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
NASA Study

• 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

![Orbital Characteristics Diagram]

**Commercial Satellite Systems**

### Summary

<table>
<thead>
<tr>
<th>System</th>
<th>Orbit Type/Service Type</th>
<th>BER</th>
<th>Service Frequency (MHz)</th>
<th>Service Data Rate (kbps)</th>
<th>STL Frequency (GHz)</th>
<th>Orbit Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inmarsat</td>
<td>LEO MSS</td>
<td>10^7</td>
<td>186-192.5</td>
<td>2.4</td>
<td>23.15-23.35</td>
<td>66 750 80.4°</td>
</tr>
<tr>
<td>ICO</td>
<td>MEO MSS</td>
<td>10^7</td>
<td>1.965-2.015</td>
<td>38.4</td>
<td>N/A</td>
<td>10-12 10.355 45°</td>
</tr>
<tr>
<td>Teledesco</td>
<td>LEO FSS</td>
<td>10^7</td>
<td>28.6-29.1 and 27.6-28.4</td>
<td>66.71</td>
<td>288</td>
<td>1350 84.7°</td>
</tr>
<tr>
<td>Spaceway</td>
<td>GEO FSS</td>
<td>10^6</td>
<td>17.7-20.2</td>
<td>38-4-6000</td>
<td>22.55-23.35</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 then 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 1 300 km, 28.5 deg</th>
<th>Case 2 500 km, 35.2 deg</th>
<th>Case 3 500 km, 57.9 deg</th>
<th>Case 4 700 km, 59.2 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV Coverage (%)</td>
<td>70.9</td>
<td>65.1</td>
<td>73.6</td>
<td>69.7</td>
</tr>
<tr>
<td>Uplink Availability (%)</td>
<td>70.9</td>
<td>65.1</td>
<td>73.6</td>
<td>69.7</td>
</tr>
<tr>
<td>Downlink Availability (%)</td>
<td>70.9</td>
<td>65.1</td>
<td>73.6</td>
<td>69.7</td>
</tr>
<tr>
<td>Average Uplink Data Transfer</td>
<td>42.7</td>
<td>46.5</td>
<td>28.5</td>
<td>42.7</td>
</tr>
<tr>
<td>Average Downlink Data Transfer</td>
<td>3.4</td>
<td>2.2</td>
<td>4.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Minimum Uplink Data Transfer</td>
<td>2.2</td>
<td>2.3</td>
<td>2.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Minimum Downlink Data Transfer</td>
<td>27.6</td>
<td>29.2</td>
<td>26.7</td>
<td>27.6</td>
</tr>
<tr>
<td>Uplink Data Transfer to Cloud</td>
<td>14.4</td>
<td>18.6</td>
<td>14.4</td>
<td>14.4</td>
</tr>
<tr>
<td>Downlink Data Transfer to Cloud</td>
<td>16.9</td>
<td>16.9</td>
<td>16.9</td>
<td>16.9</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) 59.0 seconds, 3) 77.8 seconds, 4) 77.8 seconds, 5) 33.2 seconds.
2. The estimated mean sub-beam overlap time (see) for Cases 1 through 5 as follows: 1) 17.2 seconds, 2) 15.9 seconds, 3) 5.3 seconds, 4) 14.4 seconds, 5) 14.4 seconds.
3. 4 spot beams per IRIDIUM satellite.

Communications Coverage - ICO

ICO Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1 300 km, 28.5 deg</th>
<th>Case 2 500 km, 35.2 deg</th>
<th>Case 3 500 km, 57.9 deg</th>
<th>Case 4 700 km, 59.2 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV Coverage (%)</td>
<td>90.9</td>
<td>76.9</td>
<td>85.9</td>
<td>78.9</td>
</tr>
<tr>
<td>Uplink Availability (%)</td>
<td>90.9</td>
<td>76.9</td>
<td>85.9</td>
<td>78.9</td>
</tr>
<tr>
<td>Downlink Availability (%)</td>
<td>90.9</td>
<td>76.9</td>
<td>85.9</td>
<td>78.9</td>
</tr>
<tr>
<td>Average Uplink Data Transfer</td>
<td>41.7</td>
<td>49.5</td>
<td>40.2</td>
<td>47.8</td>
</tr>
<tr>
<td>Average Downlink Data Transfer</td>
<td>2.4</td>
<td>3.2</td>
<td>3.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Minimum Uplink Data Transfer</td>
<td>2.9</td>
<td>3.5</td>
<td>3.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Minimum Downlink Data Transfer</td>
<td>22.1</td>
<td>29.3</td>
<td>20.7</td>
<td>22.1</td>
</tr>
<tr>
<td>Uplink Data Transfer to Cloud</td>
<td>14.4</td>
<td>18.6</td>
<td>14.4</td>
<td>14.4</td>
</tr>
<tr>
<td>Downlink Data Transfer to Cloud</td>
<td>16.9</td>
<td>16.9</td>
<td>16.9</td>
<td>16.9</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) 59.0 seconds, 3) 77.8 seconds, 4) 77.8 seconds, 5) 33.2 seconds.
2. The estimated mean sub-beam overlap time (see) for Cases 1 through 5 as follows: 1) 17.2 seconds, 2) 15.9 seconds, 3) 5.3 seconds, 4) 14.4 seconds, 5) 14.4 seconds.
3. 4 spot beams per ICO satellite.
## Communications Coverage - Teledesic

### Teledesic Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
<th>CASE 4</th>
<th>CASE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teledesic FOV Coverage (%)</td>
<td>97.2</td>
<td>96.6</td>
<td>96.8</td>
<td>95.5</td>
<td>90.5</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>9.5</td>
<td>9.7</td>
<td>9.2</td>
<td>9.3</td>
<td>9.3</td>
</tr>
<tr>
<td>Average Service Duration (minutes)</td>
<td>0.9</td>
<td>0.5</td>
<td>0.1</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Average Non-Duration (minutes)</td>
<td>68.5</td>
<td>72.8</td>
<td>70.9</td>
<td>70.5</td>
<td>68.3</td>
</tr>
<tr>
<td>Maximum Non-Duration (%)</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Average Round Trip Time (sec)</td>
<td>2.9</td>
<td>1.9</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Call Drop Probability (%)</td>
<td>64.7</td>
<td>60.2</td>
<td>74.1</td>
<td>70.3</td>
<td>74.1</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) 5.4 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) 4.6 seconds, 2) 4.0 seconds, 3) 4.0 seconds, 4) 4.0 seconds, 5) 1.0 seconds.
3. 64 spot beams per Teledesic satellite.

### Teledesic FOV Coverage at 300 km altitude

### Teledesic FOV Coverage at 700 km altitude

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## Communications Coverage - Spaceway

### Spaceway Service Availability Analysis Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
<th>CASE 4</th>
<th>CASE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spaceway FOV Coverage (%)</td>
<td>97.2</td>
<td>96.6</td>
<td>96.8</td>
<td>95.5</td>
<td>90.5</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>9.5</td>
<td>9.7</td>
<td>9.2</td>
<td>9.3</td>
<td>9.3</td>
</tr>
<tr>
<td>Average Service Duration (minutes)</td>
<td>0.9</td>
<td>0.5</td>
<td>0.1</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Average Non-Duration (minutes)</td>
<td>68.5</td>
<td>72.8</td>
<td>70.9</td>
<td>70.5</td>
<td>68.3</td>
</tr>
<tr>
<td>Maximum Non-Duration (%)</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Average Round Trip Time (sec)</td>
<td>2.9</td>
<td>1.9</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Call Drop Probability (%)</td>
<td>64.7</td>
<td>60.2</td>
<td>74.1</td>
<td>70.3</td>
<td>74.1</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

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### 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