MACHETE: Environment for Space Networking Evaluation

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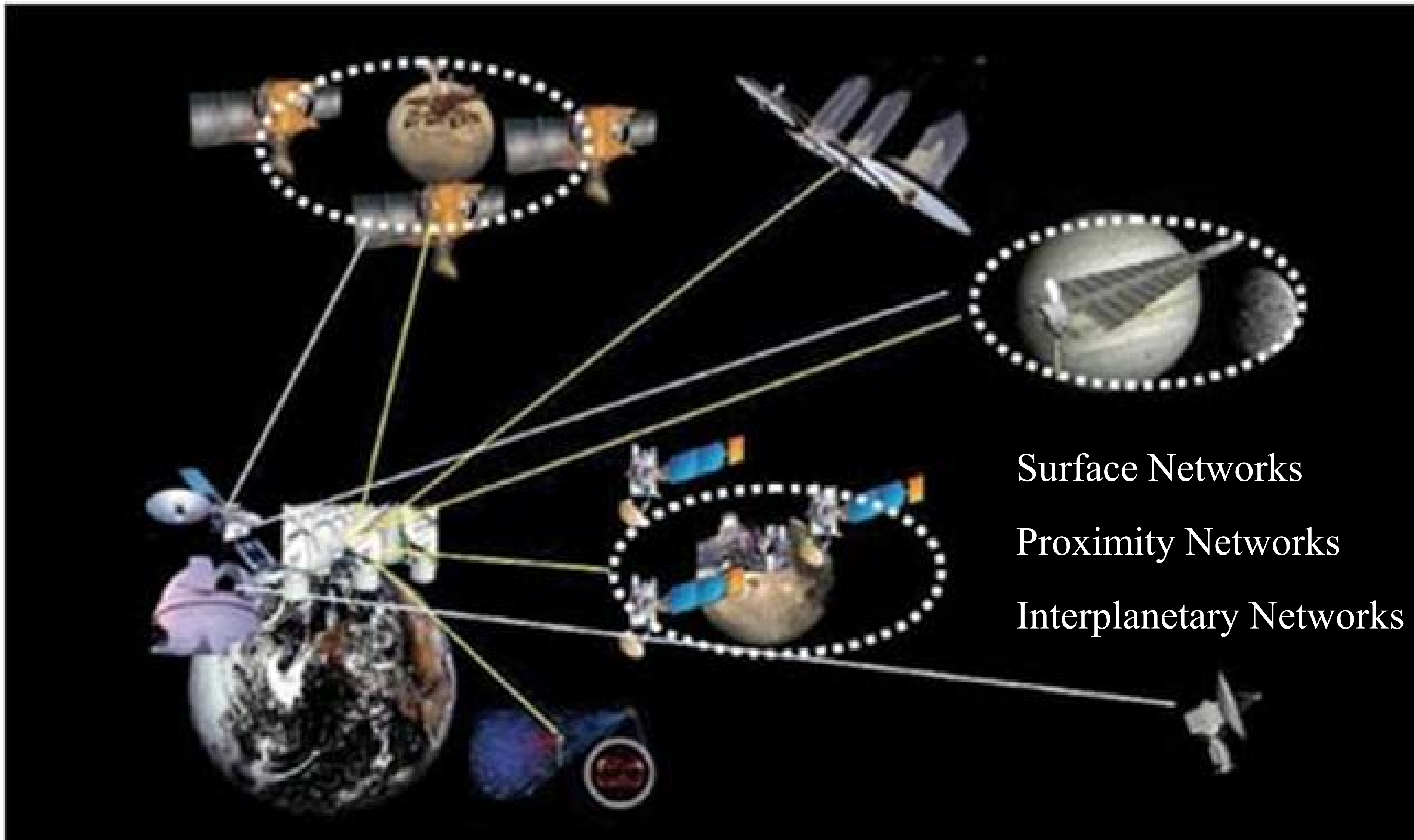
Outline

- Space Networking Overview
- JPL's MACHETE simulation environment
  - Clearing the path for network engineering
- MACHETE Use Cases
- Conclusion

Space Exploration Networks



Surface Networks

- Examples: rover to lander, astronauts to base station, surface sensor network, habitat to ISRU, habitat LAN
- Wired networks or
- Constrained wireless networks
  - Semi-predictable topology, limited nodes
  - Controlled mobility, obstruction
- Protocol Examples:
  - 802.x, IP, DTN Bundle, FTP, RTP

Proximity Networks

- Examples: rover to orbiter, orbiter to orbiter cross-link
- Predictable dynamic topology arising from orbital kinematics
- Protocols: Proximity-1, AOS, 802.11/16, CFDP

Interplanetary Networks

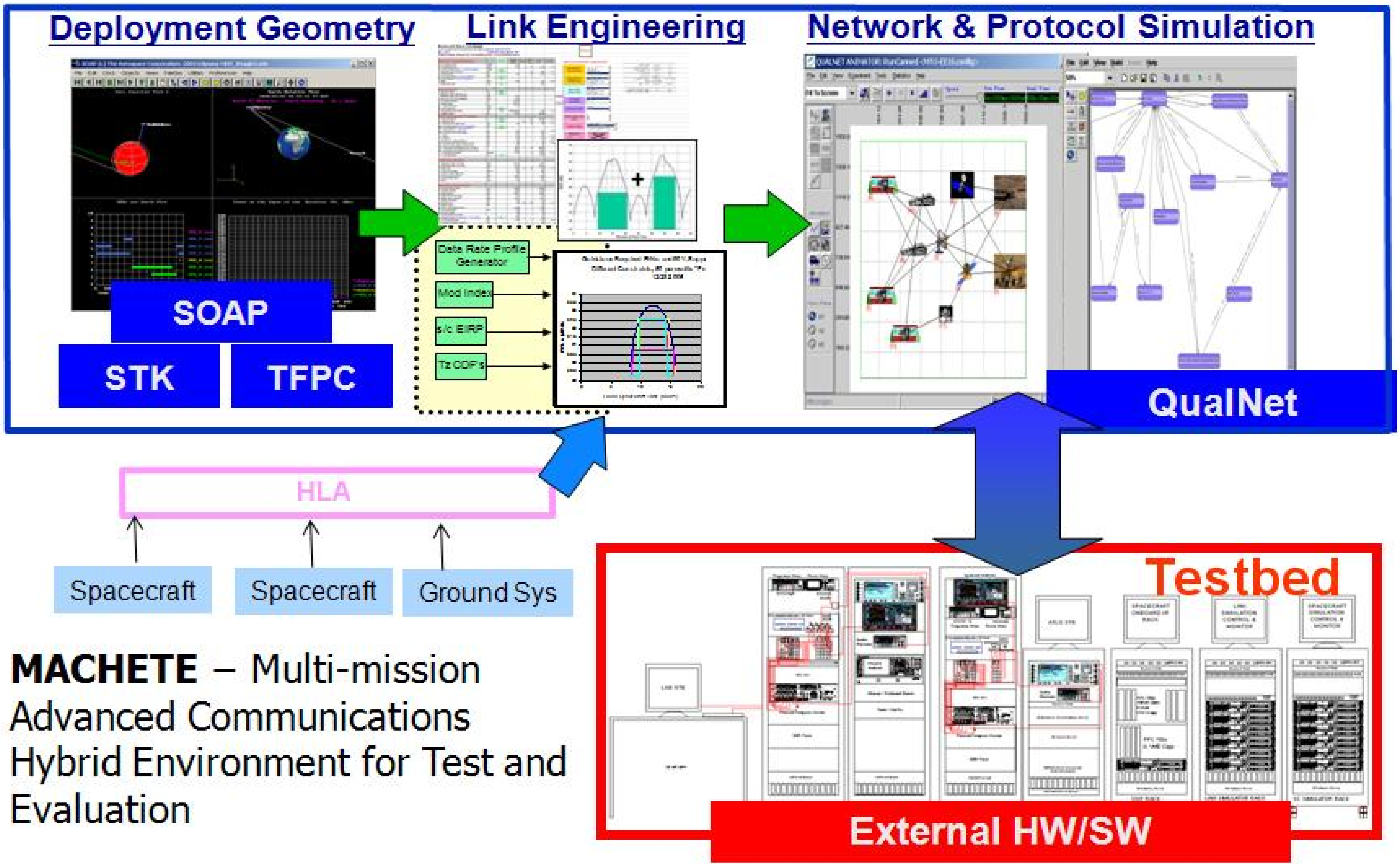
- Space exploration backbone to/from Earth
- RTTs measured in minutes and hours
- Possible use of Ka-band or optical
  - Weather effects cause unpredictable outages
- Resource sharing of ground assets
  - Reschedule due to unplanned outage has cascading effect
- Protocols: TC/TM, AOS, DTN Bundle Protocol, LTP, CFDP

JPL's MACHETE Simulation Environment

- Purpose of such tool environment
  - Space networking is different from terrestrial networks
  - To minimize risks in space flight missions, we need to design, validate and evaluate space networking protocols
- Overall MACHETE architecture
  - Orbital and Planetary Motion Kinematics Modeling
  - Link Engineering
  - Traffic and Protocol Modeling
  - External Interface for Integrated Distributed Simulations

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

MACHETE Architecture



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

MACHETE Development

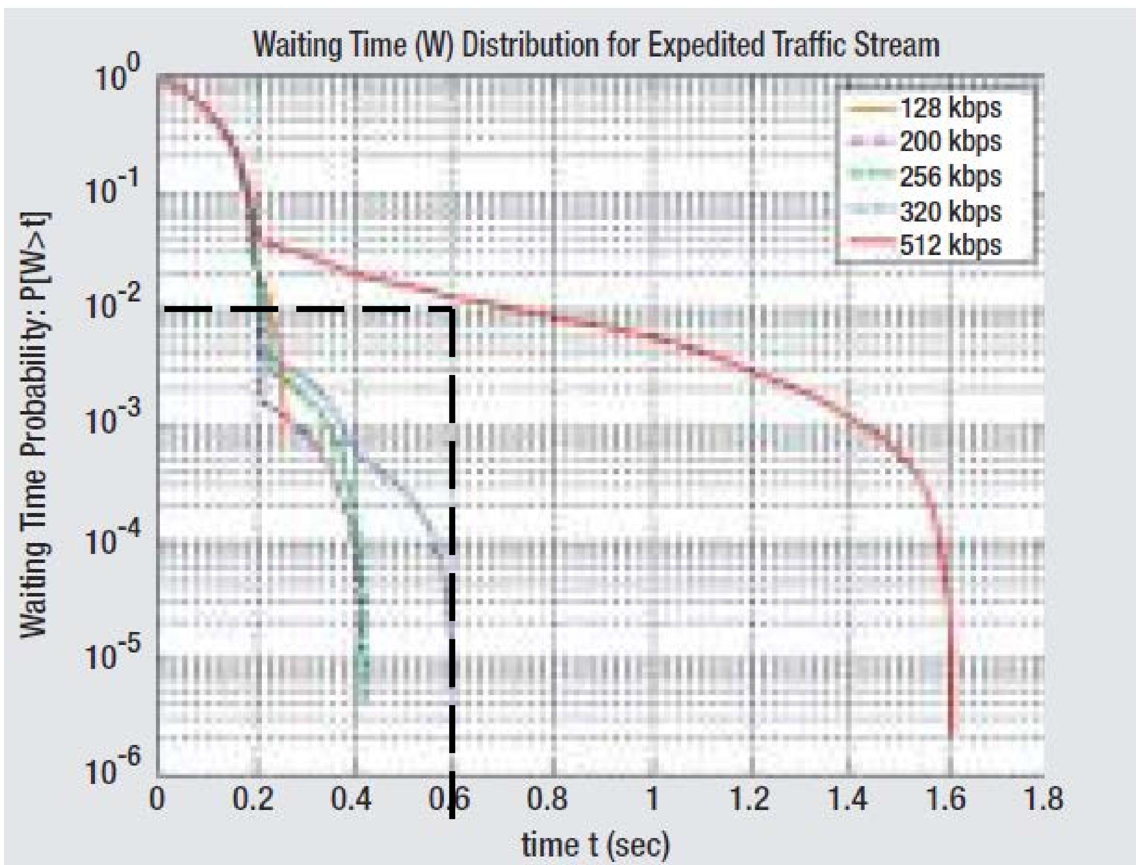
- Started in 2001
- It is a test & evaluation environment containing:
  - Custom tools & libraries
    - CCSDS Protocol Library (extension to QualNet)
    - DTN Protocol Library (extension to QualNet)
    - Additional protocols (extension to QualNet)
    - Link budget libraries (C, Matlab)
    - Telecomm tools (TFPC, TOAST)
  - Commercial tools
    - QualNet
    - Satellite Took Kit (STK)
    - Satellite Orbit Analysis Program (SOAP)

MACHETE: Example Uses

- Mars Relay Scenarios
- Near-Earth Scenarios
- Surface Scenarios
- Distributed testbeds

Proximity-1 Performance Evaluation

- Determined the optimal delay-tolerant data rate w.r.t. QoS requirement on expedited data
- Example: QoS requirement for expedited data is < 0.6 seconds 99% of the time, then the optimal supportable delay-tolerant data rate is found to be 320 kbps
  - Mars proximity access link



CFDP Buffer Requirement

- Determined buffer capacity necessary to achieve specified maximum overflow for CFDP file transfer protocol
- Tolerating a 5% data loss in files (files are 95% complete) will cut down buffer requirement by a factor of 3
  - Mars interplanetary backbone link

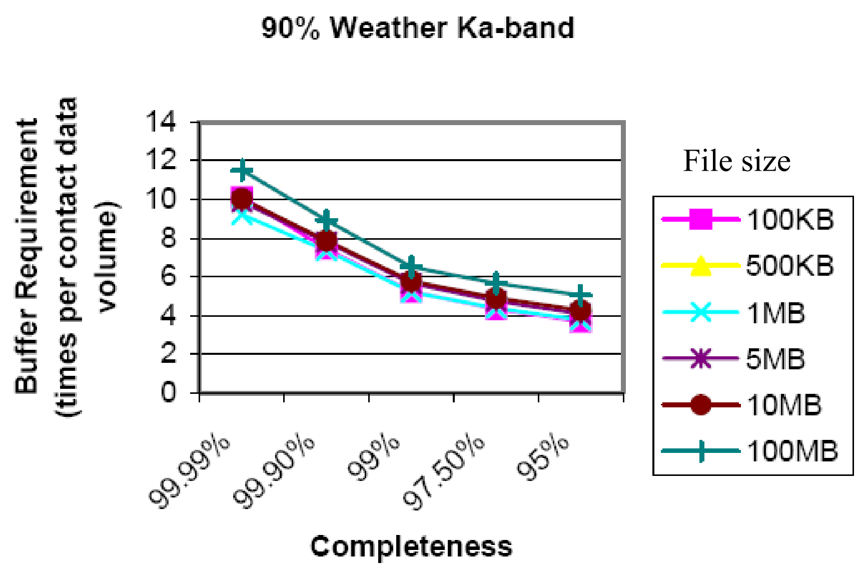
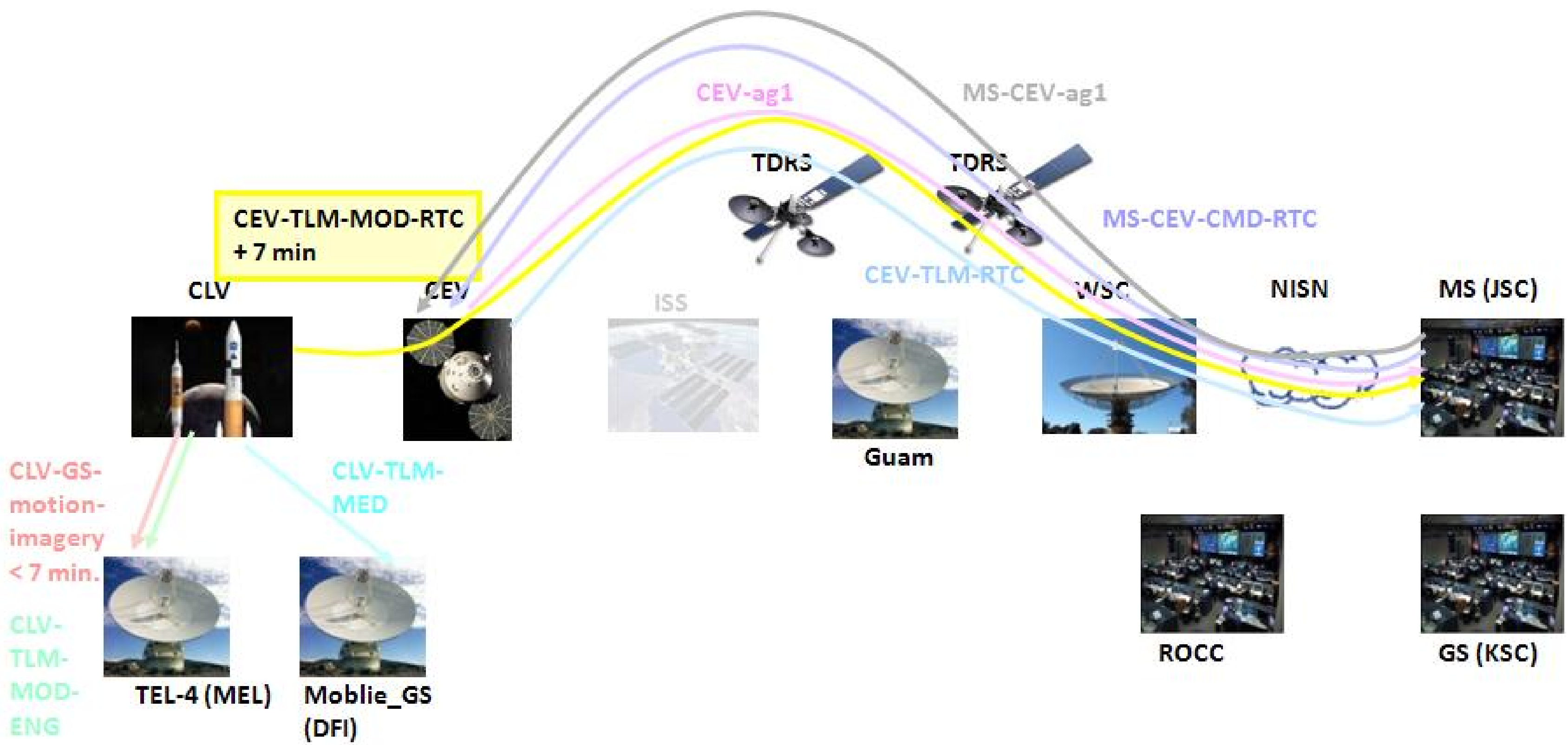


Figure 5: 90% Weather Ka-band Buffer Requirement (1Kbyte PDU)

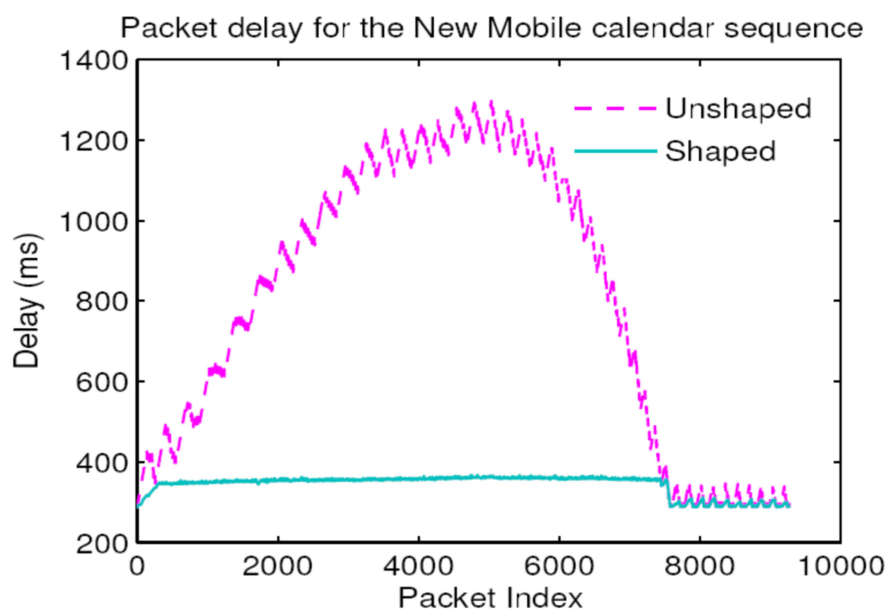
Communications Requirements Validation

- Requirements validation of communications support of mission over different phases
- Simulated nominal ISS mission scenarios and verified supportable data volume against mission requirements for launch/ascent, LEO ops, rendezvous, entry descent return
  - Near-Earth support by Space Communication and Navigation (SCaN) TDRSS network of mission including rendezvous to ISS



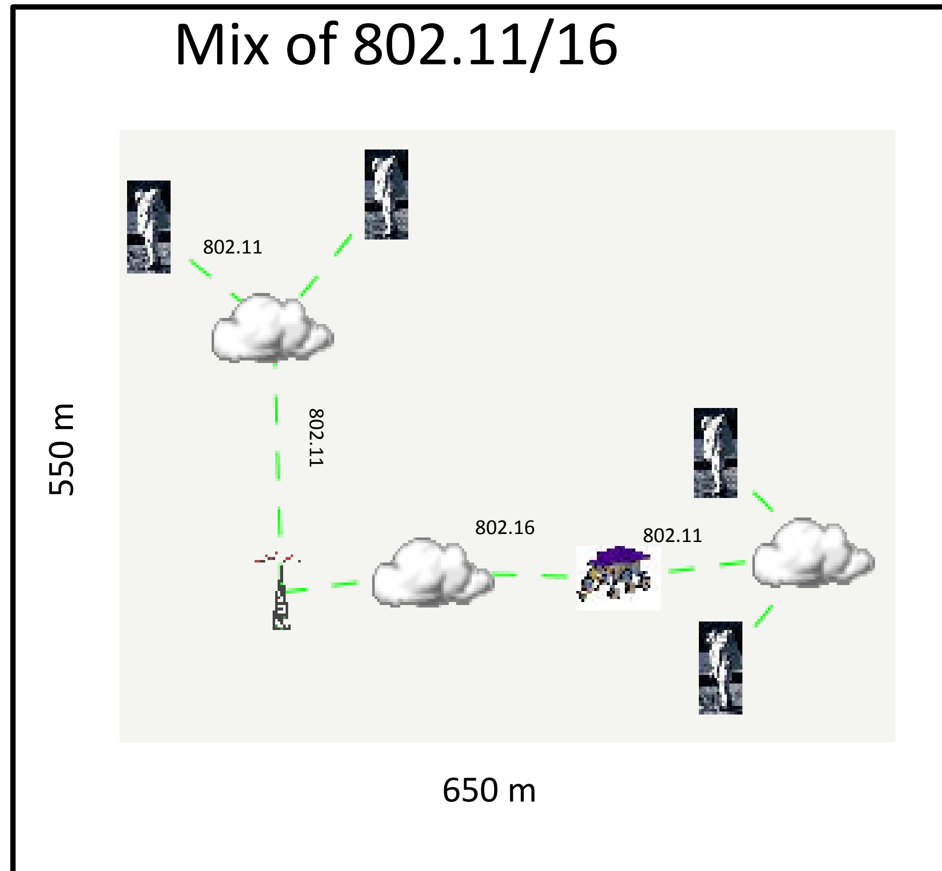
Quality of Service Performance Comparison

- Simulation demonstrated that traffic shaping improves delay and jitter performance for video traffic
- H.264 VBR video delay distribution comparative performance derived for shaped and unshaped cases
  - Low Earth Orbit phase of ISS mission. Data is from CEV to MS.



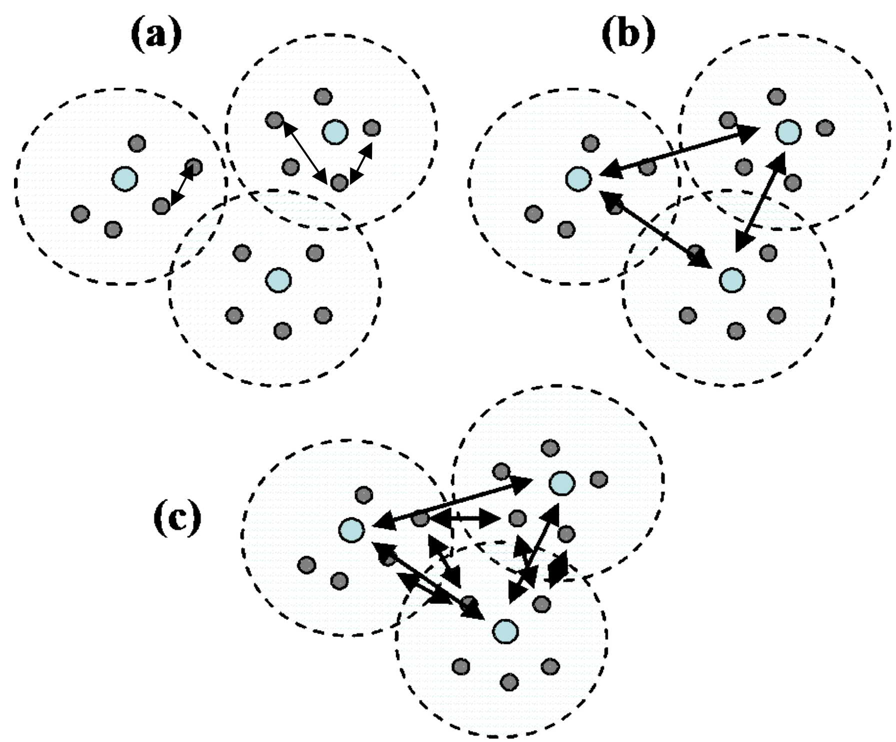
Communications Network Architectural Comparisons

- Compared architectural alternatives for surface network
- Simulated surface networks using
  - 802.11 only
  - 802.16 only
  - Mix of 802.11/802.16
- Applied anticipated traffic profiles (voice, telemetry, command, caution & warning, teleoperations)
- Configured number of nodes, spatial arrangement and topology
- Derive resulting performance for comparisons
- Lunar human exploration surface scenario



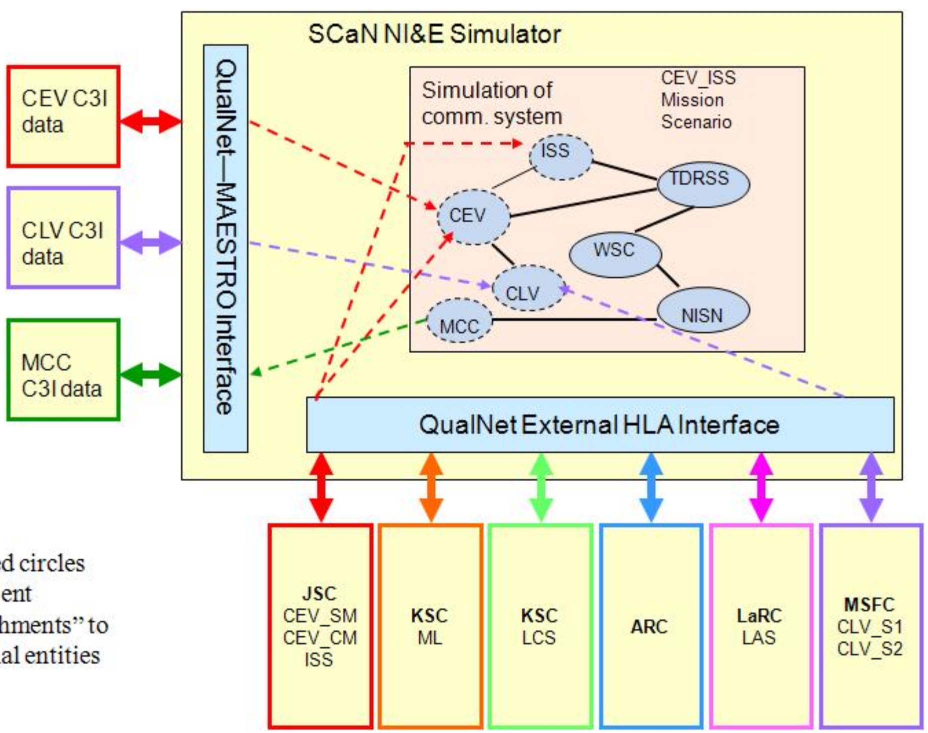
Sensor Networking Architecture Evaluation

- Extended simulation to incorporate modeling of sensing and processing
- Compared sensor networking architecture data fusion methods:
  - (a) Localized: sensors communicate within its own cluster
  - (b) Hierarchical: sensors communicate with its cluster leader; leader communicates with other leaders
  - (c) Distributed: sensors communicate with all other nodes within range
- Performance evaluation combines sensing and communications networking
  - Localized fusion → limited detection capability
  - Hierarchical fusion → takes time to propagate detection to other clusters
  - Distributed fusion → fast detection; increased communication load; more false alarms

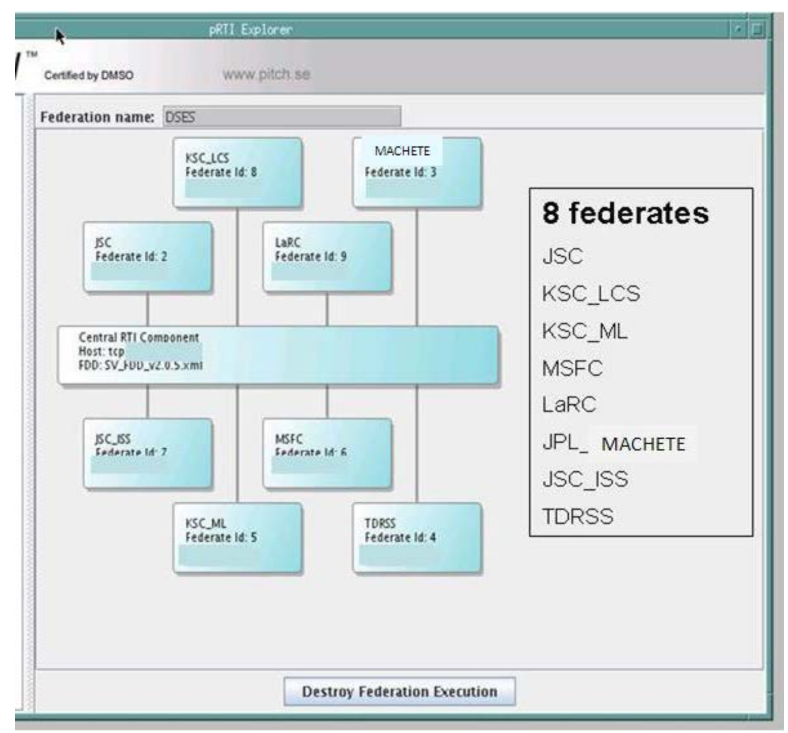


Integration with Distributed Testbed for Interoperability Validation

- Integrated testing of collaborative, distributed simulated or emulated space systems to enable interoperability validation
- HLA framework synchronizes a federation of distributed simulators/emulators across multiple entities and provides global data among the federates (pub/sub)
- A space system (spacecraft, launch control center, etc.) was simulated/emulated with distributed entities among multiple NASA centers for which MACHETE/SCaN Simulator was communications network simulator
  - MACHETE/SCaN Simulator relayed data among federates
  - MACHETE/SCaN Simulator calculated and applied propagation delays for simulated links



Dashed circles represent “attachments” to external entities



Conclusion

- MACHETE environment
  - Leverages the strengths of various specialized tools
  - Supports performance evaluation of network protocols and services in space missions
  - Stand-alone simulation or hybrid simulation-emulation capabilities
  - Has proven successful in NASA's SCaN network architecture evaluation

Acknowledgement

- Software model contribution from NASA Glenn Research Center to SCaN NI&E simulator
- IMSim, DSIL distributed simulation collaboration:
  - Ames Research Center
  - Goddard Space Flight Center
  - Glenn Research Center
  - Johnson Space Center
  - Kennedy Space Center
  - Langley Research Center
  - Marshall Space Flight Center

Backup

Customized Space Protocol Models

- CCSDS:
  - Proximity-1
  - Advanced Orbiting System Virtual Channel (AOS-VC)
  - CCSDS File Delivery Protocol (CFDP)
- DTN:
  - Bundle Protocol (BP)
  - Licklider Transport Protocol (LTP)
  - Routing:
    - Contact Graph Routing (CGR)
    - Delay Tolerant Link State Routing (DTLSR)
- SCaN NI&E Simulator (ver.2)
  - TDRSS model
  - Physical Layer Link Budget Library
  - Traffic generation (audio, video profiles)
  - CCSDS ENCAPS

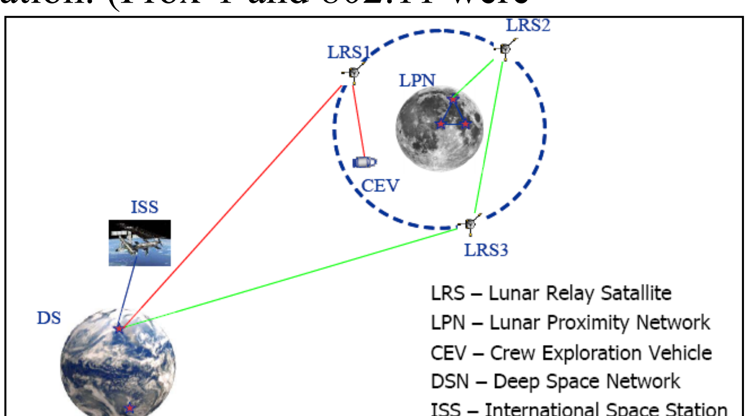
  } JPL

  - CCSDS AOS-MPDU

  } GRC

Distributed: Integrated Testbed for Lunar Mission

- **Problem statement**
  - Space CommunicationsTestbed (viaSat, JPL, GRC, GSFC, LaRC)
  - Demonstrate communications networking for NASA ESMD
  - Scenario: DSN, Lunar Relay Satellites, Lunar Proximity Network, Crew Exploration Vehicle.
- **Method**
  - Tools: MACHETE's network simulator, iperf
  - LPN: 4 astronauts, 2 landers, 1 rover, 1 base station. (Prox-1 and 802.11 were used)



- **Result**
  - Measured end-to-end effective bandwidth
  - Throughput degradation point:
    - At 10 Mbps (passing through network simulator)
    - At 70 Mbps (without network simulator)
  - Main overhead: filtering IP packets between simulator and emulator