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
Missions Overview

Orbital Characteristics

Commercial Satellite Systems

Summary

<table>
<thead>
<tr>
<th>System</th>
<th>Orbit Type</th>
<th>BER</th>
<th>Service Frequency (MHz)</th>
<th>Service Data Rate (kbps)</th>
<th>SSL Frequency (GHz)</th>
<th>Orbit Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indium1</td>
<td>LEO MSS</td>
<td>10+</td>
<td>1626.5, 1626.5</td>
<td>2.4</td>
<td>23.15-23.35</td>
<td>66, 760, 56.4°</td>
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<tr>
<td>ICO</td>
<td>MEO MSS</td>
<td>10+</td>
<td>1750-2050, 1,985-2,015</td>
<td>38.4</td>
<td>N/A</td>
<td>10-12, 10,355, 45°</td>
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<tr>
<td>Telestar1</td>
<td>LEO FSS</td>
<td>10+</td>
<td>17.8-18.5</td>
<td>28.6-29.1</td>
<td>65.71</td>
<td>20, 1350, 84.7°</td>
</tr>
<tr>
<td>Spaceway1</td>
<td>GEO FSS</td>
<td>10+</td>
<td>17.7-20.2</td>
<td>27.5-30.0</td>
<td>20</td>
<td>35,796, 0°</td>
</tr>
</tbody>
</table>

Notes:
1. Systems use inter-satellite links and onboard data processing.

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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 1 300 km 28.5 deg</th>
<th>CASE 1 700 km 28.5 deg</th>
<th>CASE 2 300 km 28.5 deg</th>
<th>CASE 2 700 km 28.5 deg</th>
<th>CASE 3 300 km 57.9 deg</th>
<th>CASE 3 700 km 57.9 deg</th>
<th>CASE 4 300 km 57.9 deg</th>
<th>CASE 4 700 km 57.9 deg</th>
<th>CASE 5 300 km 82.6 deg</th>
<th>CASE 5 700 km 82.6 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage (%)</td>
<td>10.4</td>
<td>5.1</td>
<td>12.7</td>
<td>9.1</td>
<td>15.2</td>
<td>10.5</td>
<td>12.0</td>
<td>11.6</td>
<td>15.3</td>
<td>10.5</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Average Total Duration (sec)</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
</tr>
<tr>
<td>Minimum Total Duration (sec)</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Call Capacity per Spot Beam (%)</td>
<td>3.3</td>
<td>1.7</td>
<td>3.3</td>
<td>1.7</td>
<td>3.3</td>
<td>1.7</td>
<td>3.3</td>
<td>1.7</td>
<td>3.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

**NOTES:**
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 14.1 seconds, 2) 14.1 seconds, 3) 13.6 seconds, 4) 13.6 seconds, 5) 16.3 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 17.2 seconds, 2) 15.6 seconds, 3) 14.7 seconds, 4) 14.7 seconds, 5) 14.9 seconds.
3. -8 spot beams per IRIDIUM beam.

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 1 700 km 28.5 deg</th>
<th>CASE 2 300 km 28.5 deg</th>
<th>CASE 2 700 km 28.5 deg</th>
<th>CASE 3 300 km 57.9 deg</th>
<th>CASE 3 700 km 57.9 deg</th>
<th>CASE 4 300 km 57.9 deg</th>
<th>CASE 4 700 km 57.9 deg</th>
<th>CASE 5 300 km 82.6 deg</th>
<th>CASE 5 700 km 82.6 deg</th>
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</thead>
<tbody>
<tr>
<td>Coverage (%)</td>
<td>92.9</td>
<td>89.5</td>
<td>92.9</td>
<td>89.5</td>
<td>92.9</td>
<td>89.5</td>
<td>92.9</td>
<td>89.5</td>
<td>92.9</td>
<td>89.5</td>
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<tr>
<td>Service Availability (%)</td>
<td>37.7</td>
<td>32.3</td>
<td>37.7</td>
<td>32.3</td>
<td>37.7</td>
<td>32.3</td>
<td>37.7</td>
<td>32.3</td>
<td>37.7</td>
<td>32.3</td>
</tr>
<tr>
<td>Average Total Duration (sec)</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
<td>49.7</td>
<td>32.3</td>
</tr>
<tr>
<td>Minimum Total Duration (sec)</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
<td>2.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Call Capacity per Spot Beam (%)</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
</tr>
</tbody>
</table>

**NOTES:**
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 14.6 seconds, 2) 14.6 seconds, 3) 14.6 seconds, 4) 14.6 seconds, 5) 14.6 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 17.2 seconds, 2) 15.6 seconds, 3) 14.7 seconds, 4) 14.7 seconds, 5) 14.9 seconds.
3. -8 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>Fov Coverage (%)</td>
<td>97.2</td>
<td>96.4</td>
<td>75.5</td>
<td>70.9</td>
<td>73.2</td>
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<tr>
<td>Service Availability (%)</td>
<td>97.2</td>
<td>95.5</td>
<td>75.5</td>
<td>70.9</td>
<td>73.2</td>
</tr>
<tr>
<td>Average Service Duration (minutes)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Average Non-Duration Duration (minutes)</td>
<td>6.0</td>
<td>7.2</td>
<td>8.0</td>
<td>9.9</td>
<td>9.9</td>
</tr>
<tr>
<td>Minimum Next Contacts</td>
<td>10.5</td>
<td>10.6</td>
<td>10.9</td>
<td>9.6</td>
<td>9.8</td>
</tr>
<tr>
<td>Average Next Contacts (minutes)</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Ccm Drop Probability (%)</td>
<td>64.9</td>
<td>60.2</td>
<td>71.5</td>
<td>74.7</td>
<td>74.7</td>
</tr>
</tbody>
</table>

**Notes:**
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 is 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 is as follows: 1) 1.4 seconds, 2) 1.4 seconds, 3) 1.9 seconds, 4) 1.4 seconds, 5) 1.0 seconds.
3. 64 spot beams per Teledesic satellite.

### 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>Fov Coverage (%)</td>
<td>97.0</td>
<td>97.0</td>
<td>75.7</td>
<td>71.7</td>
<td>73.7</td>
</tr>
<tr>
<td>Service Availability (%)</td>
<td>97.0</td>
<td>97.0</td>
<td>75.7</td>
<td>71.7</td>
<td>73.7</td>
</tr>
<tr>
<td>Average Service Duration (minutes)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Average Non-Duration Duration (minutes)</td>
<td>6.0</td>
<td>7.2</td>
<td>8.0</td>
<td>9.9</td>
<td>9.9</td>
</tr>
<tr>
<td>Minimum Next Contacts</td>
<td>41.7</td>
<td>41.7</td>
<td>41.7</td>
<td>41.7</td>
<td>41.7</td>
</tr>
<tr>
<td>Average Next Contacts (minutes)</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Ccm Drop Probability (%)</td>
<td>71.9</td>
<td>71.9</td>
<td>71.9</td>
<td>71.9</td>
<td>71.9</td>
</tr>
</tbody>
</table>

**Notes:**
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 is 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 is as follows: 1) 41.6 seconds, 2) 41.6 seconds, 3) 38.7 seconds, 4) 41.6 seconds, 5) 38.7 seconds.
3. 64 spot beams per Teledesic satellite.
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