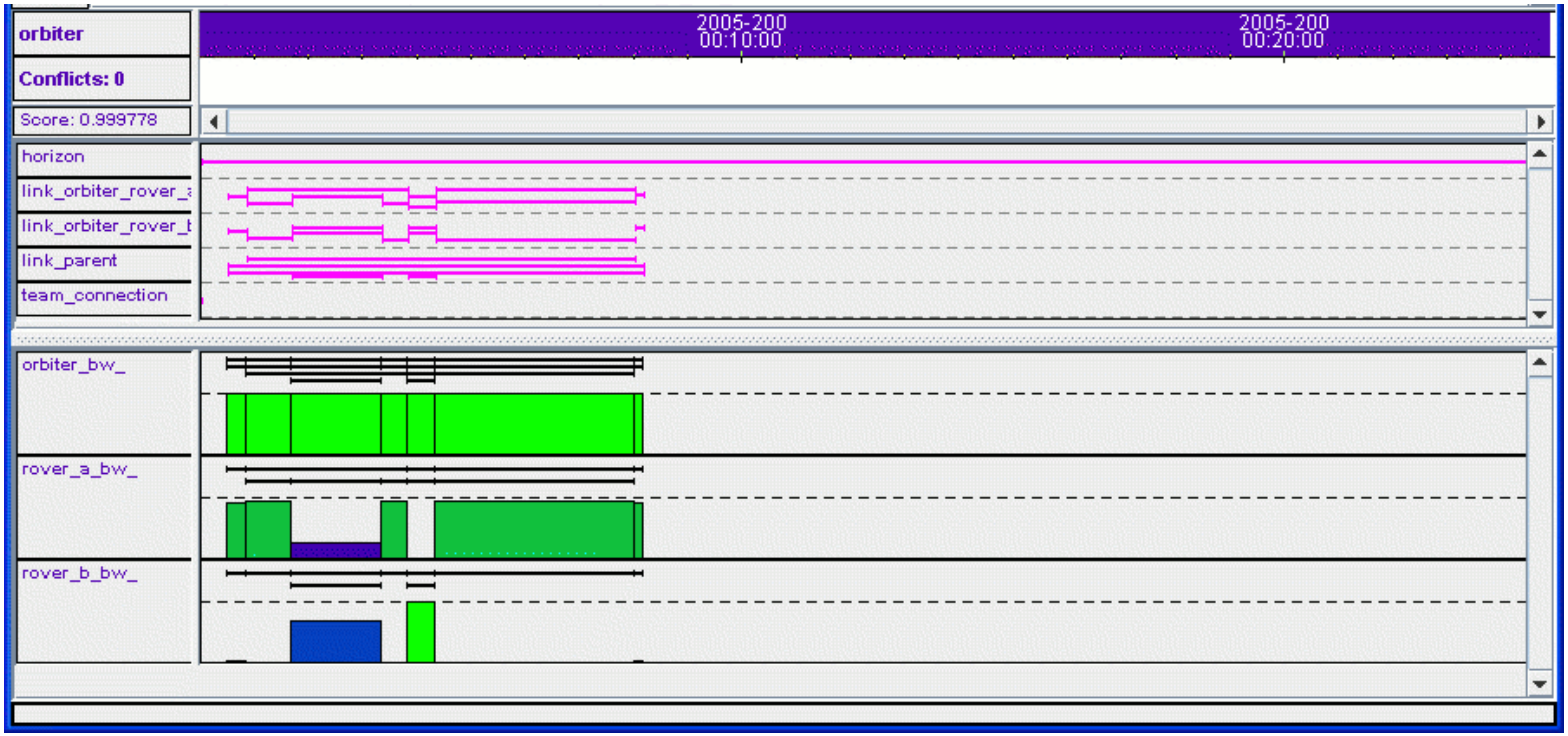
CASPER = Continuous Activity Scheduling Planning Execution and Replanning
SHAC = Shared Activity Coordination
MACHETE = Multi-mission Communications Hybrid Environment for Test and Evaluation

Communications Scheduling

- **High-level communications scheduler interacts with applications**
  - **Coarse-grain behavior: Bandwidth allocations, pass management/view periods, etc.**
  - **Knowledgeable of Quality of Service (QoS) needs of applications**
  - **Interacts with more general spacecraft scheduler, to satisfy competing demands (power, attitude control, etc.) and ensure spacecraft safety**
  - **Detailed communications queueing and buffer management maintained by lower-layer communications protocols**
- **Local scheduling**
  - **Based on ASPEN planning system**
  - **Accommodates constraints on transceiver/antenna availability, windows of communications between nodes, and memory.**
- **Distributed scheduling**
  - **Scheduling among multiple spatially distributed nodes**
  - **Based on SHAC planning/scheduling system**
  - **Planners collectively schedule shared activity(ies), coordinate to reach consensus**
  - **Shared activity structure includes roles and permissions of each planner**
  - **Communications application incorporated definition of shared parameters for request/reservation of transmit or relay activities, and delegation protocol for choosing a spacecraft to relay the data**
- **Interacts with Middleware to exchange QoS-typed bandwidth requests**

Distributed Scheduling

- Able to add, remove, and alter communication activities
- Able to incorporate additions, deletions, and changes from middleware
- For each spacecraft/lander, can perform or receive changes based on a negotiation policy regulating authorization to make changes
- When shared bandwidth oversubscribed, adjusts bandwidth based on priority



Middleware

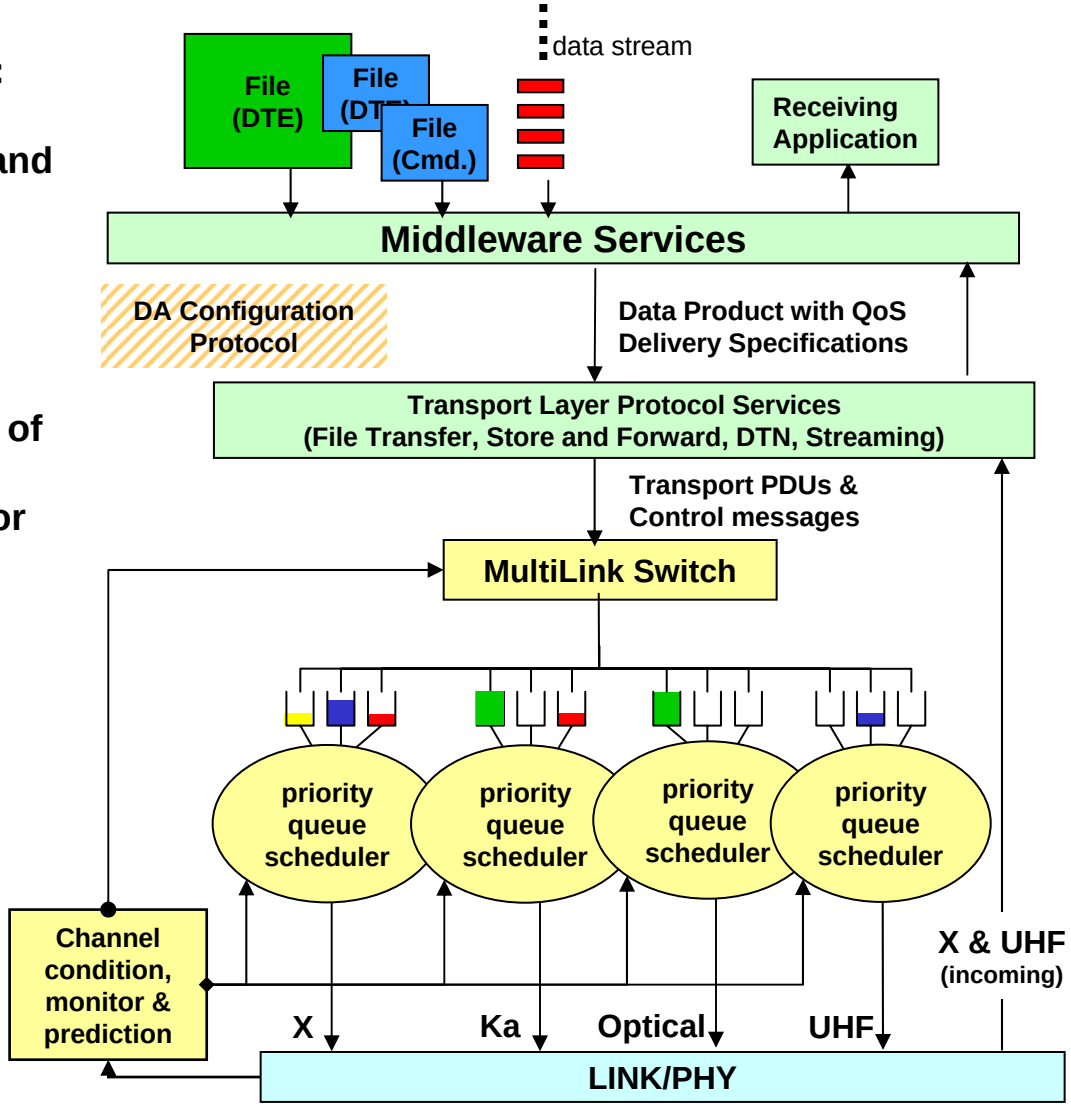
- Defined object model that provides overall structure for the distributed object communication architecture. Distributed objects are an effective approach to simplifying the communication interfaces used by software components.
  - The object model provides a context for all information contained within the system including assets, science and engineering data, communication and commands. This context establishes an implicit translation between distributed object communication API and raw message formats, eliminating many sources of coding errors.
- Applications communicate by creating, updating or deleting objects. Applications use middleware's QoS-aware subscription service to receive information in which they are interested. The context provided by the object model organizes the production and distribution of information.
- The 'Link' class represents current and scheduled communication opportunities between assets. Link information can be modified by the scheduler and by feedback from telecom (e.g. fluctuations in the actual data rate of a pass)
- The object model supports scheduler-specific information
  - Future activities (adding time attributes to existing objects)
  - Roles (e.g. sending, receiving) permissions (who can [re]schedule what)

Communications Protocols

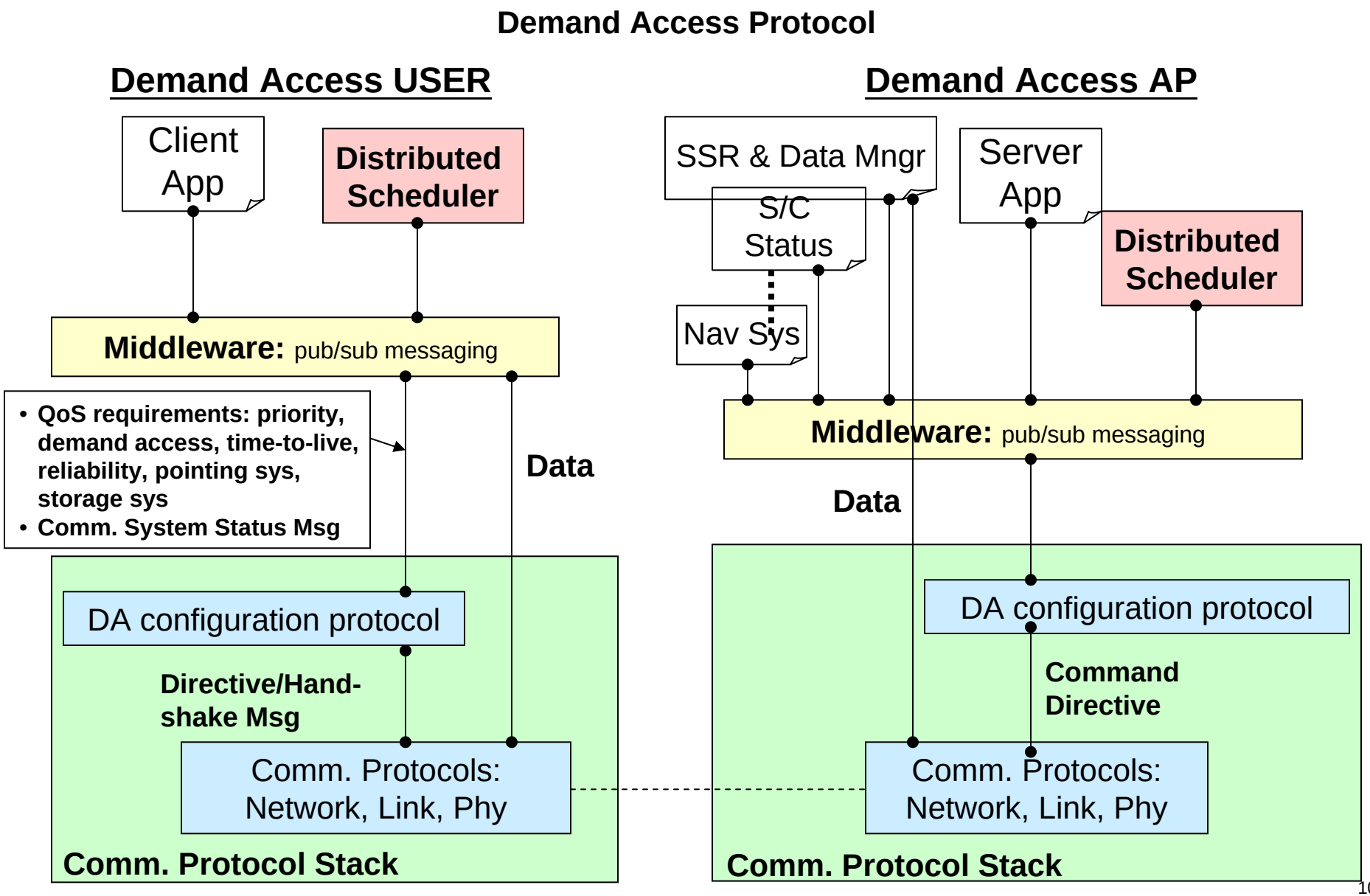
Quality of Service (QoS)-Aware Relay Management Protocol

- QoS-aware Relay Management Protocol:
  - MultiLink/Band Switch dynamically switches band (X, Ka, Optical, UHF) and determines next hop on the relay (to Earth, Orbiter, or Landers/rovers) to improve aggregate level QoS performance
  - Priority-based queue and bandwidth scheduler for fine grain prioritization of PDUs within a single link/medium
  - Interface to channel condition monitor and prediction algorithm

- QoS specifications for IPN user data:
  - Priority
  - Reliability
  - Latency/time-to-live
  - Minimum guaranteed bandwidth



Communications Protocols



Communications Protocols

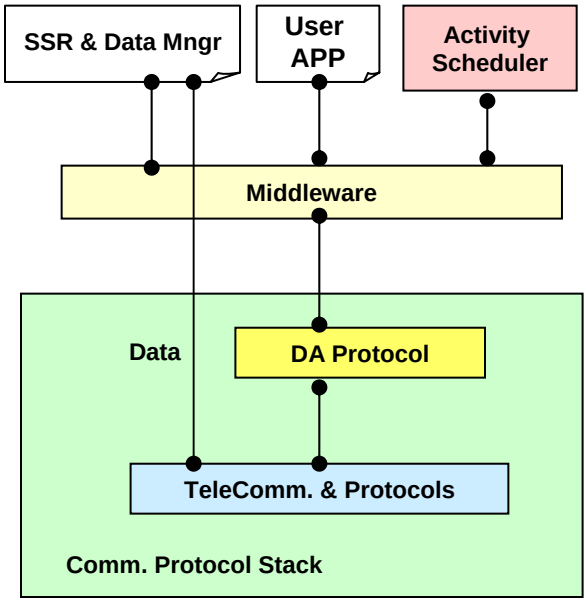
Demand Access Protocol

Demand Access Protocol Functions:

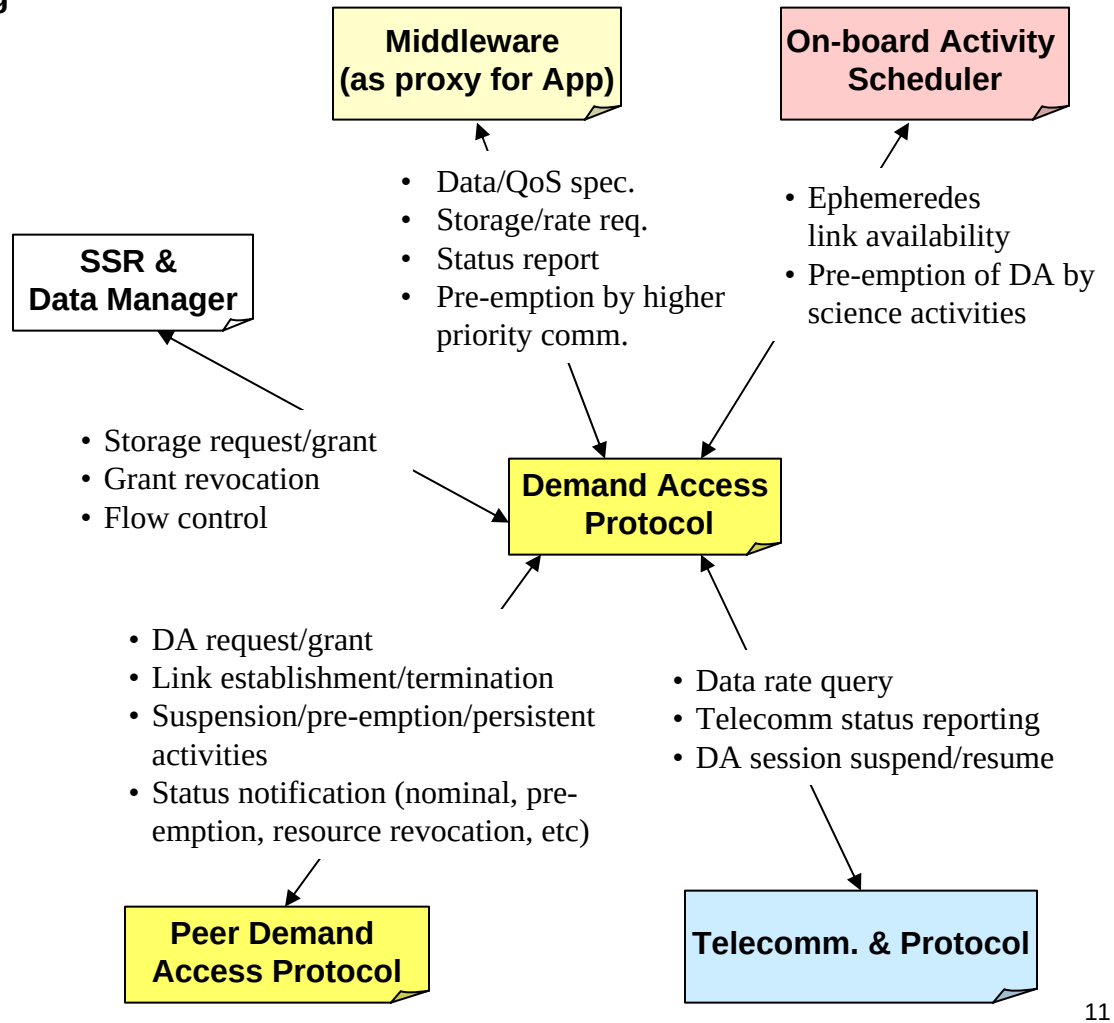
- **Establish communication link on-demand**
- **Automate link configuration and hand-shaking**
- **Manage contention with/pre-emption by other communications/science activities**
- **Status Report/Fault handling**

System Elements:

- **Middleware (as proxy of User Application)**
- **SSR & Data Manager**
- **Activity Scheduler**
- **Telecomm. Subsystem/Protocols**
- **Peered Demand Access Protocols**



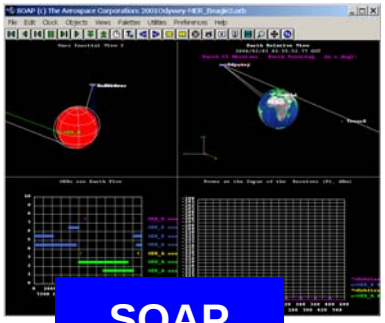
Demand Access Protocol System Connectivity View



Simulation

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

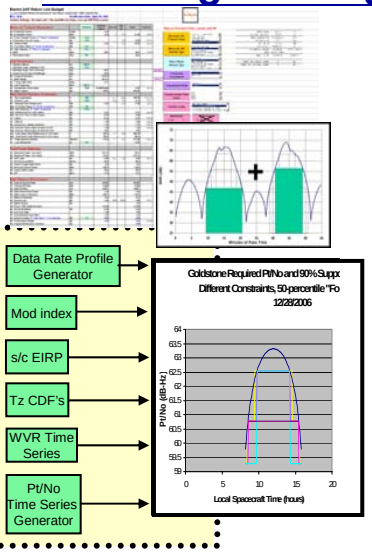
Deployment Geometry



SOAP

- **Generates**:
  - View Period
  - Slant Range
  - Declination
  - Connectivity
- **Models**:
  - Orbit ephemeredes
  - Lander position
  - EDL
  - Antenna patterns

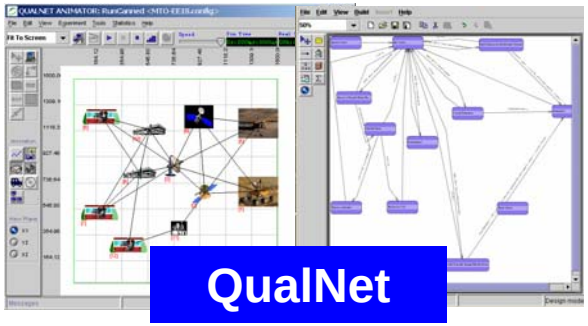
Link Engineering



X,UHF, Ka Link Models

- **Models:**
  - Modulation/Data Rate
  - Antenna Pattern
  - Multi-path Effect
  - Coding
- **Computes:**
  - Bit/Frame Error-Rate
  - Eb/No profile

Network & Protocol Simulation



QualNet

- **Simulates**:
  - Comm. Protocols
  - Relay/End-to-end Telemetry Flow
  - Data Loss/Error Process
- **Performance Metrics:**
  - Data Volume/Buffer Utilization
  - Throughput/Latency
- **Communications Effect Server (CES) Interface for Hybrid Simulation**

External HW/SW

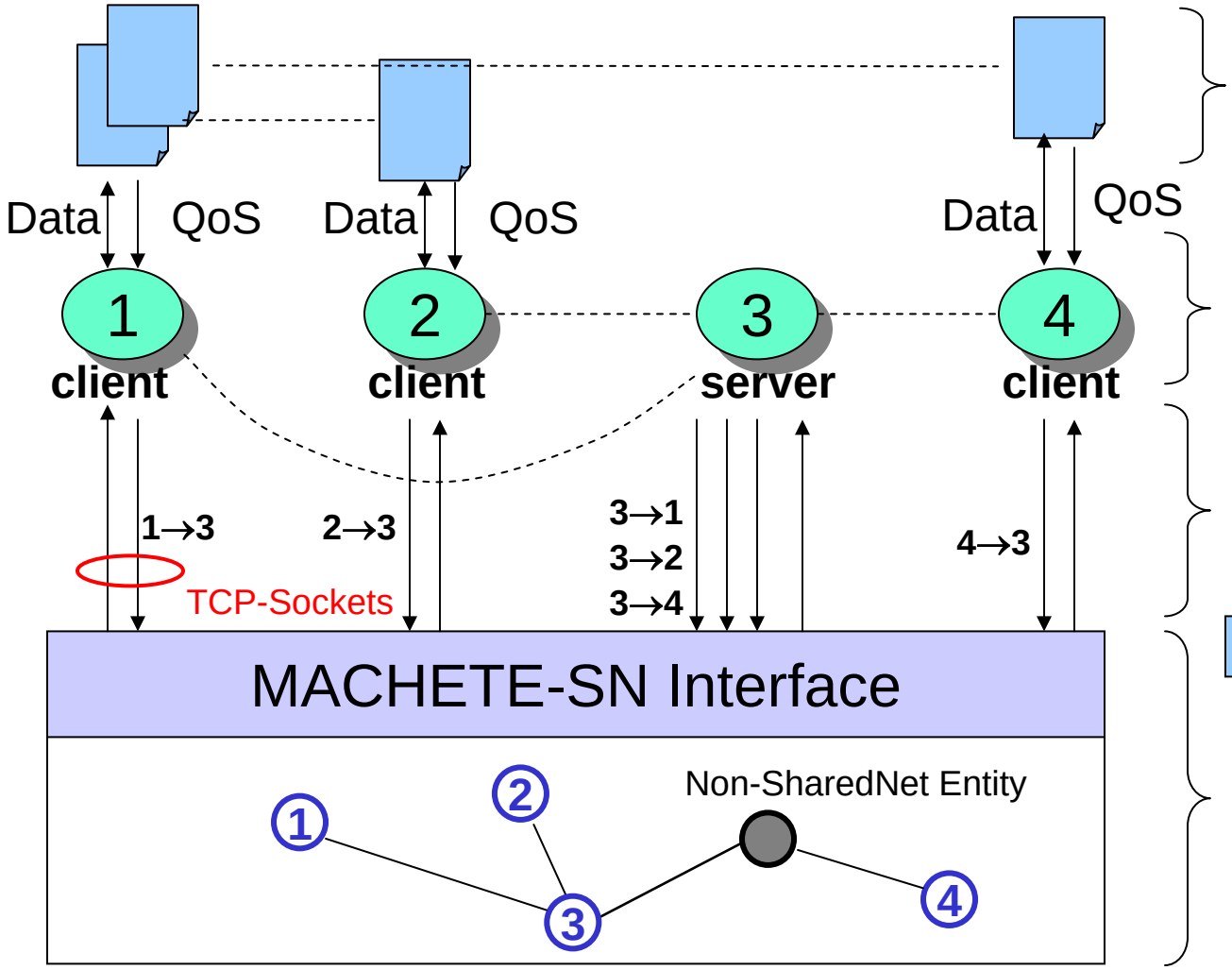
Middleware - Scheduler Interface

Implemented QoS-aware reactive capabilities for basic Demand Access. Established design concept for advanced DA capabilities.

- **Distributed Scheduler has knowledge of planned communication needs including voice, video, and data (such as from middleware) encompassing all on-board activities**
  - **It is also made aware of unplanned needs when requested**
- **Distributed Scheduler informs Middleware of new QoS-based bandwidth allocations as demands change, either planned or unplanned**
  - **Middleware adapts to new allocations, transparent to client applications, and continues QoS-based communication as needed**
- **Demand Access protocols expand scope of possible unplanned communication needs to external requests for telecom resources**
- **Integrating Middleware with Demand Access protocol layer provides the following benefits**
  - **Automatic, QoS-based reaction to DA requests by Middleware, supporting dynamic changes in communication plans with no additional required coordination or commanding, providing faster reaction times**
  - **Middleware informs Distributed Scheduler of DA requests so it can maintain desired resource allocations and activities**

MACHETE – Middleware Interface

- Enables SharedNet middleware operations over realistic space communications networking models
- Quality of Service information is passed from middleware for use by underlying communications protocols



Two-way Peer User Applications

SharedNet (SN) Topology (Middleware)

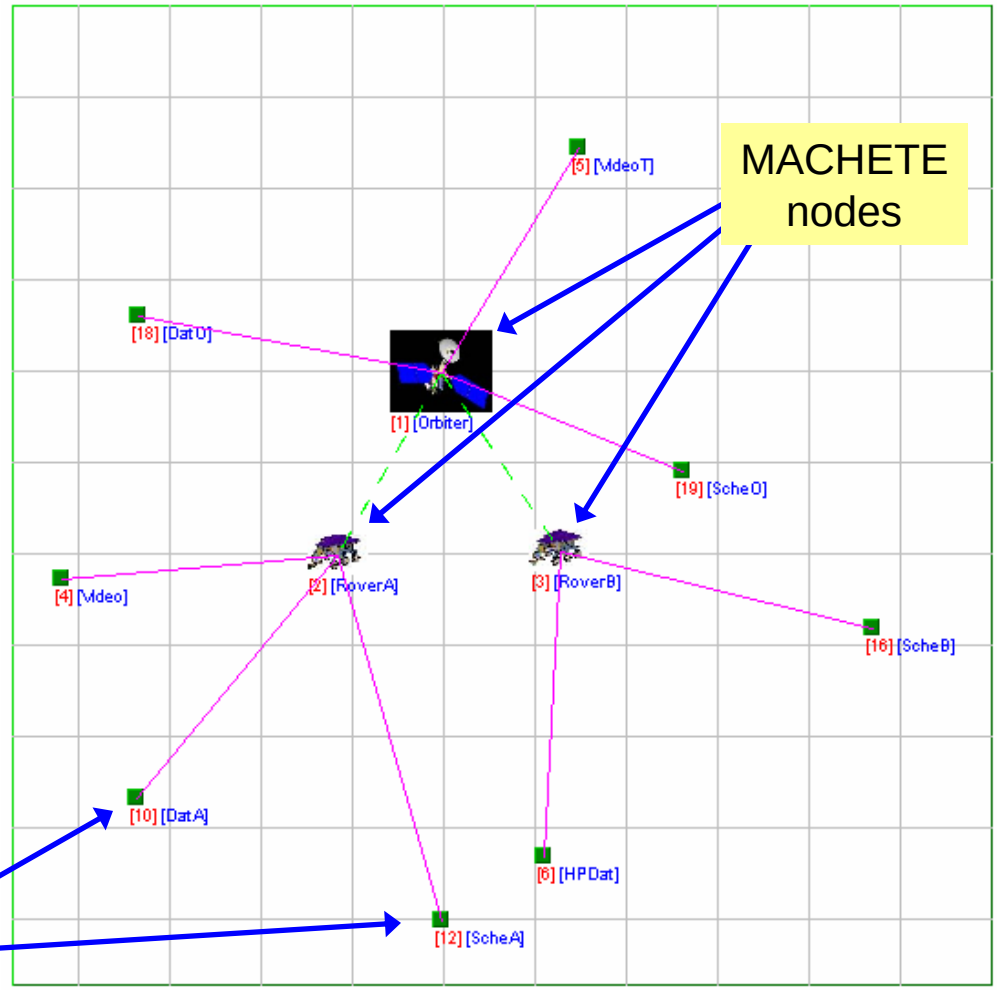
Each socket interface mapped to one SN communication pair. SN->MACHETE Data format:

Length	QoS	data

Simulation of Underlying Space Communication Network & Protocols

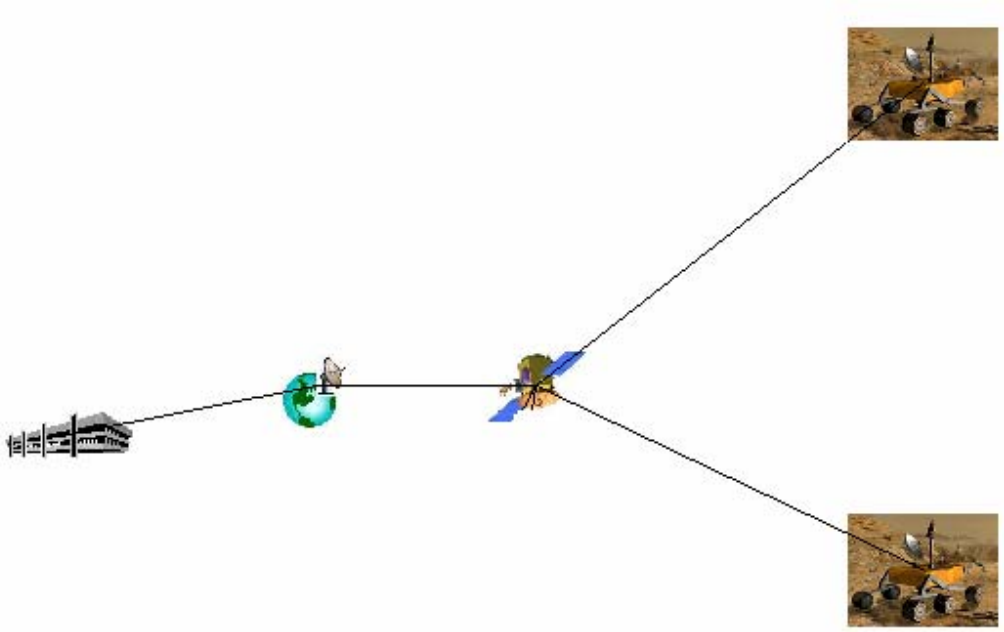
Integrated MACHETE and SharedNet QoS Functionality

- Able to signal of Quality of Service (QoS) between SN middleware and MACHETE simulator
  - Simulation maps appropriate QoS level to telecom queueing scheme (e.g. strict priority)
- Simulation entities and middleware clients and servers are interfaced to pass data, QoS and scheduling information between SN & MACHETE
- Enables MACHETE to modify link bandwidth according to dynamic schedule

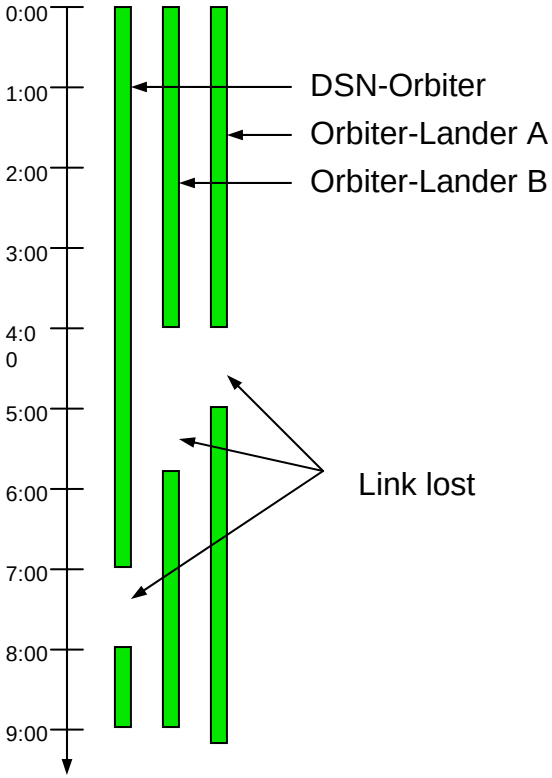


Integrated SharedNet and DTN Simulation Demo

Demonstration of SharedNet operating over MACHETE simulated Disruption Tolerant Networking (DTN) given at this conference



Simulation Sequence
(minutes)



Conclusions

- Described recent development of communications protocols, services, and associated tools targeted to reduce risk, reduce cost and increase efficiency of IND infrastructure and supported mission operations
- Space-based networking technologies developed
  - Provide differentiated quality of service (QoS) that will give precedence to traffic that users have selected as having the greatest importance and/or time-criticality
  - Improve the total value of information to users through the use of QoS prioritization techniques
  - Increase operational flexibility and improve command-response turnaround
  - Enable new class of networked and collaborative science missions
  - Simplify applications interfaces to communications services
  - Reduce risk and cost from a common object model and automated scheduling and communications protocols
- Technologies are described in three general areas: communications scheduling, middleware, and protocols
- Additionally developed simulation environment, which provides comprehensive, quantitative understanding of the technologies' performance within overall, evolving architecture, as well as ability to refine & optimize specific components