NASA’s Evolution to Ka-band
Space Communications
for Near-Earth Spacecraft

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Agenda

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- Potential Solutions
- Coverage and Loading Analysis
- Recommended Solution
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  - Proposed Space and Ground Assets
  - Spectrum Plan
  - Link Analysis
  - Propagation Impairments
  - Near-Earth Network (NEN) Ground Station Antennas Systems
  - Wide Area Network (WAN)
- Technology Considerations
- Future Considerations
- Summary
Introduction

- NASA has explored a Ka-band system design for near-Earth communications
- Motivations for Ka-band operation:
  - Higher data rates (exceeding X-band spectrum capabilities)
  - X-band spectrum crowding
- Multiple Ka-band missions flying today...
  - Lunar Reconnaissance Orbiter (LRO)
    - 100 Mbps through 18.3m WS1 antenna at White Sands Complex (WSC)
  - Advanced Land Observing Satellite (ALOS)
    - 277.52 Mbps through Tracking and Data Relay Satellite (TDRS) to WSC
  - Solar Dynamics Observatory (SDO)
    - 150 Mbps through dedicated 18.3m assets at WSC

... But future missions will need higher data rates (1 Gbps+) and expanded infrastructures
- Evolution to Ka-band for near-Earth missions has been expected
  - Ka-band capabilities will enable a new class of earth and space science missions
- Funding to begin formulation in FY2011 has been requested from the Space Communication and Navigation (SCaN) program office, the responsible program office at NASA Headquarters
Reference Mission Requirements

- DESDynI, SWOT, and HyspIRI missions recommended by National Research Council’s 2007 decadal survey have significant daily data volume requirements, motivating 1 Gbps+ downlinks
- These three missions served as references for developing a near-Earth Ka-band communications capability
- HyspIRI’s needs could be satisfied with a dual-polarization X-band solution

DESDynI
To study geologic hazards and global environmental change
Launch: 2015 – 2018+

Orbit:
• 760 km altitude
• 98° inclination
• Sun-synchronous (Dsc Node 1100)

Data Volume (w/ Compression):
• ~40 Tbits of data per day

Contact Requirements (@ 1 Gbps):
• ~667 minutes per day
• ~45 minutes per orbit

SWOT
To study both land hydrology and oceanography
Launch: 2016 – 2020+

Orbit:
• 970 km altitude
• 78° inclination

Data Volume (w/ Compression):
• ~7.2 Tbits of data per day

Contact Requirements (@ 1 Gbps):
• ~120 minutes per day

HyspIRI
To study global surface reflectance, temperature, and emissivity
Launch: 2015 – 2020+

Orbit:
• 626 km altitude
• 98° inclination
• Sun-synchronous (Asc Node 1800)

Data Volume (w/ Compression):
• ~3.5 Tbits of data per day

Contact Requirements (@ 1 Gbps):
• ~60 minutes per day

Additional Potential Ka-band Missions

<table>
<thead>
<tr>
<th>GEO-CAPE</th>
<th>ACE</th>
<th>VEGBIOM</th>
<th>LEOMAC</th>
<th>PATH</th>
<th>SCLP</th>
<th>COPS</th>
<th>Future HSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOMAC</td>
<td>ACE-Core</td>
<td>ACOB-A</td>
<td>LIST</td>
<td>GRACE-II</td>
<td>EXIST</td>
<td>GACM</td>
<td>Future Suborbital</td>
</tr>
</tbody>
</table>
Tracking and Data Relay Satellites (TDRS) are arrayed in three regions:
- Atlantic Ocean Region
- Pacific Ocean Region
- Indian Ocean Region
## Potential Solutions

<table>
<thead>
<tr>
<th>Option</th>
<th>Considerations</th>
</tr>
</thead>
</table>
| NASA Near Earth Network (NEN) | • Leverage existing “WS1” 18.3m Ka-band asset at WSC with upgrades  
• Entails establishing new Ka-band assets and integrating into NEN  
• Locations for new assets to be determined by multiple criteria (coverage, rain attenuation, operational costs, backhaul costs, existing infrastructure, etc.) |
| NASA Space Network (SN)       | • Leverage Ka-capable satellites:  
  – TDRS-8/9/10 (on-orbit)  
  – TDRS-K/L (on-order, to be launched 4/2012 and 2/2013, respectively)  
  
1-Node Solution  
• Risk-reduction/fallback solution from 2-node solution, to mitigate against TDRS launch slip/failure or SN upgrade schedule slips  

2-Node Solution  
• Greater coverage than 1-node solution  
• Avoids costly WAN bandwidth upgrade from Guam (required for 3-node solution)  

3- Node Solution  
• Worth considering if 2-node solution would not satisfy mission requirements  
• Would require potentially cost-prohibitive WAN bandwidth upgrade from Guam |
| NOAA NPOESS SafetyNet         | • Leverage 15-station Ka-band infrastructure investment for operational weather satellites by sharing capacity between NOAA and NASA |
SafetyNet

- NOAA’s National Polar-orbiting Operational Environmental Satellite System (NPOESS) SafetyNet network of 15 Ka-capable ground stations potentially offers a large infrastructure to support earth and space science missions
  - NPOESS is being reformulated to support planned new Joint Polar Satellite System (JPSS)

Constraints:
- Small asset size (4m) reduces G/T (~10 dB) vs. 12m antennas proposed in alternative solution
  - Would require redesigning SWOT spacecraft antenna system
- 150 Mbps receivers would require upgrades to support 1 Gbps
- Limited backhaul connectivity (~45 Mbps)
- Scheduling conflicts with primary SafetyNet mission constrain availability for NASA missions
- Limited expansibility
- Cannot supply sufficient contact time for DESDynI (667 minutes/day)
  - Even with all 15 stations and 1 Gbps downlink rate (!)

SafetyNet option was not recommended
## Options: Mission Support and Recommendation

<table>
<thead>
<tr>
<th>Option</th>
<th>DESDynI</th>
<th>HyspIRI</th>
<th>SWOT</th>
<th>Other Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEN</td>
<td>Would require unreasonably large number of stations</td>
<td>Mission requirements can be met with 2 or more Ka-band ground systems</td>
<td>Mission requirements can be met with 2 or more Ka-band ground systems</td>
<td>If DESDynI launch should slip past 2015, a 3 Gbps solution could potentially be used to meet mission requirements</td>
</tr>
</tbody>
</table>
| SN               | 2-node and 1-node solutions could satisfy requirements | SN can satisfy mission requirements, although a NEN solution can do so more easily | Need to minimize antenna size to limit spacecraft jitter induced by antenna movement | • Large burden on spacecraft vs. ground  
• More expensive than ground solution |
| NPOESS SafetyNet | Does not satisfy daily contact requirement | Requires upgraded receivers, ground connectivity | Impact to S/C antenna system; requires upgraded receivers, ground connectivity | • Schedule conflicts with primary SafetyNet mission  
• Limit availability for NASA missions  
• Limited expansibility |

Recommendation: Apply NEN and SN as best suited for each mission  
Cost-effectively leverages each network’s strengths and offers maximum extensibility
Coverage and Loading Analysis

<table>
<thead>
<tr>
<th>SN Support Scenario</th>
<th>DESDynI Priority</th>
<th>Contact time (average minutes/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 satellites (TDE, TDW)</td>
<td>&lt; HST, Terra</td>
<td>668</td>
</tr>
<tr>
<td>1 satellite (TDE)</td>
<td>&gt; HST, Terra</td>
<td>691</td>
</tr>
<tr>
<td>1 satellite (TDE)</td>
<td>&lt; HST, Terra</td>
<td>640</td>
</tr>
<tr>
<td><strong>Mission Requirement</strong></td>
<td></td>
<td><strong>667</strong></td>
</tr>
</tbody>
</table>

HST = Hubble Space Telescope.
Nominal spacecraft antenna configuration assumed for these approximate results.
Potential second antenna aboard spacecraft, for ground terminal operation, was not included.

<table>
<thead>
<tr>
<th>NEN Station</th>
<th>SWOT</th>
<th>HyspIRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>51.9</td>
<td>21.2</td>
</tr>
<tr>
<td>Svalbard</td>
<td>55.1</td>
<td>27.5</td>
</tr>
<tr>
<td>Wallops</td>
<td>6.9</td>
<td>13.3</td>
</tr>
<tr>
<td>White Sands</td>
<td>16.6</td>
<td>7.9</td>
</tr>
<tr>
<td>McMurdo</td>
<td>66.6</td>
<td>55.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>197.1</td>
<td>125.6</td>
</tr>
</tbody>
</table>

Mission Requirements

Analysis results are based on expected orbital parameters

- Required contact times could be reduced with data rates greater than 1 Gbps

Analysis confirms viability of SN-based solution for DESDynI and NEN-based solution for SWOT and HyspIRI
**Recommended Solution:**
*Proposed Ka-band Assets*

**Location Selection Criteria**
- Coverage
- Rain attenuation
- Operational costs
- Backhaul costs
- Existing infrastructure

**Asset Information**
- **SN assets:**
  - 2 TDRS spacecraft in Atlantic and Pacific Ocean Regions supported by WSC
- **5 NEN assets:**
  - 12+ m assets (new) at Alaska, Wallops, Svalbard
  - 18.3 m WS1 asset (existing) at White Sands, upgraded to accommodate higher data rates
  - 5.4m asset (under development) at McMurdo, with additional back-end equipment to support higher data rates, and refurbished McMurdo-TDRS Relay System 2 (MTRS-2) link
Recommended Solution: Proposed Ka-band Spectrum Plan

Proposed Ka-band spectrum plan provides NASA missions with adequate protection from interference with NPOESS. Potential interference between NASA Ka-band missions (e.g., SDO, Cx, JWST) can be accommodated through scheduling.

1 The proposed NASA Ka-band Network will procure antennas that have dual polarization capability, allowing for both LHC and RHC.
**Recommended Solution:**

**Link Analysis Summary**

<table>
<thead>
<tr>
<th>Mission</th>
<th>SN</th>
<th>Alaska (12m)</th>
<th>Svalbard (12m)</th>
<th>Wallops (12m)</th>
<th>WS1 (18.3m)</th>
<th>McMurdo (5.4m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESDynI</td>
<td>M = 2 dB N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>(1 Gbps, OQPSK, Rate-7/8 LDPC) – EIRP to SN = 60.3 dBW</td>
<td>AA = 99%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWOT</td>
<td>N/A</td>
<td>M = 3 dB N/A</td>
<td>M = 4.7 dB N/A</td>
<td>M = 3 dB N/A</td>
<td>M = 4.9 dB N/A</td>
<td>M = 3 dB N/A</td>
</tr>
<tr>
<td>(1 Gbps, OQPSK, Rate-7/8 LDPC) – EIRP to NEN = 28.8 dBW</td>
<td>AA = 99% EA = 10 deg</td>
<td>AA = 99% EA = 10 deg</td>
<td>AA = 95% EA = 12.1 deg</td>
<td>AA = 99% EA = 10 deg</td>
<td>AA = 99% EA = 17.5 deg</td>
<td></td>
</tr>
<tr>
<td>HyspIRI</td>
<td>N/A</td>
<td>M = 3 dB N/A</td>
<td>M = 4.7 dB N/A</td>
<td>M = 3 dB N/A</td>
<td>M = 4.9 dB N/A</td>
<td>M = 3 dB N/A</td>
</tr>
<tr>
<td>(1 Gbps, OQPSK, Rate-7/8 LDPC) – EIRP to NEN = 26.2 dBW</td>
<td>AA = 99% EA = 10 deg</td>
<td>AA = 99% EA = 12 deg</td>
<td>AA = 99% EA = 10 deg</td>
<td>AA = 99% EA = 10 deg</td>
<td>AA = 99% EA = 16 deg</td>
<td></td>
</tr>
</tbody>
</table>

- **DESDynI:**
  - Ground-based solution would require unreasonably many antennas (>15) to provide sufficient contact time
  - TDRS solution can support required contact time

- **SWOT, HyspIRI:**
  - Link closure to TDRS deemed infeasible
  - NEN-based solution suffices
  - NEN availability target reduced and/or elevation angle increased for Wallops and McMurdo sites to obtain desired 3 dB link margin

**Combination of SN and proposed NEN Ka-band network can satisfy mission requirements with viable RF link designs**
Ka-band propagation impairments include rain attenuation, cloud attenuation, gaseous absorption, and scintillation fading.

New Ka-band NEN antennas will be designed to support orthogonal polarizations, so cross-polar discrimination (XPD)—a measure of the polarization isolation—is a concern as well.

Literature survey and analysis were conducted to investigate these phenomena.

Analysis results (@ 26 GHz; based on ITU-R Recommendation P.618-9):

<table>
<thead>
<tr>
<th>Ground Station Information</th>
<th>95%</th>
<th>97%</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name, Latitude, Longitude, Height above MSL</td>
<td>Elevation Angle (°)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fairbanks, AK 65.974° N 147.512° W 549.0 m</td>
<td>5</td>
<td>1.32</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.77</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.57</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.46</td>
<td>0.48</td>
</tr>
<tr>
<td>Svalbard, Norway 78.23072° N 32.5425° E 1485 m</td>
<td>5</td>
<td>0.71</td>
<td>1.87</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.40</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.29</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.23</td>
<td>0.50</td>
</tr>
<tr>
<td>White Sands, NM 32.5425° N 106.6121° W 1485 m</td>
<td>5</td>
<td>3.18</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1.68</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1.40</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.15</td>
<td>0.55</td>
</tr>
<tr>
<td>Wallops Island, VA 37.9235° N 75.4761° W 4.3 m</td>
<td>5</td>
<td>4.12</td>
<td>4.02</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2.54</td>
<td>2.07</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1.93</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.60</td>
<td>1.06</td>
</tr>
<tr>
<td>McMurdo, Antarctica 77.83913° S 193.333° E 206.4 m</td>
<td>5</td>
<td>0.02</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.01</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.01</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.00</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Key conclusions:
- Careful attention must be paid to the axial ratios of both the transmitting and receiving antennas.
- Snow accumulation on radomes should be reasonably managed but does not significantly reduce polarization isolation.
- Ice particles and freezing rain can reduce polarization isolation.
June 2009 Request for Information (RFI):
- Obtain technical and costing information from industry in response to draft Ka-Band antenna system requirements

Key antenna system requirements (based on link calculations):
- Aperture size >=12m
- Continuously track LEO satellites >= 500 km above the earth
- Ka-band:
  - Simultaneous LHCP and RHCP receive
  - G/T: 42.7 dB/°K
- S-Band:
  - Simultaneous LHCP and RHCP receive
  - G/T: 23 dB/°K
  - Transmit EIRP: 63 dBW

Conclusion (based on RFI responses):
Three-axis antenna system requirements are reasonable and technically achievable by industry
Recommended Solution: 
Wide Area Network

- NASA Integrated Services Network (NISN) infrastructure will service missions’ WAN needs
- Bandwidth requirements for transferring daily data volumes for 3 reference missions studied:
  - 490.1 Mbps: minimum needed for transferring expected daily volumes
  - 735.1 Mbps: includes recommended 50% margin
    - Margin allows for recovering from data transfer reduction or disruption due to equipment outages, retransmissions, or unforeseen issues
- All NEN sites, except for McMurdo, lie on NISN WAN sites, enabling low-cost service by expanding upon existing requirements
- For McMurdo, NASA proposes to refurbish the McMurdo-TDRS Relay System-2 (MTRS-2)
  - 300 Mbps-capable ground station
  - Data is returned through TDRS to WSC
  - Ka-band transmission to TDRS will be needed to support NEN customer missions’ high data rates

Enhanced NISN infrastructures and refurbished MTRS-2 will economically satisfy the proposed Ka-band network’s WAN requirements
Technology Considerations

- Key considerations affecting technology selection:
  - Capability
  - Maturity

- Spacecraft elements:
  - On-board data storage: Multi-terabit space-qualified systems are available
  - Coding (error protection): Hardware supporting 600 Msps for each I & Q channel has been demonstrated
  - Compression: Available
  - Modulator: Space-qualified high-rate modulator (1.0+ Gbps) forecasted to exist in time for reference missions considered
  - Amplifiers (TWTA): Ka-band flight-heritage amplifiers available
  - Physical link components: Flight-heritage S- and Ka-band components available

- Ground segment elements:
  - Antennas: Ka-band systems (12-14 m) available
  - Radomes: Available
  - SN ground receivers: Planned for procurement (subject to funding)
  - NEN ground receivers: 1 Gbps receivers currently commercially available

No significant technology impediments to achieving 1 Gbps Ka-band communication
Future Considerations

➤ Technology Insertion
   – Selective retransmission, e.g. CCSDS File Delivery Protocol (CFDP)
     • LRO experience indicates prudence of protocol-based recovery for weather-induced data losses
       – LRO employs CFDP; no science (Ka-band) data lost since June 2009 launch
         (>1700 LRO supports, >1800 hours of communications)
   – CCSDS Space Link Extensions (SLE)
     • Promotes commonality and international interoperability at the link layer
   – Delay/Disruption Tolerant Networking (DTN)
     • Enables standardized network layer cross support

➤ Expansibility Options
   – Additional antennas, as needed
   – Potential partnerships with other space agencies, commercial providers
   – Dual-polarization Ka-band reception (1.5 Gbps per polarization) could provide 3 Gbps downlink
     • Single-polarization initial deployment meets currently-known mission requirements and allows deferring investments until needed

The recommended solution allows for expanding coverage, daily volume, and availability
Recommended Solution: Reference Diagram

• KaSA return service for high rate science data (up to 1 Gbps, OQPSK, Rate 7/8 LDPC)
• Low rate S-band TT&C support

S-band (LEOP & Emergency)

• Ka-band direct downlink (up to 1 Gbps, OQPSK, Rate-7/8 LDPC) for high rate science data
• Low rate S-band cmd and tim

S/Ka-Band Ground Terminals

• S-band transmit/receive and Ka-band receive ground terminal
• Terminals in each of the following locations: ASF, Svalbard, Wallops, and WS1

EDOS

White Sands Complex

A combination of SN and NEN capabilities will jointly satisfy high-data-rate Ka-band missions
Future Earth- and space-science missions will need Ka-band communications to support their extremely high data rates

SN Ka-band communication feasible today; upgrades to support high data rates are planned

NEN Ka-band capabilities can be implemented using COTS technology in time to support upcoming high-data-rate missions

Proposed Ka-band architecture leverages existing assets, where possible, to contain costs

Continued cooperation between NASA’s Science Mission Directorate and SCaN will ensure developing Ka-band communications capabilities to support upcoming spacecraft missions

The proposed Ka-band network will:
  – Enable studying Earth and space phenomena in unprecedented detail
  – Help answer scientific questions important to society