Architectural and Operational Considerations Emerging from Hybrid RF-Optical Network Loading Simulations

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BACKGROUND AND OBJECTIVE

Background:

- Demos of Deep-Space Optical Comm are coming
- Operational use of Optical Comm will follow, involving robotic and manned missions
- Deep Space Network (DSN) architecture must evolve to accommodate RF and Optical Missions

In This Paper:

- Present an tool suite capable of modeling RF and Optical missions and ground architectures
- Present Initial attempts at optical architecture simulation
- Highlight a number of open operational issues that need to be addressed

Mission Set Analysis Process Flow

Top Level Block Diagram of Architecture-Oriented Tool Suite

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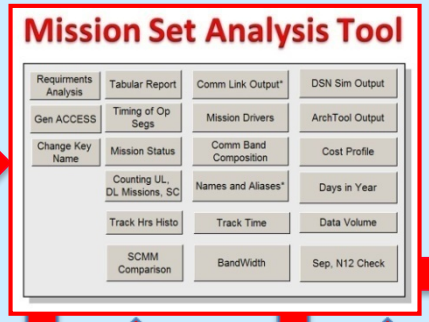
Mission set analysis involves the coordinated application of a suite of specialized tools

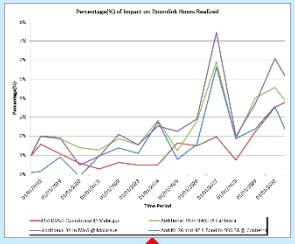
Space Communications Mission Model (SCMM)

Agreed Mission Set Between HQ, JPL, & GSFC. High-level Mission Characteristics

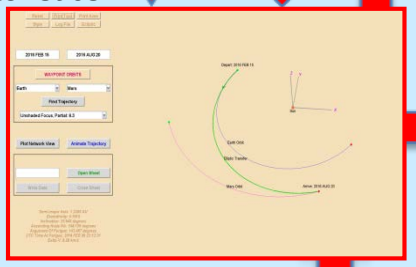
(MSAT)

Detailed Mission & Spacecraft Characteristics; RF Link Analyses



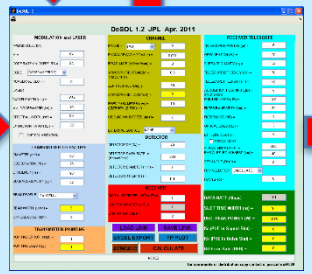


RF Link Requirements & Associated Spacecraft Telecom & Tracking Requirement Data



Orbital Trajectory Inference Engine (OTIE)

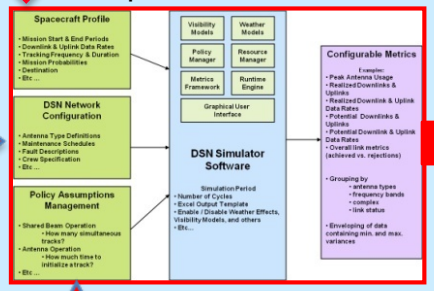
Spacecraft Range Distance, Geometry, and Visibility Relative to Ground Stations as a Function of Time



Strategic Optical Link Tool (SOLT)

Optical Link Parameters / High-Level Link Performance as a Function of Time

Visibility Files



Architecture Loading Analysis Tool (ALAT)

Antenna/Telescope Architecture Loading Simulations

Architecture Loading & Data Traffic Implications

ALAT Overview

Block Diagram of Inputs & Outputs

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Mission Set Profile

- Mission Start & End Periods
- G/T & EIRP Requirements
- Downlink & Uplink Data Rates
- Tracking Frequencies & Durations
- Etc …

Network Architecture Configuration

- Complex & Antenna Definitions
- Antenna Type Definitions
- Transmission Band Specifications
- Network Change Specifications
- Maintenance Schedules
- Etc …

Policy Assumptions Management

- Shared Beam Operation (MSPA & OMSPA)
  - How many simultaneous tracks within a beam coverage?
- Antenna Operation
  - How much time to initialize and close a track?
- Etc…

Architecture Loading Analysis Tool (ALAT)

Visibility Models

Metrics Framework

Policy Manager

Resource Manager

Scheduling Engine

Graphical User Interface

- Simulation Period
- Number of Cycles
- Start and End Dates
- Enable / Disable Flags
  - Arraying
  - MSPA Operation
  - OMSPA Operation
- Etc…

Configurable Metrics

Examples:

- Peak Antenna Usage
- Realized Downlinks & Uplinks
- Realized Downlink & Uplink Data Rates
- Requested Downlinks & Uplinks
- Requested Downlink & Uplink Data Rates
- Overall link metrics (achieved vs. rejections)

- Grouping by
  - antenna types
  - frequency bands
  - complex
  - link status
  - etc…

- Enveloping of data containing min. and max. variances

Scheduled Events Log

- Resource Identification
- Mission Identification
- Tracking Time Period
- Tracking Frequency
- Tracking Data Rate
- Etc…

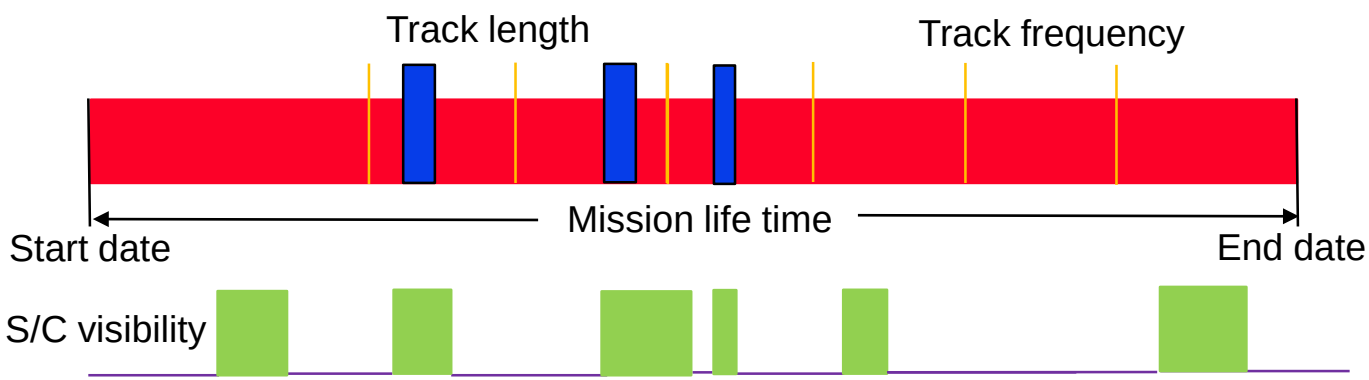
KEY MISSION INPUT CONSIDERATIONS - Mission set object hierarchy:

Mission → Operational Segments → Tracks → Links

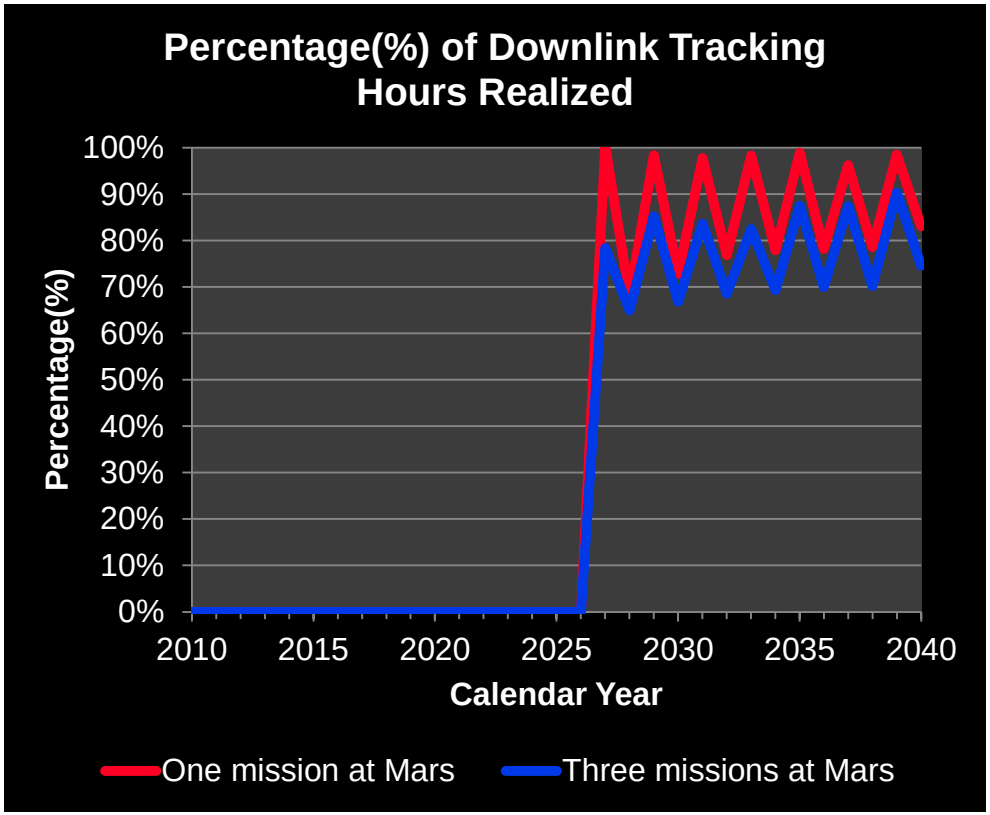
- **MISSION**: Each mission includes multiple operational segments that treat different phases of mission
- **OPERATION SEGMENTS:** Each operational segment defines how the comm system is operated during a period of time.
- **TRACKS** Assigned period of time for a ground asset (antenna) during which an RF communications link is operated
- **LINKS** RF and optical characteristics of a communication period (band, direction, G/T required, etc.)

Combined RF and Optical Architecture Loading Analysis
Rule-Based Scheduling Algorithm

- **For Each Required Track - Create Windows of Opportunity for Scheduling**
  - *Duration of windows from required track frequency*
- **Visible time at a particular site (antenna) determined by spacecraft, planetary and Earth geometry.**
  - *Determine visible times for each window of opportunity, sort from longest to shortest duration.*
- **Create a list of all Antennas that are available and can support the track**
- **If an antenna can meet requirements, assign antenna**
- **If antennas cannot provide full track time, assign a "partial track"**



Example of Optical Link loading analysis



Ground optical antennas
Goldstone (12m)
Canberra (12m)
Madrid (12m)
White Sands (1m)
Table Mountain (1m)
Alice Springs (12m)
Haleakala (12m)
Hartebeesthoek (12m)
La Silla (12m)
Mount Graham (12m)
Palomar(12m)
Tenerife (12m)

Three missions at Mars (a single location in the sky), each requiring two 8-hour tracks per day → contention → less than 100% realized track hours

% Downlink track hours realized = downlink realized track hours/downlink requested track hours *100%

Future Mission Architecture Consideration

- How should we model the operation of a hybrid RF and Optical deep-space comm system? Knowledge for operational Optical Comm is scarce
- Operational Issues:
  - How will Optical Missions be designed?
    - Optical for more data OR same data and less track time
    - Optical only missions (lower cost) OR hybrid RF/Optical missions (reliability)
    - Optical Uplink (large data volume, tech issues) OR RF Uplink (reliability)
  - How will Optical Missions be operated?
    - Weather Outage
      - Weather diversity on the ground OR RF comm backup AND/OR large spacecraft data buffers

DSN Architecture issues with optical links

- How will Optical Missions be operated (con't)?
  - SEP/SPE Outage (Sun/Mars conjunction)
    - RF backup AND Reduced Science Data
  - Navigation
    - Optical Ranging OR RF Ranging, Doppler and DDOR OR Both
  - Human Missions (Mars?)
    - Will human missions be different? Fully capable, redundant RF and Optical systems for reliability, data volume OR primarily optical OR optical only, 24/7 coverage?
- How will Ground Assets be operated?
  - Separate RF and Optical ground networks OR hybrid RF/Optical receivers (lower cost but potential scheduling contention)
  - Weather diversity in the Optical Network OR RF weather backup

Conclusions

- We have the technical capability to model hybrid deep-space RF and Optical communications networks, but …
- We have little guidance on how the missions and ground architectures will be designed and operated.
  - We exposed several issues that must be resolved before an optimal solution can be reached.
- With future studies, we may be able to determine solutions to these issues, and perform more precise loading performance analyses to arrive at the most optimal RF and optical ground assets combinations for meeting the projected future demand
- The results will then help inform NASA as it plans for infrastructure development to prepare for human/robotic missions in the coming decades