ASSESSMENT OF EMERGING NETWORKS TO SUPPORT FUTURE NASA SPACE OPERATIONS

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Introduction

• New types of global commercial satellite systems are currently under development and expected to start providing service in 1998
  – Global communication coverage
  – Mobile communication capability
  – High speed networking

• NASA GSFC is investigating the feasibility of using emerging commercial satellite systems to support NASA LEO missions
  – Reduce mission cost
  – Enhance or maintain level of service provided by TDRSS and GN
• Examines technical and operational issues related to supporting a NASA LEO satellite with commercial satellite systems
• Four commercial satellite systems are addressed in this presentation
  – Mobile Satellite Service (MSS): Iridium, ICO (1st gen)
  – Fixed Satellite Service (FSS): Spaceway, Teledesic

**Evaluation Approach**

• Communications Coverage: Geometric coverage time minus system acquisition and service acquisition time.
  – Accounts for time required for handoff
  – Accounts for dropped calls due to handoff failure

• NASA user terminal assessment including spacecraft G/T, EIRP and operational constraints relating to system acquisition, service acquisition and handoff

• Regulatory assessment
Assumptions

- No modifications will be made to commercial satellite systems to support NASA missions.
  - NASA LEO satellite will emulate a ground-based user
- User spacecraft tracking will not be performed by the commercial satellite systems.
  - Future NASA missions will incorporate on-board GPS equipment
- All evaluations of the commercial satellite systems are based on public information obtained from FCC filings

NASA LEO
Missions Overview

- NASA missions operate in a number of different orbits that depend on the mission type
  - Launch vehicles at approximate altitudes of up to 350 km
  - Suborbital missions at altitudes less than 40 km
  - Manned space flight at altitudes of 300 - 600 km altitude and inclinations of 28° - 57°
  - Astrophysics missions at altitudes of 400 - 600 km altitude and inclinations of 23° - 35°
  - Earth science missions at altitudes of 350 - 1,350 km and inclinations of 35° - 99°
- Considered missions scheduled through 2014
- Data requirements range from 1 kbps to 600 Mbps
  - Telemetry and Command: 1 kbps to 2 Mbps
  - Payload data: 1 kbps to 600 Mbps
### NASA LEO Missions Overview

#### Orbital Characteristics

#### Commercial Satellite Systems

#### Summary

<table>
<thead>
<tr>
<th>System</th>
<th>Orbit Type/Service Type</th>
<th>BER</th>
<th>Frequency (MHz)</th>
<th>Service Data Rate (kbps)</th>
<th>ISL Frequency (GHz)</th>
<th>Orbit Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indium&lt;sup&gt;1&lt;/sup&gt;</td>
<td>LEO MSS</td>
<td>10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1816-1826.5</td>
<td>2.4</td>
<td>23.16-23.38</td>
<td>66 700 80.4°</td>
</tr>
<tr>
<td>ICO&lt;sup&gt;1&lt;/sup&gt;</td>
<td>MEO MSS</td>
<td>10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.565-2.015</td>
<td>38.4</td>
<td>N/A</td>
<td>10-12 10,355 45°</td>
</tr>
<tr>
<td>Teledos&lt;sup&gt;1&lt;/sup&gt;</td>
<td>LEO FSS</td>
<td>10&lt;sup&gt;4&lt;/sup&gt;</td>
<td>17.8-18.6</td>
<td>n°16 (n=1...128)</td>
<td>65.71</td>
<td>288 1800 84.7°</td>
</tr>
<tr>
<td>Spaceway&lt;sup&gt;1&lt;/sup&gt;</td>
<td>GEO FSS</td>
<td>10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>17.7-20.2</td>
<td>92,000</td>
<td>22.55-23.55</td>
<td>20 35,786 0°</td>
</tr>
</tbody>
</table>

**Notes:**
1. Systems use intersatellite links and onboard data processing.
Simulation Assumptions

- Geometrical coverage determined through Communications Analysis Graphical Environment (CAGE) simulation
  - Ten day orbit simulation
  - Commercial satellite user antenna beam modeled as a single conic
- Communications coverage determined through CAGE simulation
  - 30 random user satellite orbit periods
  - User satellite is positioned at a randomly selected accession angle prior to each simulation pass
  - User antenna beam modeled at sub-beam level
  - System acquisition time based on IS95 specification (16.3 sec)
  - Service acquisition time based on IS95 specification (20.0 sec)
  - Handoff time based on existing ground based cellular system performance (12 s)

Simulation Results

- Emerging commercial satellite systems are designed for users at or near ground level. Communications coverage at LEO altitudes is constrained.
  - Reduced communications coverage exist at LEO altitude due to the conic shape of the radiating antenna
  - Beam-to-beam handoff for a LEO spacecraft will experience a higher call drop probability than a terrestrial user due to user spacecraft velocity (12 km/sec)
- None of the evaluated systems is capable of supporting the real time communications coverage requirements of manned space flight missions and launch vehicles
- Iridium and Teledesic provide the least communications coverage
  - Orbits similar to NASA LEO spacecraft
  - Less than 1% communications coverage for user altitudes > 500 km
- ICO provides higher communications service duration and data throughput
  - Service availability 20% - 40% for user altitudes > 500 km
- Spaceway (GEO) provides highest communications service duration and data throughput
  - Service availability is greater than 35% for user altitudes > 500 km
  - NASA LEO satellite must support beam-to-beam handoff (not available on FSS)
Communications Coverage - IRIDIUM

IRIDIUM Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1 200 km</th>
<th>Case 2 300 km</th>
<th>Case 3 200 km</th>
<th>Case 4 300 km</th>
<th>Case 5 300 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV Coverage (%)</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Average Number (per channel)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Maximum Call Duration (seconds)</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
</tr>
<tr>
<td>Maximum Call Duration (%)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Service Failure Probability (%)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>SFM Failure Probability (%)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

NOTES:
1. The estimated mean sub-beam FOV time (see) for Cases 1 through 5 as follows: 1) 21.9 seconds, 2) 11.4 seconds, 3) 11.4 seconds, 4) 11.4 seconds, 5) 11.4 seconds.
2. The estimated mean sub-beam overlap time (see) for Cases 1 through 5 as follows: 1) 3.0 seconds, 2) 3.0 seconds, 3) 3.0 seconds, 4) 3.0 seconds, 5) 3.0 seconds.
3. 4-spot beams per IRIDIUM array.

Communications Coverage - ICO

ICO Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1 300 km</th>
<th>Case 2 700 km</th>
<th>Case 3 300 km</th>
<th>Case 4 700 km</th>
<th>Case 5 300 km</th>
<th>Case 6 700 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV Coverage (%)</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
<td>10.4</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Average Number (per channel)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Maximum Call Duration (seconds)</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
</tr>
<tr>
<td>Maximum Call Duration (%)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Service Failure Probability (%)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>SFM Failure Probability (%)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

NOTES:
1. The estimated mean sub-beam FOV time (see) for Cases 1 through 5 as follows: 1) 63.7 seconds, 2) 57.8 seconds, 3) 53.2 seconds, 4) 53.2 seconds, 5) 53.2 seconds.
2. The estimated mean sub-beam overlap time (see) for Cases 1 through 5 as follows: 1) 17.2 seconds, 2) 15.6 seconds, 3) 14.4 seconds, 4) 14.4 seconds, 5) 14.4 seconds.
3. 4-spot beams per ICO array.

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Communications Coverage - Teledesic

Teledesic Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1 300 km, 28.5 deg</th>
<th>Case 2 500 km, 25.5 deg</th>
<th>Case 3 700 km, 28.5 deg</th>
<th>Case 4 500 km, 57.5 deg</th>
<th>Case 5 700 km, 99.5 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fov Coverage (%)</td>
<td>97.4</td>
<td>90.4</td>
<td>84.0</td>
<td>73.3</td>
<td>30.3</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>0.5</td>
<td>0.8</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Average Service Duration (seconds)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Average Non-Duration (seconds)</td>
<td>4.0</td>
<td>1.5</td>
<td>0.9</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum Net Duration</td>
<td>40.0</td>
<td>35.0</td>
<td>30.0</td>
<td>25.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Call Drop Rate (%)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

NOTES:
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 6.7 seconds, 2) 5.2 seconds, 3) 3.8 seconds, 4) 5.2 seconds, 5) 3.8 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 1.8 seconds, 2) 1.4 seconds, 3) 1.0 seconds, 4) 1.4 seconds, 5) 1.0 seconds.
3. 64 spot beams per Telesdesic satellite.

Communications Coverage - Spaceway

Spaceway Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1 300 km, 28.5 deg</th>
<th>Case 2 500 km, 25.5 deg</th>
<th>Case 3 700 km, 28.5 deg</th>
<th>Case 4 500 km, 57.5 deg</th>
<th>Case 5 700 km, 99.5 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fov Coverage (%)</td>
<td>97.2</td>
<td>90.4</td>
<td>84.0</td>
<td>73.3</td>
<td>30.3</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>0.5</td>
<td>0.8</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Average Service Duration (seconds)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Average Non-Duration (seconds)</td>
<td>4.0</td>
<td>1.5</td>
<td>0.9</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum Net Duration</td>
<td>40.0</td>
<td>35.0</td>
<td>30.0</td>
<td>25.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Call Drop Rate (%)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

NOTES:
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 154.0 seconds, 2) 149.0 seconds, 3) 144.0 seconds, 4) 149.0 seconds, 5) 144.0 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 41.6 seconds, 2) 40.1 seconds, 3) 38.7 seconds, 4) 40.1 seconds, 5) 38.7 seconds.

Spaceway FOV Coverage at 300 km altitude

Spaceway FOV Coverage at 700 km altitude
User Terminal Assessment

• NASA LEO spacecraft will require a smaller terminal than TDRSS, for MSS, systems due to MSS LEO and MEO constellations

• FSS systems do not provide NASA LEO spacecraft any substantial terminal size advantage over TDRSS
  - GEO systems are designed to support ground users and require a high G/T and EIRP to support high burst rate TDMA

• Large number of satellites in commercial constellations will increase NASA spacecraft memory and processing burden
  - Need to determine when and where data can be transmitted

• Additional processing burden for NASA satellites
  - Doppler correction, power management, burst transmission management (TDMA), and beam-to-beam handoff

Regulatory Considerations

• Services provided by commercial satellite systems are governed by International Radio Regulations and U.S. statutes

• Definitions of MSS and FSS do not provide for space-to-space links required for NASA support

• NASA service support scenarios would require regulatory amendments
  - Feasibility studies
  - Marketing efforts
  - 4 to 14 year estimated implementation time